ACADEMIC STUDIES ON SUSTAINABILITY DYNAMICS OF AGRICULTURE AND ENGINEERING

Editors
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PREFACE

Sustainability dynamics of agriculture and engineering disciplines have a critical importance under rapidly changing environmental, economic and social conditions. Problems such as global population growth, limited natural resources and climate change are increasing the need for efficient and environmentally friendly agricultural practices. In this context, the interaction between agricultural practices and engineering solutions plays a central role in achieving sustainable development goals. This book aims to provide an in-depth review of the sustainability of field crop production and related engineering disciplines.

The book provides a comprehensive review of engineering technologies applied in field crop production, taking into account the main challenges faced in agricultural production processes, particularly the objectives of increasing productivity and minimising environmental impacts. Innovative applications in key areas of agricultural engineering, such as tillage, irrigation systems, fertilisation methods and harvesting technologies, are improving the productivity of the agricultural sector while reducing environmental impacts. It also reveals how modern engineering approaches, such as biology, biotechnology and genetic engineering, have improved productivity in field crop production. Collaboration between agriculture and engineering disciplines is critical not only for the future of agriculture, but also for achieving global sustainability goals. The book aims to guide researchers, practitioners and decision makers towards building a sustainable future through in-depth analyses of innovative approaches and strategies in this field from various engineering disciplines such as mechanical engineering, computer engineering, electronic engineering and industrial engineering.

We would like to thank all the authors who contributed to the preparation of this book and made invaluable contributions.

Prof. Dr. A. Engin ÖZCELİK

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CONTENTS

CHAPTER 1

BREAD WHEAT LANDRACES QUALITY IN BORNOVA'S ECOLOGICAL CONDITIONS

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1. INTRODUCTION

Wheat is one of the most essential food items in our diet, both globally and in Turkey, and historically, Turkey is considered the homeland of wheat. Due to Turkey's geographical position as a gene center for wheat, it hosts a wide diversity of wild wheat species, wheat relatives, local wheat landraces, and modern cultivated wheat varieties, offering substantial diversity and richness in wheat. Preserving this genetic value and passing it on to future generations is crucial. The food security of future generations is closely linked to the conservation of the biological diversity of such a strategic crop as wheat. It is necessary to protect the thousands of years of economic, traditional, cultural, and social heritage associated with wheat and wheat products, which hold a strategic position for our country. (Atak, M., 2017)

Local varieties, which form an essential part of plant genetic resource collections and constitute significant germplasm in breeding programs due to their high diversity, play an important role. Local resources are invaluable for enriching the narrowing genetic base and are used as parents in breeding studies to develop varieties that are resistant to diseases, tolerant of stress conditions, and of high quality.

Globally and in our country, the production opportunities for local varieties or landraces, which serve as the primary genetic material in breeding programs, have rapidly declined due to the record increase in human population, technological changes, and infrastructure developments (Frankel 1970). Even more interestingly, the genetic erosion of landraces has not been thoroughly investigated; it has generally been assessed indirectly by examining the spread of newly developed varieties. Studies conducted retrospectively in developed countries have found that modern varieties have rapidly displaced local landraces (Hammer 1996), and it has even been determined that 75% of the genetic diversity in cultivated plant species has been lost in the last century (Hammer 1996; Witcombe et al. 1999).

This situation has similarly occurred in our country, starting in the 1950s, with the improvement of cultivation conditions (fertilization, irrigation, soil tillage, and widespread use of agricultural chemicals) and the development or introduction of new wheat varieties resistant to lodging. The production and distribution of certified seeds for these varieties led to the rapid replacement of local landraces, initially in coastal areas and later in the Central Anatolia and Transition Regions where winter and drought are intense.

In addition to undergoing thousands of years of natural selection locally, these landraces were also selectively bred, though to a limited extent, by Turkish farmers to suit their own consumption habits. Generally, these varieties were selected according to organic farming conditions where plowing with a traditional plow, broadcast sowing, and harvesting with a sickle or scythe were common. Another significant factor was that farmers relied on post-harvest residues (straw) as feed for their animals throughout the long winter. Considering these factors together, it is no coincidence that the local landraces of bread and durum wheat cultivated for thousands of years are tall, have long spikes, high thousand-grain weights, and quality characteristics suited to different regional consumption habits (such as bulgur, noodles, tarhana, ashure, etc.). With today's genetic knowledge, the linear relationship between traits like plant height, spike length, grain size, and long awns shows that the natural and artificial selections made specifically for the dry and cold conditions of Central Anatolia and the Transition Regions represent an extraordinary success story.

Local landraces, which are the primary genetic source in breeding programs, have been intensively collected, identified, and utilized in breeding programs both in our country and globally, beginning in the 1900s (Salantur et al., 2017).

This study was conducted to examine the quality characteristics of eight bread wheat landraces (Çalıbasan, Zerun, Kızılca, Kars Kırmızı, Kafkas Kızılı, E-Halil, Ak Buğday, Kırik Buğdayı) obtained from various regions of Turkey, as well as three standard varieties (Efe, Kayra, Meltem) planted for control purposes.

Figure 1. An image of the bread wheat landraces and control varieties in the experimental field

2. MATERIAL AND METHOD

MATERIAL

Research Site:

This study was conducted in the field at the trial area of Ege University, Bornova Faculty of Agriculture, Department of Field Crops, during the 2023-2024 vegetation period (Figure 2).

Figure 2. Ege University Faculty of Agriculture, Department of Field Crops, Bornova Trial Area

Climate Characteristics of the Research Site:

Some climate characteristics of the research site are presented in Table 1.

Table 1. Some climate characteristics of the research site

	Air Temperature (ºC)		Precipitation (mm)	
Month	2022-2023	Long-Term Average	2022-2023	Long-Term Average
December	15.8	13.8	70.6	109.7
January	10.1	8.8	110.2	134.8
February	11.2	9.6	87.5	102.4
March	13.08	11.7	83.24	75.3
April	15.7	15.9	76.25	46.0
May	20.07	20.8	15.01	31.1
June	29.8	25.4	56.67	13.1
July	29.9	28.3	0.1	2.1

Reference: General Directorate of Meteorology

Soil Characteristics of the Research Site:

The soil structure, chemical and organic matter contents of the experimental area during the 2023-2024 wheat growing season were analysed in the laboratory of the Soil Science and Nutrition Department of the Faculty of Agriculture of Ege University. The resulting soil analysis values are presented in Table 2. The soil is slightly alkaline, with no salinity risk, medium lime content, clay-loam texture, and low in organic matter and total nitrogen.

Table 2. Some physical and chemical properties of the test soil

Depth (cm)	Soil Reaction (pH)	Total Salt (%)	Lime ($CaCO_3$) (%)	Sand (%)	Silt (%)	Clay (%)	Texture Class	Organic Matter (%)	Total N (%)
0-30	7,88	0,091	14,18	42,20	20,72	36,88	Slightly alkaline	1,99	0,05

Plant Material:

In this study, eight local bread wheat landraces collected from various regions of Turkey and three control varieties registered by the Aegean Agricultural Research Institute (AARI) were used. The genotypes used in the study are given in Table 3.

Table 3. Bread wheat genotypes used in the study

Landraces:	**Source**	**Control Varieties:**	**Source**
Çalıbasan	Yozgat	Efe	AARI
Zerun	Sivas	Kayra	AARI
Kızılca	Balıkesir	Meltem	AARI
Kars Kırmızı	Kars		
Kafkas Kızılı	Çanakkale		
E-Halil	Kula		
Ak Buğday	Yozgat		
Kırik	Erzurum		

*AARI: Aegean Agricultural Research Institute

METHOD

The trial was established as a randomized block design with three replications.

- Plot Size: 1.20 m x 5 m = 6 m²
- Row Spacing: 20 cm – 6 rows
- Seeding Rate: 550 seeds per m²
- Seeding Depth: 3-4 cm
- Seeding Date: December 27, 2022
- Harvest Date: July 13, 2023

Figure 3. Parceling process in the experimental field

Figure 4. Manual row planting process

Fertilization:

Due to low nitrogen in the soil, 7 kg N (nitrogen), 5 kg P (phosphorus), and 5 kg K (potassium) per decare were applied. A base fertilizer of 15.15.15 Compound was applied, followed by urea (46%) during stem elongation.

Herbicide Application:

Dimetrin at 200 mL/da was used for weed control during the tillering stage, and manual weeding was also conducted (Figure 5).

Figure 5. Pesticide application process in the experimental field

Harvest:

The plants were manually harvested upon reaching physiological maturity and subsequently threshed using a mechanical threshing machine on July 13, 2023 (Figure 6).

Figure 6. Wheats at the harvest stage

Mesaured Traits

The wheat varieties cleaned after harvest were processed using the NIR (Near Infrared Reflectance) Device located in the Quality Laboratory of the Department of Field Crops at Ege University Faculty of Agriculture to measure quality parameters (Figure 7).

Figure 7. NIR (Near Infrared Reflectance) device

Near-infrared Reflectance (NIR) spectroscopy, based on the absorption of electromagnetic radiation in the wavelength range of 80-2500 nm, has recently emerged as an increasingly popular, rapid alternative technology in the analysis of food components that does not destroy the sample. This technique is used for quantitative analysis of various components in foods. Compared to other traditional methods, NIR has several advantages, including the elimination of the need for chemical use during analysis, low analysis cost, simultaneous and rapid (15-90 s) analysis of multiple components, reusability of the sample for other analyses after NIR analysis, and the requirement of only a small amount of sample (Ertugay et al., 2011).

Wet Gluten: A high amount of wet gluten indicates that the flour has good baking quality. It refers to the amount and properties of gluten present in the protein. A high wet gluten content is an indicator of good bread-making quality in flour. Wet gluten content reflects the quantity and characteristics of gluten in the protein. This content decreases during rainy crop years, similar to the protein ratio, while in dry years during the grain filling period, it increases, again similar to the protein ratio (Caglar et al. 2006; Caglar et al. 2011).

Hardness: The hardness of the grain indicates a higher amount of gluten and good quality Grain hardness is one of the most important determinants of wheat quality because of it influences on the end-use quality and also yield. Hard or medium hard grain is preferred for manufacture of leavened and flat breads because the levels of damaged starch produced from these wheat classes are appropriate to achieve to high dough water absorption desired by the baker. Their strong flour doughs are also more suitable for mechanized production of leavened breads (Basciftci et al. 2015).

Protein: Used as a criterion to determine the baking value of the grain and flour, it is considered the most important indicator of baking quality and loaf volume. The protein quality of wheat endosperm is the most crucial factor determining the baking quality of bread. Flours obtained from wheat grains with the same total protein content can produce very different results during baking due to differences in the quality of gluten proteins (Annet et al. 2007). A drier and hotter period after flowering in wheat leads to a decrease in grain weight and an increase in crude protein content (Panozzo and Eagles 2000; Ozturk et al. 2006; Bulut, 2009).

Moisture (Humidity): Important for storage and milling. Excess water in wheat reduces its commercial value by decreasing dry matter content and makes storage more challenging, as it promotes germination due to bacterial and fungal activity. Many factors affect the moisture content in wheat, including cultivation and storage conditions as well as harvest timing (Elgün et al. 1998). It has been observed that grain moisture content is higher in years with more rainfall during the maturity period of wheat. The moisture content in Turkish wheat ranges from 8% to 14%, with an average of 9% to 11%. The upper limit for moisture content in wheat is 14.6% (Ünal, 2002).

Hektoliter: One of the quality criteria, it indicates the flour yield. The hectoliter weight changes depending on the size of the grain. As the grain size increases, the hectoliter weight decreases. In the presence of weeds, lower hectoliter weights are obtained, and flour yield decreases due to the competition of weeds with wheat for moisture and nutrients. In crop years dominated by hot and dry climatic conditions during the grain filling period, the shortened maturation period results in weak and small grains, leading to significantly lower flour yield values. As the proportion of small grains in wheat increases, flour yield decreases, while ash content rises (Shuey and Gilles, 1969). On the other hand, it has been reported that as flour yield increases, sedimentation value and gluten content decrease (Seçkin, 1975). The ash content in wheat is closely related to flour yield; flours with the same yield obtained from

different wheats may show very small variations in ash content, and a high ash content is not desired (Ünal, 2002).

Sedimentation: A method used to estimate the protein content of wheat with the same gluten quality. High sedimentation indicates that the gluten holds water well. The Zeleny sedimentation value represents the volume of flour particles that settle after a certain period in a suspension prepared with flour and lactic acid solution. According to the TS 2004 wheat standard, for bread wheat, a Zeleny sedimentation value above 36 ml is considered very good, between 25-36 ml is good, between 16-24 ml is weak, and below 15 ml is poor. In Turkey, the sedimentation volume of different wheat varieties varies between 26.0 and 56.0 ml (Ozturk and Gokkus, 2008; Bayram et al. 2008).

Falling Number: A parameter used to determine diastatic activity in wheat flour, important for gas produced during bread making, bread volume, bread texture, and bread color. A lower falling number is desirable. The falling number of wheat starch represents the time in seconds it takes for the starch in the flour to lose its viscosity due to the activity of amylase enzymes (Ünal, 2002). A falling number of 220-250 seconds is desirable in wheat (Diepenbrock et al. 2005). High rainfall during the yellow ripening (starch formation) period in wheat decreases the falling number (Erekul et al. 2009). Ünal (2002) states that if enzyme supplementation is not added to flours with falling numbers outside acceptable limits, bread volume and quality decrease, the dough does not generate sufficient gas, and the bread crumb becomes dense.

Ash: Gives an idea about flour yield. As the whiteness of the bread increases, the ash content decreases. The Turkish Standards Institute (TSE) has classified flours into types based on their ash content. Ash content is used as a factor in flour classification. The crude ash content can vary depending on wheat varieties, climate, and soil conditions, and it decreases in drier crop years due to a reduction in available phosphorus (Elgün et al. 1999). As the whiteness degree of bread increases (with more bran and germ removed), the ash content is lower; as the whiteness degree decreases (with less bran and germ removed), the ash content is higher. Therefore, the highest ash content is found in flours with the least bran and germ removed. Ash content also indicates yield: for example, if the ash content is 0.65%, it roughly corresponds to a 650-yield bread flour; if the ash content is 0.55%, it corresponds to a 550-yield pastry flour; and if the ash content is 1%, it indicates high-ash flours such as whole wheat, chapati, and tandoori flour (Anonim 2012).

Starch: A polysaccharide that serves as a storage carbohydrate in plants. It is formed by the storage of glucose. Cereal grains store energy in the form of starch. The starch content in a grain can vary between 65-70% of the grain's dry weight. The chemical composition of wheat grains varies among varieties. Most technological parameters that describe seed quality are defined for human benefit (Mut et al., 2017).

Fat: High fat content shortens the shelf life of the flour.

Fiber: Increases the nutritional value of bread and supports digestion. The characteristics of grain fiber in bread wheat are crucial for both nutritional value and baking quality. Wheat grain primarily contains dietary fibers such as arabinoxylan and β-glucan, which vary significantly among different wheat varieties. Understanding these characteristics can enhance bread quality and health benefits. The following sections detail the key aspects of grain fiber in bread wheat. In terms of bran characteristics different wheat varieties exhibit variations in insoluble dietary fiber (IDF) and phytate content, affecting dough properties and bread quality. Hard wheat brans generally enhance water absorption and dough mixing time (Cai et al., 2014). When the inheritance of fiber traits is examined, there is significant genetic diversity in fiber

composition among wheat genotypes, which allows targeted breeding to increase fiber content in bread wheat (Shewry and Lovegrove, 2014)(Charmet et al., 2009).

Statistical Analysis

Statistical analyses were performed using the TOTEM-STAT program, with differences among means determined by the Least Significant Difference (LSD) Test. The results were recorded in a unified data framework in Excel.

3. RESULTS AND DISCUSSION

In the thesis study conducted under Bornova's ecological conditions, the quality parameters of local bread wheat landraces were measured and recorded using the NIR (Near Infrared Reflectance) device.

The results of the analysis of variance for the means of squares concerning the examined traits are presented in the Table 4 below.

Table 4. The results of the analysis of variance concerning the traits of wet gluten, hardness, protein, moisture, hectoliter, and falling number

Source of Variation	Degrees of Freedom	Wet Gluten	Hardness	Protein	Moisture	Hektoliter	Falling Number
Genotype	10	10,9	39,5	2,1	0,07	441,9	6668,1
Replication	2	5,5	26,1	0,9	0,08	88,2	1708,9
Error	20	4,1	32,9	0,7	0,16	224,8	1158,2
Total	32	6,3	34,5	1,2	0,13	284,1	2914,4
F-value		**2,61***	**1,20 ns**	**2,78***	**0,46 ns**	**1,96 ns**	**5,75****

ns = not significant
*= significant at the 5% alpha level
** = significant at the 1% alpha level

In terms of the examined traits, hardness, moisture, and hectoliter do not show differences among wheat varieties; however, wet gluten and protein are statistically significant at the 5% level, while falling number is significant at the 1% level.

The mean values and groupings for the bread wheat landraces and control varieties with respect to wet gluten, hardness, protein content, moisture, hectolitre weight, and falling number are presented in Table 5.

Table 5. The mean values and formed groups for the traits of wet gluten, hardness, protein, moisture, hectoliter, and falling number

Varieties	Wet Gluten (%) 6 groups	Hardness (%)	Protein (%) 7 groups	Moisture (%)	Hektoliter (g/L)	Fall Number (s) 5 groups
Çalıbasan	26.6 *bcd*	72.3	13.0 *bcd*	9.7	935.4	462.1 *ab*
Zerun	26.2 *bcd*	62.0 (min)	13.5 *abc*	10.0	935.3	426.7 *bc*
Kızılca	26.9 *abc*	71.3	13.1 *bcd*	9.7	920.2	489.3 *a*
Kars Kırmızı	30.2 *a* (max)	67.4	14.6 *a*	9.6	907.4	422.1 *bc*
Kafkas Kızılı	25.6 *bcd*	64.8	12.3 *cd*	9.8	926.6	474.8 *ab*
E-Halil	28.1 *ab*	69.5	13.7 *abc*	9.7	904.1	421.8 *bc*
Ak Buğday	25.0 *bcd*	73.0	12.3 *cd*	9.4	933.7	465.6 *ab*
Kırik Buğdayı	27.7 *abc*	73.7 (max)	14.0 *ab*	9.5	923.1	354.8 *d*
Efe (ST)	24.5 *cd*	67.4	12.5 *bcd*	9.9	929.5	382.2 *cd*
Kayra (ST)	23.2 *d* (min)	68.6	11.7 *d*	9.7	903.6	447.2 *ab*
Meltem (ST)	25.7 *bcd*	66.5	13.1 *bcd*	9.6	927.3	351.8 *d*
Landrace Average	**27.1**	**69.2**	**13.3**	9.7	**923.2**	**439.6**
CV Average	24.5	67.5	12.4	9.7	920.1	393.7
Total Average	26.3	68.8	13.1	9.7	922.4	427.1
LSD (0.05)	3.4	9.7	1.4	0.6	25.5	57.9

*CV: control varieties

The average value for wet gluten in the landrace is 27.1, while the standard varieties have an average of 24.5. The overall average for the study is 26.5. In a study conducted in 2017, the variety average was found to be 28.8 (Keçeli et al., 2017). Kars Kırmızı recorded the highest wet gluten value, 30.2%, while the lowest value, 23.2%, was recorded by the Kayra variety.

In terms of hardness, the landrace average (69.2) was higher than the standard variety average (67.5). The overall average was found to be 68.8. The Kırik wheat recorded the highest hardness value, 73.7%, while the lowest value, 62%, was recorded by the Zerun.

For protein, the landrace average (13.3%) was higher than the standard variety average (12.4%). The general average value was 13.1%. The highest protein content, 14.6%, was found in the Kars Kırmızı, while the lowest content, 11.7%, was found in the Kayra standard variety. The protein content, which plays a key role in determining the quality of wheat (Sade, 1997), varies between 6-22% depending on the variety and environmental conditions (Ünal, 2002). The quality of the protein is as important as its proportion as a quality criterion. In a study by Baker et al., (1971), it was noted that protein content, water absorption value, and dough

development time are positively related to bread volume. In a study by Şahin et al. (2013), a positive and significant relationship between protein content and bread volume was found. He and Hoseney (1992), in their study using flours with the same protein structure but different protein contents, demonstrated a linear relationship between protein content and bread volume and found that protein content positively affects development time and extensibility values.

Regarding moisture, both the landrace and standard variety averages were the same, at 9.7%. The highest moisture content, 10%, was found in the Zerun, while the lowest content, 9.4%, was found in the Ak Buğday. In a study conducted to determine the variation of physical and chemical criteria of bread wheat and durum wheat produced in Konya Province and traded at the Commodity Exchange, according to years and subregions, the average moisture content of bread wheat in 2015 was 15%, while the regional average value was 9.98% (Paran et al., 2018).

For falling number, the landrace average was 439.6s, while the standard variety average was 393.7s. A high falling number is not considered desirable for quality. Therefore, the standard variety showed a better value in this respect. The highest falling number, 489.3s, was recorded by the Kızılca, while the lowest, 351.8s, was recorded by the Meltem standard variety. Falling number is a parameter used to determine diastatic activity in wheat flour and is important in terms of the amount of gas to be formed during bread making, bread volume, crumb texture and bread color (Bulut 2012). It is desired that the falling number is not too high as an indicator of normal enzyme activity in wheat varieties. It is desired that the falling number in wheat is between 220-250 s (Diepenbrock et al. 2005). In their studies, Loje et al. (2003) reported the average falling number of *Triticum monococcum* (einkorn) wheat as 362 seconds and the average falling number of *Triticum dicoccum* (emmer) wheat as 436 seconds. In the analyses conducted by Zengin (2015), the average falling number of *Triticum monococcum* (einkorn) wheat was determined as 344 seconds and the average falling number of *Triticum dicoccum* (emmer) wheat as 400 seconds. Breads made with flours with insufficient amylase activity have a small volume, insufficiently developed and heterogeneous pore structure. The crust colors are light and dull (Altan, 1986).

Considering the averages, the landraces showed superior characteristics in terms of wet gluten, hardness, protein, hectoliter, and falling number compared to the standard varieties. The Kars Kırmızı landrace had the highest wet gluten and protein content. In terms of hardness, the Ak Buğday, Kırik, and Çalıbasan landraces had similar and the highest values. The highest hectoliter values were recorded in the Çalıbasan and Zerun, and the highest moisture content was found in the Zerun landrace. The landrace with the maximum falling number was Kızılca landrace.

The results of the analysis of variance for the means of squares concerning the examined traits are presented in the Table 6 below.

Table 6. The results of the analysis of variance concerning the traits of sedimentatiton, ash, starch, fat, and fiber

Source of Variation	Degrees of Freedom	Sedimentation	Ash	Starch	Fat	Fiber
Genotype	10	137,5	0,1	4,5	0,14	0,3
Replication	2	58,1	0,02	0,2	0,11	0,07
Error	20	33,4	0,06	0,8	0,12	0,06
Total	32	67,5	0,08	1,9	0,13	0,1
F-value		**4,11****	**2,04 ns**	**5,16****	**1,20 ns**	**4,66****

The analysis revealed no significant differences between wheat varieties in terms of ash and fat content. However, sedimentation, starch, and fiber content were found to be statistically significant at the 1% level.

The mean values and groupings for the bread wheat landraces and control varieties with respect to sedimentation, ash, starch, fat and fiber are presented in Table 6.

Upon examining Table 6, the average sedimentation value for landraces is 38.9 ml, whereas the average for standard varieties is 36.5 ml. The overall mean value for the study is 38.2 ml. The highest sedimentation value was observed in the Kars Kırmızı landrace, at 46.1 ml, while the lowest value was recorded in the Kafkas Kızılı landrace, at 23.1 ml.

Table 7. The mean values and formed groups for the traits of sedimentation, ash, starch, fat and fiber

Varieties	Sedimentation (ml) 6 groups	Ash (%)	Starch (%) 4 groups	Fat (%)	Fiber (%) 2 groups
Çalıbasan	40.6 *ab*	1.9	48.7 *ab*	4.6	5.6 *b*
Zerun	35.4 *bc*	2.1	49.3 *ab*	4.1	5.6 *b*
Kızılca	41.1 *ab*	1.8	48.8 *ab*	4.5	5.7 *b*
Kars Kırmızı	46.1 *a*	2.1	48.4 *ab*	4.6	5.8 *b*
Kafkas Kızılı	23.1 *d*	2.3	45.3 *c*	4.1	6.6 *a*
E-Halil	45.8 *a*	2.0	48.5 *ab*	4.9	5.7 *b*
Ak Buğday	37.8 *abc*	1.7	49.1 *ab*	4.7	5.4 *b*
Kırik Buğdayı	40.9 *ab*	2.4	49.8 *a*	4.8	5.6 *b*
Efe (ST)	38.8 *abc*	2.0	49.8 *a*	4.4	5.4 *b*
Kayra (ST)	29.6 *cd*	1.9	48.0 *b*	4.4	5.6 *b*
Meltem (ST)	41.2 *ab*	1.9	48.5 *ab*	4.5	5.5 *b*
Landrace Average	**38.9**	**2.1**	48.5	**4.5**	**5.7**
CV Average	36.5	1.9	**48.7**	4.4	5.5
Total Average	38.2	2.0	48.5	4.5	5.7
LSD (0.05)	9.8	0.4	1.5	0.5	0.4

For ash, the landrace average is 2.1%, while the standard variety average is 1.9%. The general average is 2.0%. The highest ash value, 2.4%, was recorded by the Kırik, while the lowest value, 1.7%, was recorded by the Ak Buğday.

Regarding starch, the landrace average is 48.5%, which is lower than the standard variety average (48.7%). The general average value is 48.5%. The highest starch content, 49.8%, was found in the Kırik and Efe, while the lowest content, 45.3%, was found in the Kafkas Kızılı.

In terms of fat, the landrace average is 4.5%, while the standard variety average is 4.4%, showing similar values. The highest fat content, 4.8%, was recorded by the Kırik, while the lowest, 4.1%, was recorded by the Kafkas Kızılı.

For fiber, the landrace average is 5.7%, while the standard variety average is 5.5%. The Kafkas Kızılı recorded the highest value, 6.6%, while the Ak Buğday recorded the lowest value, 5.4%.

Considering the averages, the landraces showed superior characteristics in terms of sedimentation, ash, fat, and fiber compared to the standard varieties. The sedimentation value for the Kars Kırmızı is the highest among all varieties. The highest ash and fat contents were found in the Kırik wheat, while the highest fiber content was found in the Kafkas Kızılı. The highest starch content was found in the local Kırik wheat and the control variety, Efe.

In this study, based on the quality characteristics measured using the NIR device, the local wheat genotypes exhibited superior values in several traits compared to the control varieties. It is anticipated that these genotypes, which demonstrate favorable characteristics under the ecological conditions of Bornova, could be valuable for use in breeding programs and/or agricultural production by farmers.

Considering the protein and wet gluten levels, which are critical determinants of baking quality, the bread wheat landraces demonstrated superior traits compared to the control varieties. It can be recommended that these bread wheat landraces be grown and used in ecological environments similar to Bornova. More comprehensive and long-term studies are needed for this.

4. CONCLUSION AND FUTURE PERSPECTIVES

Considering the mean values and resulting groupings, the protein content, a key determinant of baking quality, was highest in the Kars Kırmızı, with a value of 14.6%, making it the top-performing variety. On average, the protein content of the landraces (13.3%) surpassed that of the standard varieties (12.4%).

In terms of fiber content, Kafkas Kızılı showed the highest value at 6.6%, distinguishing itself from other wheat landraces and varieties.

Regarding the examined traits, Kars Kırmızı stood out with the highest values in wet gluten (30.2%), protein (14.6%), and sedimentation (46.1 mL), outperforming other landraces and standard varieties.

The falling number, a parameter used to determine diastatic activity in wheat flour and important for bread color, should be low, and the Meltem standard variety showed the lowest value (351.8 s), standing out among the other bread wheat varieties.

In conclusion, the bread wheat landraces demonstrated superior average values compared to the standard varieties across several key quality parameters, including wet gluten (27.1%), hardness (69.2%), protein content (13.3%), sedimentation (38.9 mL), fiber (5.7%), and hectoliter weight (923.2 kg/L). These superior values suggest that the local landraces possess enhanced baking and milling quality, which are critical factors for both bread-making performance and flour processing. The higher protein content and wet gluten levels, in particular, are crucial for improving dough strength and bread volume, while the increased sedimentation and fiber content can contribute to the nutritional value and overall quality of the final product.

Given these advantages, the local wheat genotypes not only demonstrate their potential for improving wheat quality under the specific ecological conditions of Bornova but also offer valuable genetic resources for future breeding programs aimed at developing wheat varieties with superior baking and processing qualities. Furthermore, these landraces, with their robust performance across multiple quality parameters, could be considered for broader cultivation in similar agro-ecological zones, benefiting both farmers and the milling industry. This research highlights the importance of preserving these landraces and using them in agricultural practices to ensure the production of high-quality wheat products, thereby contributing to food security and the sustainability of local agricultural systems.

REFERENCES

Akar, T., Mert, Z., Yazar, S., Sanal, T., and Avci, M. (2009). Sustainable use of Winter Durum Wheat Landraces Under Mediterranean Conditions. Afr. J. Biotechnol., 8(17), 4108-4116.

Akçura, M. (2011). The Relationships of Some Traits in Turkish Winter Bread Wheat Landraces. Turk. J. Agric. For., 35, 115-125.

Altan, A., 1986, Cereal Processing Technology. Çukurova University, Faculty of Agriculture Publications, Offset Workshop, Adana, 107 pages.

Altay, F. (2016). A Pioneer of Plant Breeding in Turkey: Emcet Yektay. TÜRKTOB, 20, 4-7.

Annett, L.E., Spaner D. and Wismer W.V. (2007). Sensory profiles of bread made from paired samples of organic and conventionally grown wheat grain. Journal of Food Sci., 72 (4): 254-260.

Atak, M. (2017). Wheat and Turkish Wheat Village Varieties. Mustafa Kemal University Journal of Agriculture Faculty, 22(2), 71-88.

Başçiftçi, Z. B., & Kınacı, G. (2015). Investigation of the relationships between hardness and quality traits in bread wheat. Food, 40(4), 187-192.

Bulut, S. (2009). The effects of different fertilizer sources and planting density on plant development, yield, and quality in organic wheat. PhD Dissertation, Atatürk University, Institute of Science.

Bulut, S. (2012). Quality in bread wheat. Erciyes University Journal of Science, 28(5), 441-446.

Caglar, O., Karaoglu M.M., Bulut, S., Kotancilar, H.G. and Ozturk, A. (2011). Determination of Some Quality Characteristics in Winter and Facultative Bread Wheat (*Triticum aestivum* L.) Varieties. Journal of Animal and Veterinary Advances, 10: 3356-3362.

Cai, Liming, Induck, Choi., Choon-Ki, Lee., Kwang-Keun, Park., Byung-Kee, Baik., Byung-Kee, Baik. (2014). Bran Characteristics and Bread-Baking Quality of Whole Grain Wheat Flour. Cereal Chemistry, doi: 10.1094/CCHEM-09-13-0198-R

Charmet, Gilles, U., Masood-Quraishi., Charlotte, Ravel., Isabelle, Romeuf., François, Balfourier., M.R., Perretant., Jean-Louis, Joseph., Mariann, Rakszegi., Fabienne, Guillon., Pierre-Etienne, Sado., Zoltán, Bedo., Luc, Saulnier. (2009). Genetics of dietary fibre in bread wheat. Euphytica, doi: 10.1007/S10681-009-0019-0

Diepenbrock, W., Ellmer F., Leon J. (2005). Ackerbau pflanzebauund pflanzenzüchtung Stuttgart, Germany: Verlang Eugen Ulmer.

Ertugay, M. F.., & Başlar, M. (2011). NIR Spectroscopy in Determining the Quality Characteristics of Foods, Gıda, 36(1), 49-54.

Keçeli, A., Kaplan Evlice, A., Pehlivan, A., Şanal, T., et al. (2017). Investigation of the Relationship Between Zeleny Sedimentation Analysis and Other Quality Parameters in Bread Wheat (*Triticum aestivum* L.). KSÜ Journal of Natural Sciences, 20, 303-307.

Loje, H. et al., (2003). Chemical composition, functional properties and sensory profiling of einkorn (*Triticum monococcum* L.), Journal of Cereal Science, 37 (2), 231.

Mut, Z., Erbaş Köse, Ö. D., & Akay, H. (2017). Determination of grain yield and quality traits of some bread wheat (*Triticum aestivum* L.) varieties. Anadolu Journal of Agricultural Sciences, 32(1), 85-95. https://doi.org/10.7161/omuanajas.288862

Özberk, F., Karagöz, A., Özberk, İ., Atlı, A. (2016). Local and Cultivar Varieties from Wheat Genetic Resources; Wheat and Bread in Turkey. Journal of the Field Crops Central Research Institute, 25(2), 218-233.

Paran, N., & Topal, A. (2018). Determination of quality criteria of wheat grown in Konya Province and traded at the Commodity Exchange according to subregions. Bahri Dağdaş Journal of Agricultural Research, 6(2), 7-17.

Shewry, Peter, R., Alison, Lovegrove. (2014). Exploiting natural variation to improve the content and composition of dietary fibre in wheat grain: A review. Acta Alimentaria, doi: 10.1556/AALIM.43.2014.3.1

Taş, N., Kırcalıoğlu, G., Kurşun Kırcı, K., Özer, U. (2017). Conservation of Local Variety Genetic Resources in Turkey. Turkish Scientific Reviews Journal, 10(1), 48-52.

Ünal, S. (2002). Importance of wheat quality and methods in wheat quality determination. Cereal Products Technology Congress and Exhibition, October 3-4, 2002, pp. 25-37, Gaziantep, Turkey.

Yılmaz, M. S., & Meral, R. (2019). Relationships between bread wheat flour quality parameters. ADYUTAYAM Journal, 7(1), 33-45.

Zengin, G. (2015). A research on determination of quality parameters of some ancient wheats. Master Thesis., Institute of Science and Technology, Selcuk University. Konya. p 89. (in Turkish)

CHAPTER 2

PLANT PROPERTIES AND UTILIZATION AREAS OF PHACELIA (*Phacelia tanacetifolia* Benth.), AN ALTERNATIVE FORAGE PLANT

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1. INTRODUCTION

Phacelia *(Phacelia tanacetifolia* Benth.) is an annual herbaceous plant (herbacea) belonging to the Hydrophyllaceae family, not belonging to the legume family, also known as Phacelia. Phacelia is native to Mexico and the south west region of America. In Europe, it can be widely cultivated as a cover crop and bee pasture, also known as honey pasture. Since our country is one of the rare countries with rich flora and fertile soils, the cultivation and interpretation of phacelia in our country has an important potential. *Phacelia tanacetifolia* Benth. is a very valuable, high quality and rich pollen and nectar source for bees. Honey obtained from phacelia stands out with its quality and flavor. In addition, phacelia has a rich range of uses such as animal feed, green fertilizer, landscape and ornamental plants, soil improvement, erosion control.

Characteristics of *Phacelia tanacetifolia* Benth

Phacelia, native to California, is an annual herbaceous plant of the Hydrophyllaceae family, growing 60-120 cm tall. The chromosome number is 2n= 18 (Tyebbes, 1986.). The stem is covered with spiny hairs. Leaves are arranged alternately on the stem. Inflorescences are terminal and emerge from the upper part of the stem. As the growth period progresses, it branches from the stem close to the soil and develops horizontally.

Phacelia seeds require a temperature of 3-20 °C for germination. The first flowering in *Phacelia tanacetifolia* starts at the bottom of the panicle and lasts about 1 week towards the top. The flowering period can last about 1 month for a plant and 2 months for a field. *Phacelia tanacetifolia* is a long day plant and requires a day length of 13 hours for flowering to occur. Flower density per unit area is high and flowering period is long. (Williams and Christian, 1991) reported that the flower density of phacelia is 2000-4000 flowers/m^2. This level of flowering is not seen in most field crops (Sağlamtimur et al.,1988) found that under the conditions of Çukurova Region, phacelia is a suitable plant to utilize the 78 months idle period before cotton sowing and the number of flowers per square meter reached 9250. Fruits are capsule-shaped with many seeds inside. The seeds are brown and the thousand grain weight is 2-2.5 grams.

The flowers are usually light purple in color. One *Phacelia tanacetifolia* flower secretes 0.81.62 mg of nectar per day under various environmental conditions, especially climate and fertilization. Depending on the strength of the colony, 5-9 kg of *Phacelia tanacetifolia* honey

can be harvested in a good season, and honey yield per decare varies greatly, but is between 30100 kg. *Phacelia tanacetifolia* 13 species are known and 5-6 species are important for beekeeping.

Phacelia is also suitable as a winter cover crop that leaves the field in spring without leaving much residue. For this reason, it is a good rotation plant. Although it has abundant mass production potential, the plant is damaged at temperatures below 0 °C. In Europe, it has gained importance as a fall/winter cover crop before potatoes **(**Gilbert, 2003).

Figure 1. General view of Phacelia (Anonymous, 2024a)

2. ADAPTATION

Phacelia tanacetifolia plant is not very selective in terms of soil requirements, it is successfully grown in various soil types. The pH level of the soils where *Phacelia tanacetifolia* will grow should be between 6.4-8.6. It is a plant that can adapt very well to many soil mixtures. However, moist and heavy soils reduce the percentage of emergence. It is grown as winter crops in temperate regions with low altitude and as summer crops in regions with cold winters. In European countries, it is sown in early autumn to limit nitrate leaching caused by excessive nitrogen fertilization (Gilbert, 2003). Winter mortality occurs at -7 °C. It should be sown in October-November in the Mediterranean climate and in April-May in Eastern Anatolia. It can

be grown without irrigation where spring rainfall lasts long. However, when summer sowing is done in arid regions, irrigation should definitely be done in order to prolong flowering and delay seed maturation in the plant. Irrigation should be started with the end of spring rains.
Since *Phacelia tanacetifolia* seeds are small, good seedbed preparation is of great importance. When sowing, a gap of 20-70 cm should be left between the rows. Under irrigated conditions wet grass yield was obtained as 1116 kg/ha and dry grass yield as 305 kg/ha with 50 cm row spacing between plants. The amount of seed to be sown per decare should be 1-1.5 kg/ha. Sowing depth should be kept between 1-2 cm. The amount of seed should be slightly increased in broadcast sowing (Sağlamtimur et al., 1988). For *Phacelia tanacetifolia,* 5-6 kg pure nitrogen and 5-6 kg/da phosphorus fertilizer should be applied per decare (Sağlamtimur et al., 1989).

For silage production, mowing can be done at the beginning of the flowering period. However, after being left to develop in the field and used as bee pasture for 1.5-2 months, it is more economical to make silage by mowing in the period when the flowers decrease. After being used as bee pasture, silage can be made by mowing the plants and adding additives. In *Phacelia tanacetifolia* pasture, honey yield can be increased 2-3 times in each colony. The honey (bean honey) obtained from *Phacelia tanacetifolia* is of high quality. Nectar secretion is 0.800.85 mg/flower/day, honey potential is 30-100 kg/ha and pollen yield is 0.5 mg/flower (Crane, 1975).

The most important point to be considered in harvesting *Phacelia tanacetifolia* seeds is to harvest the ripened seeds before they fall on the land. For this purpose, when the inflorescences turn brownish, the plants are mowed and collected in one place and spread to dry. The seeds are separated by beating the dried plants with wooden sticks or driving a tractor over them. After this work, the seeds are separated from the plant residues with the help of wind. Phacelia seed yield per decare is 50-60 kg depending on conditions such as variety, climate and soil. Green grass yield varies significantly between 332-3458 kg/ha depending on climate and cropping type. (Sağlamtimur et al.,1988)

Phacelia tanacetifolia Benth is sown in rows 20-30 cm apart. Seed amount is 1-1.5 kg/ha and sowing depth is between 1-2 cm. 5 kg each of pure nitrogen and phosphorus fertilization should be applied per decare. There is no need to spray against any diseases and pests in phacelia cultivation (Korkmaz, 2009).

Figure 2. *Phacelia tanacetifolia* Benth. Leaf (Anonymous (2024b)

Figure 3. *Phaceli tanacetifolia* Bent. flowers (Anonymous (2024a).

Phacelia tanacetifolia is one of the 20 most preferred honey plants by honey bees and is one of the top 20 honey plants in the world as a pollen source (Demiroğlu Topçu and Özkan, 2020; Kumova and Korkmaz 2002; Gilbert, 2003; Bato, 2024). It is used as bee pasture in countries such as the USA, Germany, Russia and Serbia. Plants such as mustard, geven, sainfoin and thyme are highly preferred by bees. However, *Phacelia tanacetifolia* Benth is more visited by honey bees because it flowers longer than these plants. It is more common to use *Phacelia tanacetifolia* as a source of pollen and nectar for bees by extending the flowering period by planting it on different dates (Ozkan, 2014; Kumova, and Korkmaz, 2002). *Phacelia tanacetifolia* is an important nectar source for wild bees such as bumblebees (Korkmaz, 2009). Honey bees visit the bumblebee 22% of the time and bumblebees 3% of the time to collect pollen. On the other hand, bumblebees visit phacelia 97% of the time to collect nectar (Williams and Christian, 1991). According to the researches, 2 honey bee hives can benefit from 1 decare of land. In addition, since the plant is resistant to diseases and pests, pesticides are not used in its cultivation. Therefore, this plant offers great opportunities for organic honey production.
Phacelia tanacetifolia Benth, known by beekeepers all over the world as a very good nectar source, is among the top 20 nectar plants in the world (Crane, 1975), with a nectar secretion of 0.800.85 mg/flower/day, honey potential of 30-100 kg/da; pollen yield of 0.5 mg/flower and pollen potential of 13.3 kg/da (Crane,et al., 1984). Although the flowering period varies depending on many factors such as climate and variety, it is approximately 1 month for a plant and 1.5-2 months for a field. *Phacelia tanacetifolia* Benth flower has 5 anthers and a two-part female organ. The color of the petals varies from white to bluish pink depending on the variety (Williams and Christian, 1991).

In addition to these uses of *Phacelia tanacetifolia* Benth., its ability to attract insects has been the source of various studies. Today's agricultural practices are developing to the extent of destroying nature in order to increase productivity and this situation causes the feeding areas of beneficial insects to shrink. In order to eliminate the negativities brought about by unconscious agriculture in large areas or in a way that disrupts the natural balance, new feeding areas are created by creating pastures from the mixtures of *Phacelia tanacetifolia* Benth. with various plants. In this way, the plant ecosystem is tried to be developed and the insects that shelter on the plant ecosystem and pollinate many plants will also survive in this process.

Figure 4. Phacelia tanacetifolia Benth. unpollinated appearance Anonymous (2024a).

Phacelia tanacetifolia Benth is planted around the plants and between the rows in order to attract pollinators to some plants that have problems in pollination due to the fact that they are not attractive enough for pollinators and do not provide sufficient food sources. In this case, in parallel with providing additional food source for honey bees, plant producers increase their profitability by increasing their crops. In addition, at the end of flowering, plowing the cultivated plants and mixing them into the soil contributes to the improvement of the soil structure. Chemicals are even used to remove pollinators from *Phacelia tanacetifolia* Benth. as it is highly attractive to some plants (Long et al., 1998).

Phacelia tanacetifolia can be used to feed animals after flowering, either fresh or dried. However, since the plant becomes more difficult for animals to digest in the later stages of flowering, some additives may need to be added to the phacelia during silage making, which is a type of feed.

Figure 5. *P. tanacetifolia* Benth. from seed Anonymous (2024c).

Figure 6. *P.tanacetifolia* Benth. view from seed Anonymous (2024c).

Phacelia tanacetifolia is harvested mainly for the purpose of using the plant as animal feed. For this reason, phacelia should be harvested when its nutritional value is at its highest. This period coincides with the budding and half-flowering period of the phacelia. In this way, it is observed that the grass is more efficient in terms of protein, fat and fiber.

Apart from being used as bee pasture and forage, since it grows on rocky and stony lands, it can be used as a green manure plant for the improvement of poor soils and as a cover crop for erosion control It is also used as an ornamental plant. Since *Phacelia tanacetifolia* Benth is attractive to many insects, it can be used as a trap plant in biological control against pests damaging cultivated plants (Sağlamtimur et al., 1988; Korkmaz, 2009). After the pest population concentrates on *Phacelia tanacetifolia*, the plants are harvested and destroyed en masse. Thus, the damage to the ecosystem by using agricultural pesticides is eliminated (Kahl, 1996).

It has given very positive results when used in intercropping with maize and sugar beet, as a subcrop in vineyards and apple orchards, and as mulch in stubble in tomato fields

REFERENCES

Anonymous (2024a). https://www.inaturalist.org/taxa/58185-*Phacelia-tanacetifolia*

Anonymous (2024b). https://www.freenatureimages.eu/plants/flora%20or/Phacelia%20tanacetifolia/index.html#Phacelia%2520tanacetifolia%252019%252C%2520Phacelia%252C%2520Saxifraga-Sonja%2520Bouwman.jpg

Anonymous (2024c). https://gobotany.nativeplanttrust.org/species/phacelia/tanacetifolia

Bato, E. (2024). The Importance and Uses of Phacelia. Journal of Animal Science and Economics, 3(1), 17-22.

Crane, E., (1975), Honey: A Comprehensive Survey. Heinemann in Co-operation with International Bee Research Association. London. UK. 608 pp.

Crane, E., Walker, R. Day. (1984), Directory of Important World Honey Sources. Inter- national Bee Research Association, London, UK, 384 pp.

Demiroğlu Topçu, G., Özkan, Ş.S. (2020). The important of bees in rangelands. *Innovative Approaches in Meadow-Rangeland and Forage Crops*, Iksad Publishing House, Editır.Seyithan Seydoşoğlu, Chapter 14, Iksad Publishing House, 315-333 pp.Ankara.

Gilbert, L., (2003). What We Knom About İts Suitability As An Insectary Plant And Cover in The Mid-Atlantic Region, Small Farm Success Project, Susta- inable Agricultural Sysmems Lab., USDA.

Kahl, H., (1996). Border Strip Planting to Enhance Biological Control of the Cabbage Aphid, *Brevicoryne brassicae* (L.) by Hoverflies (Diptera: Syrp- hidae). Christ. Polyt. Inst. of Tech.

Korkmaz, A., (2009). Phacelia Cultivation Republic of Turkey Samsun Governorship Provincial Directorate of Agriculture. Samsun.

Kumova, U., Korkmaz, A., (2002). Research on Bee Forage Plant (*Phacelia tanacetifolia* Bentham) in Turkey and its Importance in Beekeeping. Uludag Bee Journal2(1):11- 16

Long, R. F., Corbett, A., Lamb, C., Reberg-Horton, C., Chandler, J., Stimmann, M., 1998. Beneficial Insects Move from Floering Plants to Nearby Crops.California Agriculture. 52(5):23-26.

Ozkan, U.,(2014), Importance of Phacelia (*Phacelia tanacetifolia* Benth.), Its Cultivation, Studies Conducted in Our Country and the World, Agricultural Engineering. Sayı: 361

Sağlam, T., Tansı, V., Baytekin, H. (1988). Cultivation of Fodder Crops.Çukurova Univwersity Agriculture Faculty, No.74, Adana.

Sağlamtimur T., Tansı, V., Baytekin H., (1989). A study on the effect of cutting time on plant height and hay yield in Phacelia (*Phacelia californica* Cham) grown as winter catch-up crop in Çukurova Conditions. Journal of Çukurova University Faculty of Agriculture, 4 (1) Pg.76-83.

Sağlamtimur, T., Tansı, V., (2009), Phacelia (*Phacelia tanancetifolia* Bentham), Republic of Turkey Ministry of Agriculture and Rural Affairs, General Directorate of Agricultural Production and Development, Forage Crops Book. Pg 779-783.

Tyebbes K,., (1986). The chrosome number of some flowering plants. Instutition For Sugarbeet Research, Hilleshög, Landskrona. Sweden. Sf 328-331

Williams, I.H., Christian, D.G., (1991). Observations on *Phacelia tanacetifolia* Bentham (Hydrophyllaceae) as a Food Plant for Honey Bees and Bombus Bees .Journal of Apicultural Research 30(1): 3-12.

CHAPTER 3

CLASSIFICATION OF MATH EXAM RESULTS OF 10th GRADE STUDENTS USING PHYSIOLOGICAL PARAMETERS WITH MACHINE LEARNING ALGORITHMS

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1. INTRODUCTION

In today's world, the effects of the rapidly developing information and technology age are evident in every field. With the impact of these developments, keeping up with these changes, which have become a common goal for countries, will be possible not only by strengthening the technological infrastructure, but also by raising individuals who understand and use these innovations and can shape the future. One of the most important steps to achieve this goal is to adapt the education system to technology. Raising individuals who can use technology effectively, have critical thinking and problem-solving skills will be the guarantee of the future development of societies. In addition, being able to follow scientific and technological developments will ensure that countries are in a strong position in global competition. As a result, each individual's ability to comprehend technological developments and integrate these developments into their lives will play a critical role in the sustainable development of societies (Karamustafaoğlu et all., 2012).

Ateş, Keskin and Çotuk, in comparisons made for manager and engineer categories, found statistically significant differences between managers and engineers for heart rate change values (Ateş et all., 2017).

Asgarpour and Yavuz, according to the results of their studies, stated that increases in body temperature caused a decrease in arterial blood pressure average and oxygen saturation values and an increase in pulse rate. Based on these findings, it can be commented that the applicability of measurement tools can be explained by physiological parameters (Pour and Yavuz, 2010).

Çoban, with his study, is a research that aims to increase computational thinking skills and this is done with a performance-based method. According to the determined measurement tool results, it was stated that there were differences depending on gender but there was no significant difference according to class levels. In the study, computational thinking skills can be measured safely and validly thanks to the online performance measurement tool (Çoban, 2021). In the study, it was stated that the interactive web application developed to determine computational thinking skill levels measured better than the psychometric scale.

Studies on the evaluation of mathematics exams generally focus on teacher opinions, the effectiveness of question types, and student performance evaluation. In the evaluation of high school exams, exam analysis methods are used to examine student performance in detail. In this process, statistical methods such as mean, median, and mode are applied to determine the strengths and weaknesses of the student. Exam analyses are used to develop strategies for improving learning processes (Totan, 2018).

Totan conducted a study examining the validity and reliability of the Westside Test Anxiety Scale to assess test anxiety in high school and middle school students. This research contributes to the lack of psychometric tools for the measurement of test anxiety and supports the applicability of the scale to Turkish students. The study shows that it provides a valid and reliable tool for understanding test anxiety in high school students (Totan, 2018).

In the study conducted by Yavuz and Bilgeç, the contributions of open-ended questions to the measurement and evaluation processes in mathematics exams were examined. While open-ended questions can better measure students' problem-solving skills and conceptual understanding levels, they can make the evaluation process more difficult for teachers. The use of these questions is recommended because they improve students' critical thinking and interpretation skills (Yavuz and Bilgeç, 2016)

Sadık and Bal conducted an evaluation on the types of questions and measurement-evaluation methods used by mathematics teachers in exams. Although most teachers try to use questions that develop students' thinking skills, it has been observed that in practice they mostly

tend to use multiple choice or short answer questions. Teachers prefer open-ended questions less due to time constraints and concerns about objective evaluation (Sadık and Bal, 2017).

Bayırlı et al. measured the physiological reactions of students during mathematics exams and examined how these reactions were related to anxiety and stress. In the study, physiological variables such as heart rate, sweating, and blood pressure of students were monitored and the relationship between these parameters and their exam success was analyzed. In particular, it was found that high anxiety levels could negatively affect students' exam performance (Bayırlı et all., 2021).

In most studies, what needs to be done to improve measurement and evaluation in education has been investigated using traditional methods and the parameters on which student success depends have been examined. The connections between student success and parameters such as gender, age, chosen department, sociological differences, genetic predisposition, education received, etc. have been examined. However, no study using physiological data has been found to improve measurement and evaluation tools. In this study, the connection between the success rates of mathematics exams applied to 10th grade high school students and physiological parameters and the effects of these parameters on each other have been investigated. The study will provide support to teachers in the evaluation of question difficulty levels. It is seen that faster, more reliable and more accurate results will be obtained in the classification of exam difficulty levels with this method.

2. MATERIALS

2.1. Dataset

It was conducted with a cluster consisting of 10th grade students of Meram/Konya Vocational and Technical Anatolian High School who participated in the study on a voluntary basis and who did not have any chronic diseases and did not have a special education report within the scope of BEP. Physiological parameter data were obtained from 36 students while answering a mathematics exam with a Masimo Rad-G pulse oximetry device and Kanz thermometer. These physiological parameters were SpO2, PR(bpm), RRp(rpm), PVi, Pi and C°. These students were randomly divided into 2 groups during the exam phase. The aim here is to compare the similarity of the exam questions directed to the students. In this direction, 15 different data were recorded from each student for each question, and the dataset size obtained from each group consists of a matrix in the format of 1350x6.

Here, Spo2 is the oxygen saturation in the blood. It is expressed as the percentage of hemoglobin that can carry oxygen. PR (bpm) is the pulse rate, that is, it is expressed as the heartbeat felt in the arteries. RRP (rpm) is the respiratory rate and expresses the number of respirations per minute (rpm). Pi is the circulation rate or perfusion index. It is the ratio of pulsatile blood flow in the peripheral tissue to nonpulsatile or static blood flow. In other words, it is known as the noninvasive measurement of peripheral perfusion obtained continuously and noninvasively from the pulse oximeter. PVi is the fluid response. Fluid response (PVi) is a measurement of the dynamic changes in the Perfusion Index (Pi) that occur during the respiratory cycle. C° is the body temperature and also constitutes the balance of metabolic reactions of the organism (Rad-G, 2021), (Çakır et all., 2017), (Kuzu et all., 2017).

Exams refer to the application carried out to monitor their development over the years, to evaluate them with grades or to determine their passing status. Exam questions were prepared in the form of a written examination consisting of open-ended and short-answer questions within the scope of the Written and Applied Exams Directive published by the Ministry of National Education, updated on 12.10.2023, and within the framework of previously announced scenarios (32304-Resmi Gazete, 2021).

Therefore, in this study, open-ended and short-answer short-term written questions were asked to the students within the scope of the scenarios announced to them, taking into account the level and readiness of the students. The exam questions were obtained from the common exam questions of mathematics, which were conducted in the butterfly system at Konya Vocational and Technical Anatolian High School, where the physiological data were obtained from. Thus, questions suitable for the student's readiness and level were used.

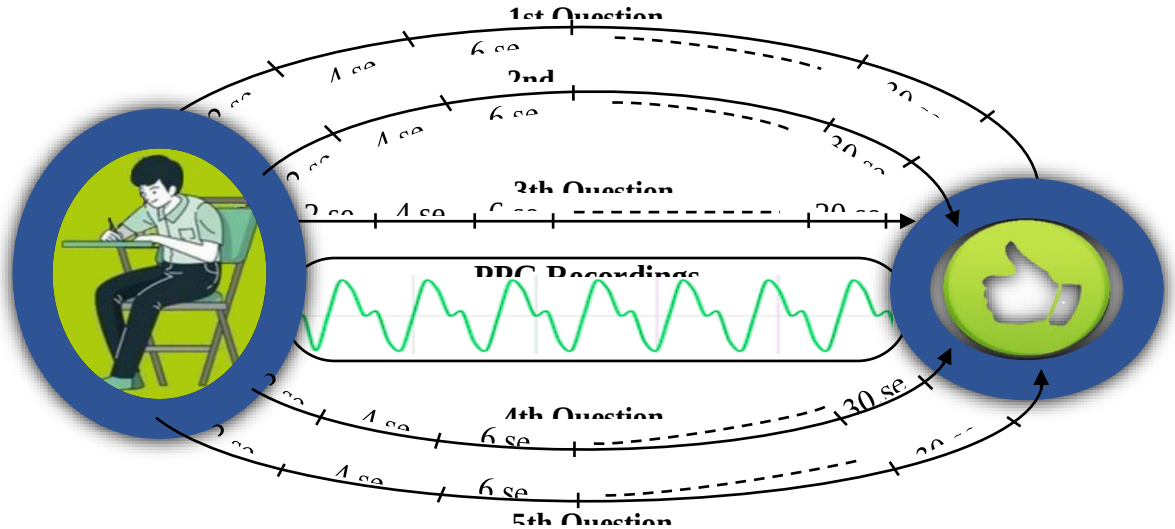

Figure 1. Data Acquisition Flow

As shown in Figure 1, 5 questions were asked to each student in the exam. For each question, a total of 15 data were recorded from each student with a Masimo Rad-G pulse oximeter and thermometer every 2 seconds for 30 seconds, and a 10-second waiting period was given between questions.

2.2. Evaluation and Class Scale

Each of the 5 questions asked to the student during the exam is worth 20 points and the exam is evaluated out of 100 (one hundred) points. The exam evaluation was made according to a graded answer key. The grades given to the answers given by the students were classified as 0-8 points as difficult questions, 9-14 points as normal questions and 15-20 points as easy questions, as shown in Figure 2.

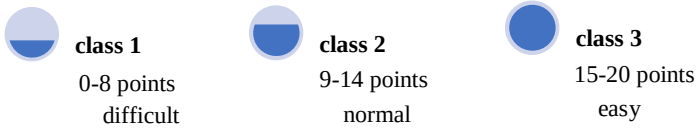

Figure-2. Evaluation and Class Scale

3. METHOD

The machine learning process can detect patterns and relationships in the dataset and estimate the difficulty levels of the questions according to the new input data. At this stage, the recorded physiological parameters are first normalized as shown in equation 1 in order to obtain faster results with machine learning algorithms.

$$X_s^{\text{norm}} = \frac{X_s - X_{min}}{X_{max} - X_{min}} \quad (1)$$

Here; X_s represents physiological parameters of data, X_{min} and X_{max} define the minimum and maximum values in the dataset, respectively (Nardelli et all., 2015), (Görür et all., 2021), (Han et all., 2011), (Sola and Sevilla, 1997).

3.1.k-Fold Cross-Validation

k-Fold Cross-Validation is a widely used method for machine learning and model evaluation. It does not divide a dataset into a certain part as training and a certain part as testing, as in traditional classification methods. This method divides the dataset into multiple parts (layers) to more reliably evaluate the accuracy of the model and measures how the model performs in each layer. This process allows the model of each part to be classified and tested in turn. As seen in the k-Layer Cross-Validation diagram in Figure 3, cross validation is obtained by taking the average of the errors and classification accuracies (Kohavi, 1995), (Bishop, 2006), (Arlot and Celisse, 2010). Classification accuracy is the average of the classification accuracies obtained for each k value.

In our study, the data of 1350x6 is divided into 10 parts. For each k value, the model is established with 9 different parts and tested with the remaining 1.

Figure 3. 10-fold Cross Validation Diagram [20]

In this study, k-Nearest Neighbors (kNN) algorithm and Support Vector Machine (SVM) methods were applied. Equations 2-4 express the classification accuracies.

$$ACC(TS) = \frac{\sum_{i=1}^{|TS|} estimate(n_i)}{|TS|} \quad , n_i \square TS \quad (2)$$

$$Estimate(n) = \{3, if\ \ estimate(20 \geq x \geq 15)\ \ = c_n\ 2, if\ estimate(\ 14 \geq x \geq 9) = c_n\ \ 1, otherwise \quad (3)$$

$$\text{Class}.ACC = \frac{\sum_{i=1}^{|k|} \quad accuracy(TS_i)}{|k|} \quad (4)$$

Here; TS represents the test dataset, cn refers to the class n. Estimate(n) represents the classification value for n and k represents the k-fold cross-validation value (Powers, 2011). True negative (TN), true positive (TP), false negative (FN) and false positive (FP) are the primary parameters applied for specificity (SPEC) and sensitivity (SENS) are shown in equations 5-6 (Kaggle, 2024), (Sokolova and Lapalme, 2009).

$$Sensitivity = \frac{TP_1\ + TP_2\ + TP_3}{TP_1\ + FN_1\ \ + TP_2 + FN_2 + TP_3 + \ FN_3} \quad (5)$$

$$Specificity = \frac{TN_1\ + TN_2\ + TN_3}{TN_1\ + FP_1\ \ + TN_2 + FP_2 + TN_3 + \ FP_3} \quad (6)$$

3.2. K-Nearest Neighbors (KNN)

The K-Nearest Neighbors (K-NN) algorithm works by finding the K "nearest neighbors" of a data point and then using the class labels of these neighbors to predict the label or value for the given data point (Cover et all., 1967). The KNN structure used in the study is seen in Figure 4.

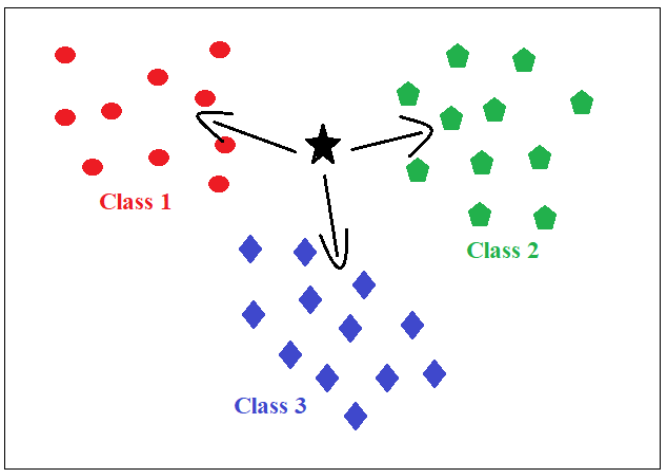

Figure 4. The Structure of KNN

The KNN algorithm can be used as a tool to help estimate the difficulty level of a math exam. This structure has a Euclidean-based structure and all neighbors are voted equally, and the class with the most voters among the neighbors is selected. The degree of the correction parameter is controlled by k in the neighborhood of kNN (Atman, 1992). Mathematical approximations for the Euclidean distance between a and b for each example are given in equation 7.

$$d_1(x) \leq d_2(x) \leq \cdots \leq d_N(x) \quad (7)$$

The distances are in ascending order from the nearest distance $d_1(x)$ to the next nearest distance $d_2(x)$. x^t is defined as the data points and t is the index of the samples:

$$d_1(x) = min\ t\ |x - x^t| \tag{8}$$

In this study, the k step that provides the best results was selected as 3.

3.3. Support Vector Machines (SVM)

It is the simplest and most basic method used to separate two classes with a linear line. Support Vector Machines, called SVM, separate two classes with a linear line called a hyperplane and perform the classification process with linear or non-linear lines on both sides of the lines that will maximize the distance between the support vectors (Görür et all., 2016), (Burges, 1998).

The algorithm is based on the Kernel function based classification method and maximizes the separation between the training data by linearly separating the two-class feature space and creates an ideal hyperplane known as the decision surface as seen in Figure 5. The mathematical expressions of the SVM structure are shown as given below.

$$\{x_i\ ,\ y_i\ \},\ i = 1, 2, \dots, N,\ y_i \in \{-1, +1\},\ x_i \in R\ n \tag{9}$$

$$(w.\ x_i\ ) + b = 0 \tag{10}$$

$$x_i.\ w + b \geq +1 \ \text{ for } \ y_i = +1\ x_i\ .\ w + b \leq +1 \text{ for } \ yi = -1 \tag{11}$$

Here: xi represents the training data, yi represents the classes, N represents the data size, w represents the hyperplane weights and b represents the kernel constant (Cortes, 1995).

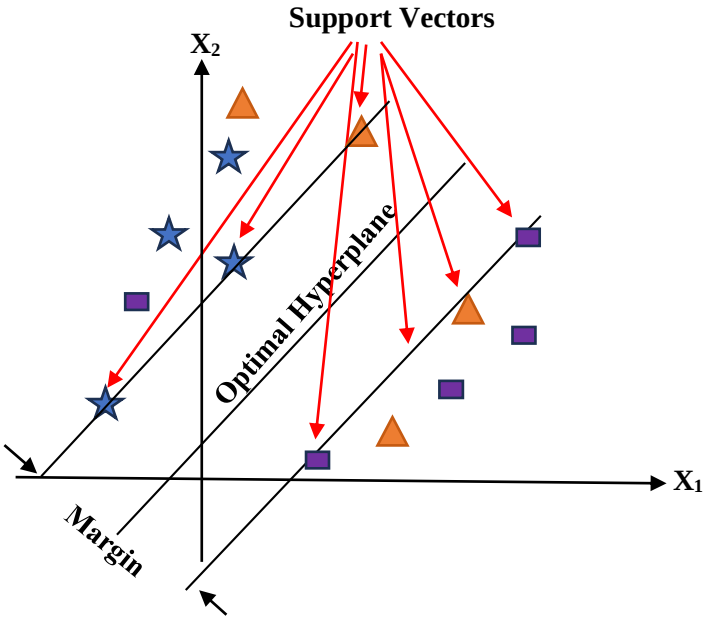

Figure 5. The Structure of SVM

4. RESULTS

KNN and SVM methods are effective tools in estimating the difficulty levels of questions with physiological parameter data recorded in the mathematics exam. The results obtained with these methods can help guide teachers in evaluating the difficulty levels of the exam and create their plans accordingly. The statistical values of the physiological parameters recorded in the 10th grade mathematics exam for all questions are given in Table-1 below.

Table 1. The Statistical Values of All Recorded Data

Statistical Values	SpO2 %	PR (bpm)	RRp (rpm)	PVi	Pi	C°	Mark	Class
Mean	98,12	89,03	17,97	22,22	4,26	36,83	9,76	1,84
Std. Deviation	1,20	15,64	4,40	8,42	3,10	0,30	8,40	0,92
Variance	1,44	244,47	19,33	70,88	9,63	0,09	70,54	0,85
Mode	98,00	82,00	16,00	27,00	3,01	36,90	20,00	1,00
Median	98,00	87,15	18,00	21,00	4,00	36,90	8,00	1,00
Max.	100,00	140,00	32,00	54,00	20,00	37,70	20,00	3,00
Min.	94,00	54,00	6,00	7,00	0,09	36,00	0,00	1,00

The values given in Table 1 include statistical values obtained according to the real magnitudes of physiological parameters. Mean, Standard Deviation, Variance, Mode, Median, Maximum Value and Minimum Values of SpO2, PR, RRp, PVi, Pi, C°, Mark and Class values are shown. For example, while the SpO2 value varies between 94-100, Mode and Median values are determined as 98, Variance value as 1.44, standard deviation value as 1.2 and Mean value as 98.12. Other physical variables are calculated in this direction. However, in order to bring the magnitudes closer to each other in the graphical representation and to interpret them more easily, normalized parameter values are used for all data.

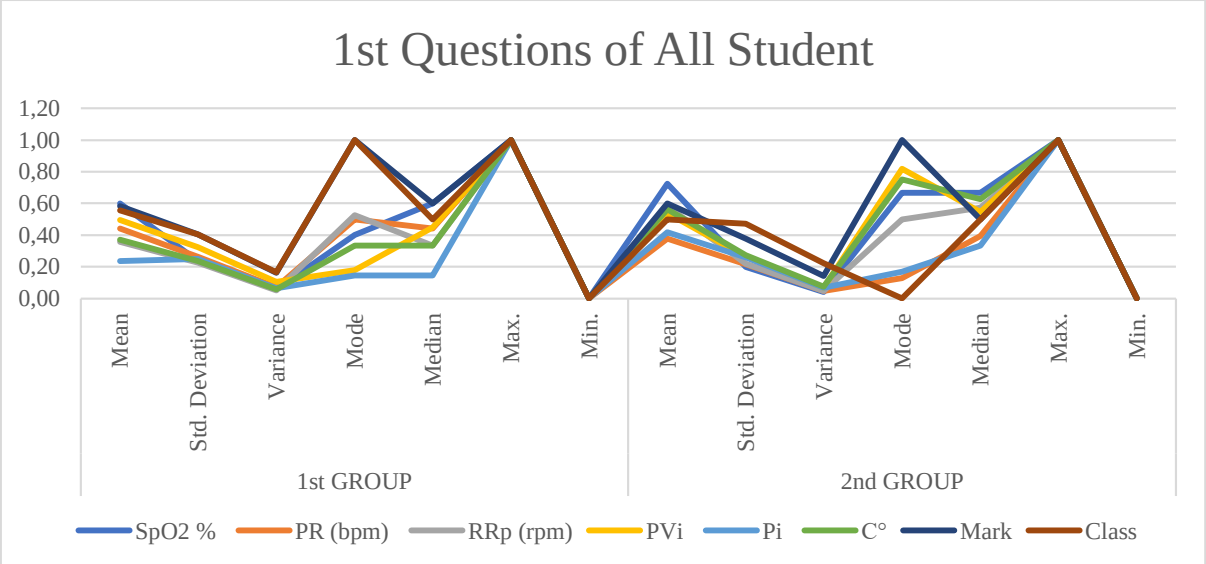

Figure 6. Statistical Results of 1st Questions of Groups

Figure-6 shows the visual that emerged after the normalized magnitudes of the physiological parameters recorded during the answers to the first question from the students divided into 2 groups. It is seen that the average of all values is close to each other in both groups. This situation can be interpreted as the question levels are similar. The average of the

SPo2 value is slightly lower in the students of the first group than in the students of the second group. It can be said that this situation is due to the change in the breathing rates and the differences in the excitement levels of the students depending on the adaptation process while they are comprehending the exam. Other parameters related to SpO2 have changed in parallel with this. Although the average of the class variable is at a similar level in both groups for the first questions, the mode value of this variable shows that the students in the first group received higher scores for this question. Similarly, it is seen that the mark variable also changes in this direction. The mode variable of the PVi value was encountered more in the second group. This situation can be associated with the students being excited. Similarly, body temperature has also changed in parallel with this. RRP value is also observed to be close for both groups. The fact that PR variable changes more in the first group students shows that this group is more excited or stressed than the others. Pi is the respiratory cycle depending on these parameters and it was close in both groups.

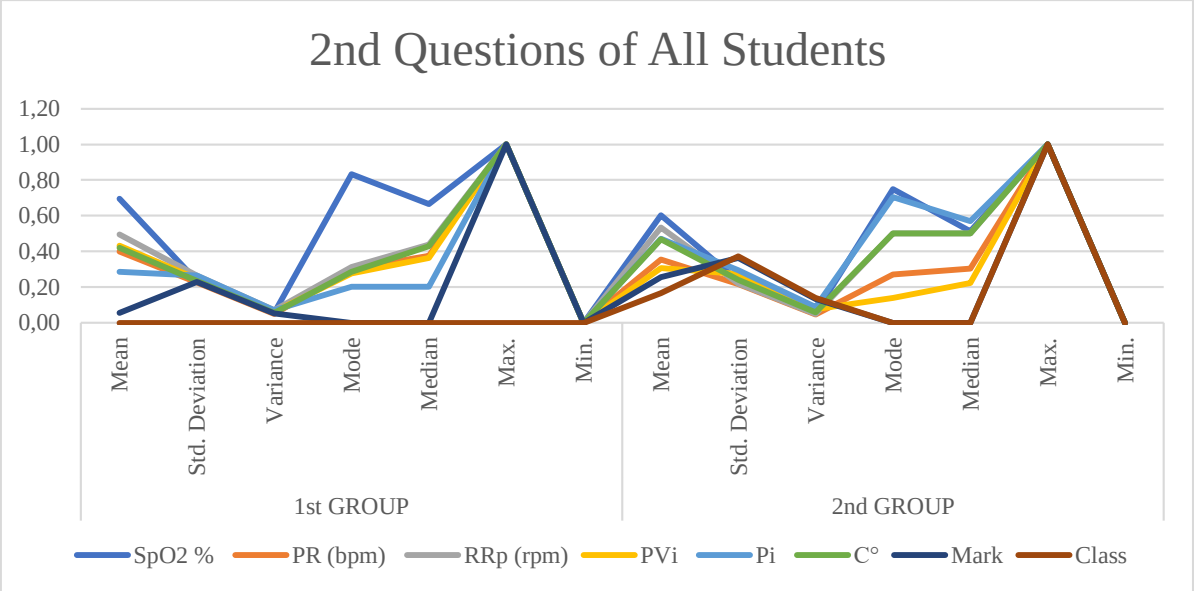

Figure 7. Statistical Results of 2nd Questions of Groups

When Figure-7 is examined, it can be stated that the change in the Class value is quite difficult for the 1st group students in the 2nd question. Because all the values depending on this variable are at a very low level. Accordingly, differences are clearly seen in the variables depending on other values.

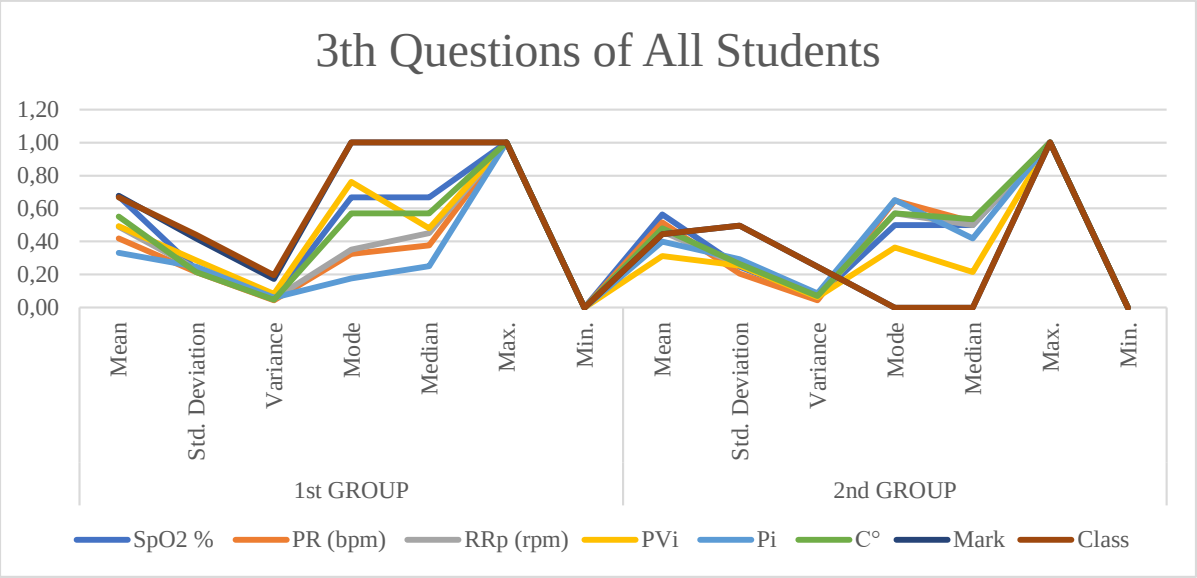

Figure 8. Statistical Results of 3th Questions of Groups

When Figure-8, which shows the 3rd questions based on groups, is examined, it can be said that this question was easier for the students of Group 1. Because, the mode and median variables of the class value are higher for the students of Group 1. In other words, it was observed that many students received full points in Group 1. Other variables exhibit close distributions.

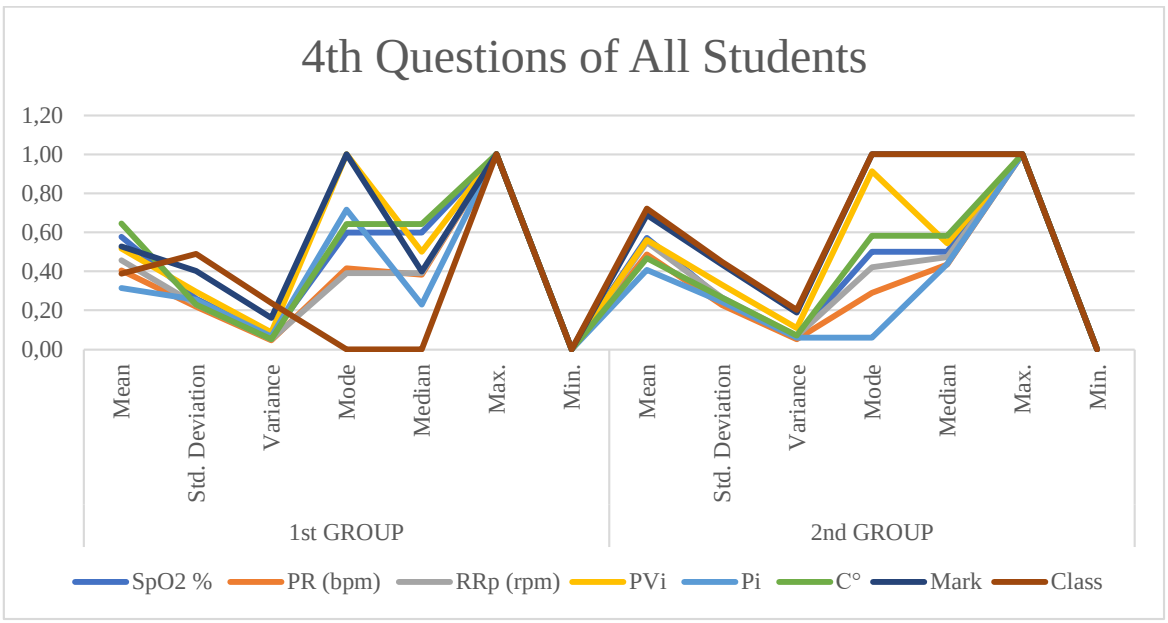

Figure 9. Statistical Results of 4th Questions of Groups

When we look at Figure 9, we can see that Question 4 is easier for the students of group 2, unlike Question 3. The mode and median values of the Class variable are high for Group 2, and most students in this group received full marks from this question. In addition, the Pi value, which is the respiratory cycle, was higher in Group 1. The average body temperature was also higher in Group 1.

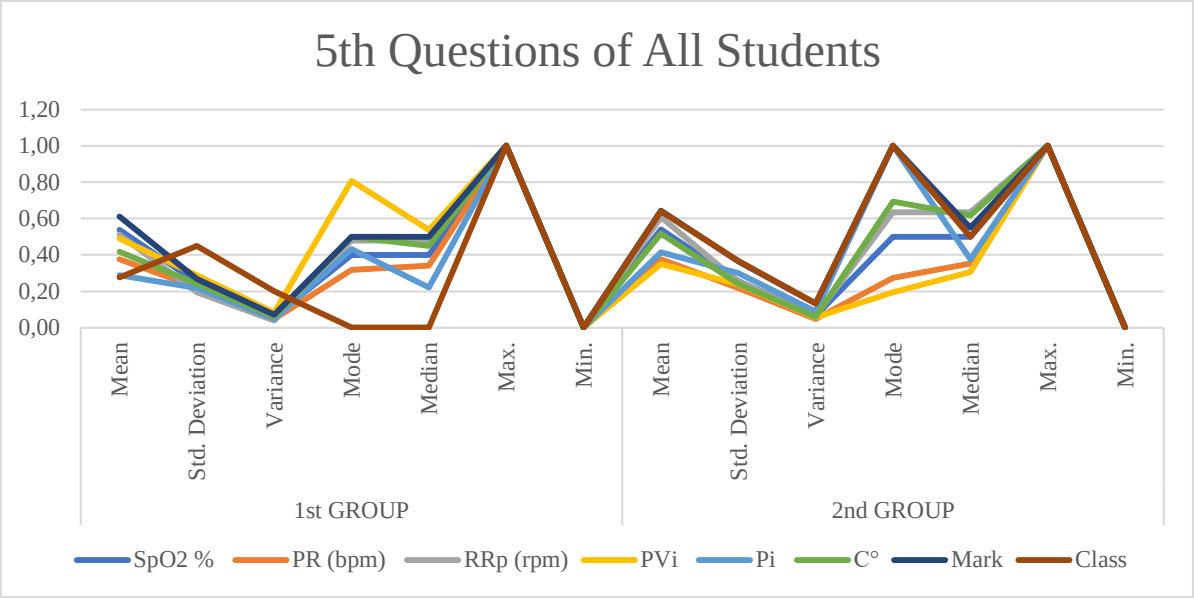

Figure 10. Statistical Results of 5th Questions of Groups

In Figure 10, where the statistical drawings of the questions are shown, it is seen that the class value is low in the 1st group, and it can be concluded that this question is more difficult for the 1st group students. It is clear that the respiratory cycle of this group is higher and the mark values are also lower than the 2nd group. Other parameters also showed a parallel trend.

Table 2 shows the classification accuracies of groups based on questions.

Table 2. Classification Results of All Questions According to Groups

METHOD	1st Question 1.Group / 2.Group	2nd Question 1.Group / 2.Group	3th Question 1.Group / 2.Group	4th Question 1.Group / 2.Group	5th Question 1.Group / 2.Group
	k=10 fold cross validation				
KNN (k=3)	100% / 100%	100% / 100%	100% / 100%	100% / 100%	100% / 100%
SVM (One-vs-One)	100% / 100%	100% / 100%	100% / 100%	100% / 100%	100% / 100%

As seen in the table, the results of both KNN and SVM machine learning algorithms provided a high-level classification performance based on the questions posed to the groups. Therefore, it is seen that the scoring of the questions in the study, as well as the assignment of class values, was made very accurately by looking at these values. Similarly, it would not be wrong to say that the student levels in the groups were similar based on these classification results.

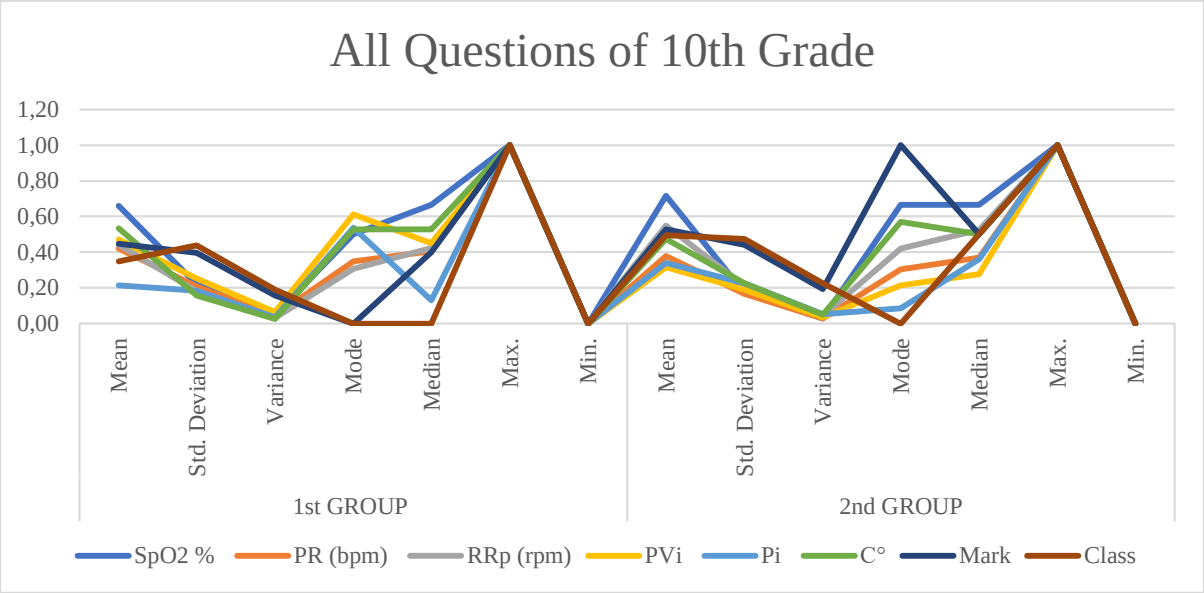

Figure 11. Statistical Results of All Questions on 10th Grade According to Groups

Figure-11 shows the statistical changes of the parameters recorded while all students answered all the questions according to the groups. The mean value and median value of the Class variable are higher in the students in the 2nd group. This may mean that the questions in the 2nd group are generally easier. The mode and median value of the Mark variable support this view as seen in the Figure. Similarly, the fact that the Pi circulation rate is generally high in the 1st Group also contributes to this. The PVi respiratory cycle was also generally high in the 1st Group students. Other variables were similar in both groups.

Table 3 shows the classification accuracies based on groups.

Table-3. Classification Results of All Questions According to Groups

METHOD	All Questions of Groups
	k=10 fold cross validation
KNN (k=3)	**98,9%**
SVM (Gaussian)	**98,8%**

As can be seen from the table, the results of both KNN and SVM machine learning algorithms provided very high accuracy rates in the classification made on a group basis. In other words, it would not be wrong to say that the questions divided into groups were correctly separated according to these classification results. The fact that the student levels in the groups

are similar also contributes to these results. The figures below show the confusion matrix, TPR and FNR results, which express the reliability results of the classifier.

Figure 12. KNN Confusion Matrix, TRP and FNR Tables

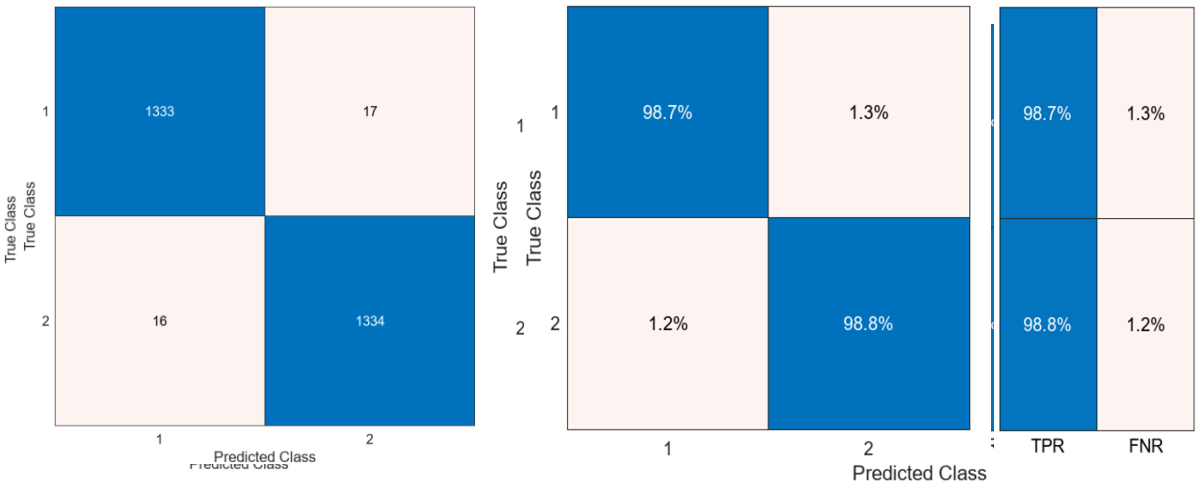

Figure 13. SVM Confusion Matrix, TRP and FNR Tables

According to the results of the KNN classifier given in Figure 12, it is seen that 16 data from Group 1 and 14 data from Group 2 were incorrectly classified. Similarly, the SVM classifier given in Figure 13 also incorrectly classified 16 data from Group 1 and 17 data from Group 2. In addition, the TPR and FNR rates are presented as percentages. These values are important in terms of comparing the accuracy of both the KNN and SVM classifiers and proving their reliability.

5. DICUSSION

In this study, SpO2, pulse, temperature, respiratory rate, fluid response and circulation rate were used in the field of education, not in a health field as usual. . This study aimed to investigate the connections with physiological parameters in the 10th mathematics exam evaluation. Thus, it was investigated whether there was a significant relationship between the physiological changes of the students and the measurement and evaluation tools. Unlike traditional classification methods, the k-fold cross-validation technique, which increases the reliability of classification accuracies, was used.

It has been observed that physiological parameters change according to the level of excitement and stress in the student and that a change in one parameter can affect another parameter. When the statistical tables created for question-based comparisons are examined, it is seen that the mode and median values of the mark and class variables are generally parallel. This situation shows that the values determined as class are parallel according to the scores received by the students. However, it was inversely proportional for some questions in the 1st group and for some questions in the 2nd group. In this case, it is an indication that the students received low marks and caused density in a region as class. In other words, it can be interpreted as the question being difficult or that the students may have been excited about this question. The 2nd question can be given as an example of this and it can be stated that this question was perceived as more difficult for the 1st group. Similarly, it is clear that the change in the values

of the SpO2 variable provides parallel results. If the example for the 4th question is given, although the mean, variance and standard deviation values of this value are close in both groups, there are visible differences between the mode and median values. These values are higher for group 1. It would not be wrong to say that the students had difficulty with this question. Circulatory rate Pi and fluid response PVi values also provide important contributions to question-based comparisons. Almost all values of these parameters for question 1 are higher for group 2 students. If this situation is interpreted by looking at the class and mark values, it can be explained by the fact that this question is seen as a more familiar situation for group 2, that is, the students were able to handle the situation a little more calmly. Pulse PR, respiratory rate RRp and body temperature Co variables also play an important role in comparing question difficulty levels. While body temperature and respiratory rate were higher in group 2 students for question 5, pulse value was almost parallel in both groups. It can be interpreted that these parameters are inversely proportional to the mark and class values and therefore question 1 was more difficult for the first group. Similarly, when the changes in these variables are examined for question 3, similar results can be seen. For this reason, it can be said that the third question was perceived as more difficult for the second group students.

At the same time, when the statistical table created for group-based comparisons is examined, when the mode and median changes of the mark and class variables are compared, it can be said that the students of the 2nd group received higher grades and that this group had a higher success rate. The fact that the PVi and Pi changes are generally higher in the 1st group indicates that this group is more accustomed to the situation during the exam but tends to have more difficulty. Although body temperature and PR changes are similar in both groups, it is seen that RRp is generally higher in the 2nd group and SpO2 is slightly higher in the 2nd group. This situation can be interpreted as the 2nd group generally adapting to the exam more.

As a result, it is clear that each parameter is meaningful on its own and affects other parameters in comparing question difficulty levels and making comparisons between groups. When the results of the machine learning algorithms made in this direction are taken into account, it is seen that both question and group distinctions can be made successfully at a very high rate. In this direction, it can be said that this study will contribute to the measurement and evaluation stage for teachers.

6. CONCLUSION

In studies conducted for measurement and evaluation, exam questions have always been analyzed with traditional methods and exam questions have been evaluated according to taxonomies in educational sciences. This study, in addition to traditional methods compared to previous studies, has tried to measure the level of exam difficulty for students by examining both question-based and inter-group changes with the help of physiological data machine learning algorithms for the first time. In addition, it is the first to prepare more subjective exams that can be suitable for the student level during the preparation of exam questions. As a result of the classification, it is seen that question-based comparisons with both KNN and SVM have reached an excellent accuracy rate of 100% and a very high classification accuracy of 98.9% has been achieved in group-based classification. Therefore, it is thought that this study helps educators to make more stable and more accurate evaluations during the exam question analysis phase with the help of physiological parameters and machine learning. In addition, it is anticipated that this way will contribute to the most appropriate preparation of exams for students.

REFERENCES

Arlot, S., & Celisse, A. (2010). A Survey of Cross-Validation Procedures for Model Selection. *Statistics Surveys, 4, 40-79.*

Altman, N. S. (1992). An Introduction to Kernel and Nearest-Neighbor Nonparametric Regression. *The American Statistician, 46(3), 175-185.*

Ateş, O., Keskin, B. and Çotuk, B. (2017). The effects of mental workload and exercise on heart rate variability. *National Journal of Sports Sciences, 1(2): p. 55-65.*

Bayırlı, H., Geçici, M. E., & Erden, C. (2021). The Relationship Between Mathematics Anxiety and Mathematics Achievement: A Meta-Analysis Study. *Pamukkale University Faculty of Education Journal, 53, 87-109.*

Bishop, C. M. (2006). *Pattern Recognition and Machine Learning.* Springer.

Burges, C. J. C. (1998). A Tutorial on Support Vector Machines for Pattern Recognition. *Data Mining and Knowledge Discovery, 2(2), 121-167.*

Cortes, C., & Vapnik, V. (1995). Support-Vector Networks. *Machine Learning, 20(3), 273-297.*

Cover, T. M., & Hart, P. E. (1967). Nearest Neighbor Pattern Classification. *IEEE Transactions on Information Theory, 13(1), 21-27.*

Çakır, S., Yaman, S., Eroğlu, O., Telatar, Z. (2017). Noninvasive pulse measuremetn and wireless transmission. Noninvaziv Nabız Ölçümü ve Kablosuz İletilmesi. *Medical Technologies National Congress (TIPTEKNO), pp. 1-4.*

Çoban, E. (2021). An alternative approach to measuring computational thinking skills: Performance-based measurement. *Amasya University, Master Thesis*. Türkiye.

Görür, K., Başcıl, M. S., Bozkurt, M. R., Temurtaş F., (2016). Classification of Thyroid Data Using Decision Trees, kNN and SVM Methods. *International Artificial Intelligence and Data Processing Symposium '16 (IDAP 2016), September 2016, Malatya Turkey, 130-134*

Görür, K., Bozkurt, M. R., Başçıl, M. S., Temurtaş, F., (2021). Tongue-operated biosignal over EEG and processing with decision tree and kNN. *Academic Platform-Journal of Engineering and Science, 9(1): p. 112-125.*

Han, J., Kamber, M., & Pei, J. (2011). Data Mining*: Concepts and Techniques* (3rd ed.). Morgan Kaufmann.

Kaggle, (2024). Introduction to Machine Learning. *Available on: https://www.kaggle.com/code/mustafagerme/introduction-to-machine-learning/notebook*.

Karamustafaoğlu, S., Çağlak, A. and Meşeci, B. (2012). Self-Efficacy of Classroom Teachers Regarding Alternative Assessment and Evaluation Tools. *Amasya University Faculty of Education Journal, 1(2): p. 167-179.*

Kohavi, R. (1995). A Study of Cross-Validation and Bootstrap for Accuracy Estimation and Model Selection. International Joint Conference on Artificial Intelligence (IJCAI), 14, 1137-1145.

Kuzu, M., O. Taş, and G. Tulum, (2017). Remotely Monitorable Patient Parameters System. *2nd National Biomedical Device Design and Manufacturing Symposium*, Türkiye.

Nardelli, M., Valenza, G., & Scilingo, E. P. (2015). Application of Machine Learning in Psychophysiological Signal Processing. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 23*(6), 867-877.

Pour, H. A. and Yavuz, M. (2010). Vücut Sıcaklığındaki Yükselmenin (Ateşin) Hemodinamik Parametrelere Etkisi. *Doktora Tezi.*

Powers, D. M. W. (2011). Evaluation: From Precision, Recall and F-Measure to ROC, Informedness, Markedness and Correlation. *Journal of Machine Learning Technologies, 2(1), 37-63.*

Rad-G, (2021). *Pulse Oximeter kullanıcı el kitabı*.

Resmi Gazete, (2023). Ministry of National Education Measurement and Evaluation Regulation No. 32304. *Available on: https://www.resmigazete.gov.tr/eskiler/2023/09/20230909-2.htm*

Sadık, F., & Bal, A. P., (2017). An Evaluation of Mathematics Teachers' Views on Measurement and Evaluation and the Questions They Ask in Exams. *IV International Eurasian Educational Research Congress, (pp.81-94). Denizli, Türkiye.*

Sola, J., & Sevilla, J. (1997). Importance of Input Data Normalization for the Application of Neural Networks to Complex Industrial Problems. *IEEE Transactions on Nuclear Science, 44*(3), 1464-1468.

Sokolova, M., & Lapalme, G. (2009). A Systematic Analysis of Performance Measures for Classification Tasks. *Information Processing & Management, 45(4), 427-437.*

Totan, T. (2018). Evaluation of Exam Anxiety in Middle and High School Students: Westside Exam Anxiety Scale. *Western Anatolian Journal of Educational Sciences, 9(2), 143-155.*

Yazuz, İ., & Bilgeç, İ, (2016). Investigation of the Measurement and Evaluation of Mathematics Exams with Open-Ended Questions. *Journal of Research in Education and Teaching, Vol.5, 183-193.*

CHAPTER 4

A HYBRID APPROACH COMBINING BINARY HIKING OPTIMIZATION ALGORITHM WITH GENETIC PROGRAMMING FOR MATHEMATICAL EQUATION GENERATION

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1. INTRODUCTION

In recent years, metaheuristic algorithms have gained prominence as powerful tools for solving complex optimization problems across various fields. These algorithms are very successful in navigating large and complex search spaces where classical optimization methods may struggle. Many of these algorithms are designed for continuous optimization problems, but binary search spaces present unique challenges that demand specialized approaches. One such approach is the Binary Hiking Optimization Algorithm (BinHOA), an adaptation of the Hiking Optimization Algorithm (HOA), which is inspired by the movement of hikers across rugged terrains. HOA has been shown to be effective for continuous problems, but its binary variant, BinHOA, introduces flexibility for discrete and binary search spaces.

On the other hand, Genetic Programming (GP) is an evolutionary algorithm that automatically evolves programs, or more generally, mathematical expressions, to solve a given problem (John R Koza, 1990; O'Neill, 2009). GP's ability to generate complex mathematical functions makes it suitable for a wide variety of tasks, including symbolic regression and function discovery. However, GP's performance heavily depends on the selection of appropriate function and terminal sets, which may limit its effectiveness if not properly set. Tree-based GP (John R Koza, 1990; John R. Koza, 1994) is the first form of the GP; however, over the years, a variety of GP representations has been developed, such as Linear GP (LGP) (Brameier & Banzhaf, 2007), Cartesian GP (Miller & Turner, 2015), and grammar-based GP (Whigham, 1995).

GP and metaheuristic algorithms are among the most actively researched areas, each generating thousands of publications and continuing to attract substantial academic interest. However, a Web of Science analysis reveals that studies employing both genetic programming and metaheuristic algorithms in combination are considerably less prevalent. Figure 1 illustrates the yearly distribution of publications indexed in SCIE journals that integrate these methodologies, along with the citation counts these studies have accumulated over time. The following discusses several significant studies in recent years that combine metasearch algorithms with GP to tackle various engineering and optimization challenges. These studies showcase the adaptability and versatility of GP in addressing complex problems, each utilizing GP innovatively to meet specific requirements, ultimately enhancing decision-making and predictive accuracy.

(Hasanzadeh, Bashiri, & Amiri, 2018) tackle the single-allocation hub covering location problem, incorporating queue estimation to optimize hub placement and server allocation by accounting for fixed, transportation, and waiting costs. They employ GP to establish a lower bound for this model, which not only increases solution precision but also demonstrates the effectiveness of a particle swarm optimization algorithm in minimizing the gap to this lower bound. (Li et al., 2024) concentrate on predicting the State of Health (SOH) for lithium-ion batteries through a two-stage framework that integrates metaheuristic algorithms with GP for feature selection and symbolic regression. Their approach employs a binary multi-objective grey wolf optimization algorithm to identify optimal feature sets, while GP is used to create symbolic equations that enhance the accuracy and cost-effectiveness of SOH predictions. (Onyelowe et al., 2022) use GP in conjunction with artificial neural networks and evolutionary polynomial regression (EPR) to predict the erodibility of lateritic soil in erosion-prone regions. Through laboratory tests and hybrid cement treatments, they demonstrate that EPR, optimized by a genetic algorithm, achieves higher predictive accuracy than other models, underscoring GP's effectiveness in environmental geotechnics. (Russo, Bernardino, & Barbosa, 2018) investigate GP for knowledge discovery within multi-objective optimization, introducing modifications to improve consistency, prevent trivial solutions, and preserve significant results. When applied to engineering case studies, this modified GP approach successfully uncovers

useful design principles, highlighting GP's potential for extracting meaningful mathematical relationships from optimization outputs.

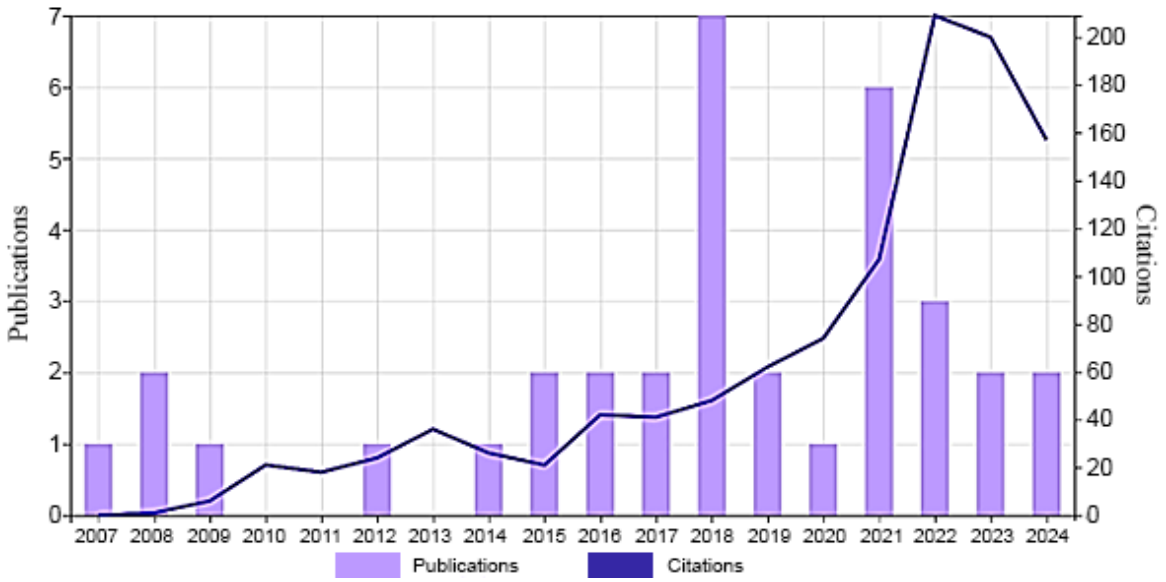

Figure 1. The number of publications and citations in SCIE indexed journals by years.

This study proposes a novel method that combines BinHOA with a part of the LGP to enhance the function discovery process in binary search spaces. BinHOA is utilized to optimize the sequence of instructions used in LGP. BinHOA has the potential to explore the search space more efficiently, thereby offering a robust solution for generating mathematical models in discrete domains. The experimental results show that this combined approach can effectively generate optimized mathematical functions, demonstrating superior performance in complex optimization problems compared to traditional methods.

The motivation and main contributions of this study can be summarized as follows: First, the growing need for efficient function discovery methods in binary search spaces has driven the development of a proposed approach that leverages the strengths of both BinHOA and GP. Second, this study introduces a novel synergy between a binary metaheuristic algorithm, BinHOA, and an evolutionary programming technique, GP, for mathematical function generation. Third, the proposed method demonstrates improved exploration and exploitation capabilities, providing an effective solution for discovering optimized mathematical models in complex discrete domains. Lastly, the experimental results validate the effectiveness of this approach, showing its potential to solve challenging optimization problems in binary contexts.

The remainder of this paper is organized as follows: Section 2 provides a detailed explanation of LGP, covering its structure, operations, and role in function generation. Section 3 introduces the BinHOA, discussing its adaptation for binary search spaces and how it integrates with LGP. Section 4 presents the proposed approach, outlining the method's structure and workflow. Section 5 discusses the experimental setup and results, highlighting the performance of the proposed approach. Finally, Section 6 concludes the paper and suggests directions for future research.

2. LINEAR GENETIC PROGRAMMING

LGP is a powerful evolutionary computation technique and a variant of GP where computer programs evolve in the form of linear sequences of instructions, rather than in tree structures. Unlike traditional GP, which represents solutions as tree structures, LGP encodes programs as straight-line code, mimicking the structure of imperative programming languages or low-level machine code. This method can provide computational benefits, such as producing more compact solutions and executing programs faster than tree-based GP, as well as making them easier to interpret. In LGP, each individual in the population is represented by a sequence of commands, or instructions, each of which operates on specific memory locations, known as registers. Registers act as temporary storage for values, and instructions manipulate these values to compute results. Each command in an LGP program specifies an operation to be performed on one or more registers, with the result stored in a target register. This characteristic allows LGP to mimic a low-level programming style, where data is manipulated directly through registers and updated incrementally as the program executes. LGP leverages several key concepts: registers, instructions, functions, operators, terminals, and introns (Brameier & Banzhaf, 2007).

2.1. Key Concepts in LGP

- **Registers:** Registers are essential storage units, used for holding intermediate results during program execution. Commands manipulate the contents of these registers, with specific registers acting as inputs for operations and one or more registers holding the output or final result.
- **Instructions:** Each instruction in an LGP program performs a specific operation on one or more registers and assign the result to a target register. For example, an instruction like (r0 := r1 + r2) adds the values in registers r1 and r2, storing the result in r0. The operations used in instructions vary and can be arithmetic, logical, or specialized domain-specific functions.
- **Functions:** LGP uses various functions to manipulate register values. These functions include basic arithmetic operations (addition, subtraction, multiplication, division), more complex mathematical operations (logarithmic, exponential, trigonometric), and logical functions (AND, OR, NOT). The choice of functions is highly customizable based on the problem domain.

  LGP relies on various mathematical and logical functions to perform computations, as illustrated in Table 1 below. These functions are applied within the instructions to carry out the operations defined in the program.

Table 1. Some types of Functions used in LGP

Type	Function
Arithmetic Functions	r0 ← r1 + r2 r0 ← r1 - r2 r0 ← r1 * r2 r0 ← r1 / r2
Logarithmic and Exponential Functions	r0 ← ln(r1) r0 ← exp(r1)
Trigonometric Functions	r0 ← sin(r1) r0 ← cos(r1)
Logical Functions	r0 ← r1 AND r2 r0 ← r1 OR r2 r0 ← NOT r1
Introns	non-effective code segments

- **Operators:** Genetic operators in LGP include mutation, crossover, and recombination. These operators are crucial for introducing genetic diversity, enabling the evolution of robust solutions.
  - ✓ **Mutation:** Mutation involves randomly altering an instruction in the program, which may involve changing the operation or the registers used. For example, (r2 := r3 * r4) might mutate to: (r2 := r3 / r1), changing the multiplication to division and modifying a register.
  - ✓ **Crossover:** In crossover, segments of two parent programs are exchanged, promoting diversity in the population by blending characteristics of the parent solutions. For example, two programs may swap portions of their instruction sets.
  - ✓ **Recombination:** Recombination combines parts of different programs, often by splicing segments of code to form a new individual. This operation helps create novel solutions by merging beneficial traits from multiple programs.
- **Terminals:** Terminals in LGP refer to variables, constants, or input parameters. In LGP, terminals can represent either a constant value or a value stored in a register. For instance, the r0 register can be used as a terminal and serve as the input for a mathematical operation. Additionally, constant values (such as numeric constants like 3.14) can be directly included in commands. An example of terminal usage can be shown as follows: (r1 := 3.14 + r2). This command adds the value 3.14 to the value in the r2 register and stores the result in r.
- **Introns:** Introns are non-effective code segments that do not affect the output of the program. Although introns do not contribute to the solution directly, they can provide benefits by protecting key parts of the program from disruptive mutations, adding a layer of resilience.

2.2. Advantages and Disadvantages of LGP

LGP presents several advantages over traditional tree-based GP. Its linear structure enables faster execution by reducing the complexity of traversal through nodes and branches, which are typically present in tree structures. This simpler, more compact representation makes LGP programs more efficient and easier to interpret. Additionally, LGP's register-based system optimizes memory usage, which is advantageous when processing large datasets or performing computations that require significant memory resources. The linear representation also tends to produce shorter, more concise programs that are easier to debug and refine at a granular level.

However, LGP also has certain limitations. One challenge is the fragility of LGP code since each instruction depends heavily on the preceding instructions, minor mutations or alterations in one part of the program can have a cascading effect, potentially disrupting the entire program's functionality. The strict order of execution can make the initial random programs weak, especially in early generations when the population lacks sufficient diversity. Moreover, without adequate protective mechanisms, LGP is more vulnerable to producing invalid programs due to these dependencies.

2.3. Applications of LGP

Due to its unique characteristics, LGP has been successfully applied across diverse fields. In machine learning, it is often used for regression, classification, and function approximation tasks, where the efficiency and compactness of linear representations are beneficial. In optimization, LGP is used to solve problems where solutions can be effectively represented as

sequences of operations, such as scheduling or parameter optimization. In data modeling, LGP enables efficient data transformation and feature extraction processes. Moreover, in robotics, LGP aids in evolving programs that control robotic behaviors, as it allows for compact and interpretable control strategies. LGP thus remains a valuable and versatile approach within Genetic Programming, providing an effective framework for evolving concise, interpretable programs that operate efficiently on memory and computational resources.

3. BINARY HIKING OPTIMIZATION ALGORITHM

The Binary Hiking Optimization Algorithm (BinHOA) (Sağ, 2024) is an adaptation of the continuous Hiking Optimization Algorithm (HOA) (Oladejo, Ekwe, & Mirjalili, 2024), which simulates the movement of hikers on rugged terrains. In BinHOA, the search space is restricted to binary values (0 and 1), making it suitable for binary optimization problems. The key principles behind HOA, and by extension BinHOA, include slope-based movement and exploration of new terrain based on probabilistic rules.

In BinHOA, each solution (or hiker) is represented as a binary string of length D, where D is the dimensionality of the problem. Each binary string represents a potential solution in the search space. Similar to other metaheuristics, the fitness of each hiker is evaluated based on how well it solves the optimization problem. In this study, fitness is the error between the generated mathematical function and the target data. It can be defined in Eq. (1) as follows:

$$f(x) = \sum_{i=1}^{N} |r_0(x_i) - y_i| \tag{1}$$

where $r_0(x_i)$ is the predicted output from the generated formula, and y_i is the actual output.

The movement of hikers is governed by Tobler's Hiking Function, which models the velocity of movement based on the slope of the terrain given by Eq. (2).

$$velocity_{i,t} = 6e^{-3.5|S_{i,t}+0.05|} \tag{2}$$

where $velocity$ is the velocity of hiker i at iteration t, and $S_{i,t}$ is the slope of the terrain defined in Eq. (3). In the binary version, the slope translates into the likelihood of flipping bits in the binary string, allowing the algorithm to explore new regions of the binary search space.

$$S_{i,t} = \frac{dh}{dx} = tan\,\theta_{i,t} \tag{3}$$

The variables dh and dx represent the elevation change and the distance traversed by the hiker, respectively. The angle of terrain inclination $(\theta_{i,t})$ falls within the range of [0, 50°]. The hiker's speed is adjusted based on their starting velocity, the position of the lead hiker, and a sweep factor that ensures they remain reasonably close to the lead hiker. This adjustment is detailed in Eq. (4).

$$new\_velocity_{i,t} = velocity_{i,t-1} + \gamma_{i,t}(\beta_{best} - \alpha_{i,t}\beta_{i,t}) \tag{4}$$

Here, $\gamma_{i,t}$ represents a random variable uniformly distributed in the interval [0,1], β_{best} corresponds to the lead hiker's position, and $\alpha_{i,t}$ denotes the sweep factor, which can take values between 1 and 3. The revised position $\beta_{i,t+1}$ for hiker i is provided by Eq. (5).

$$\beta_{i,t+1} = \beta_{i,t} + new\_velocity_{i,t} \tag{5}$$

In BinHOA, new generated position $(\beta_{i,t+1})$ is transformed into {0,1} A values by using Eq.(6).

$$\beta_{i,t+1} = \{0 \quad \square\square\ \square\square\square\square\ < tf(\beta_{i,t+1})\ 1 \quad \square\square\ \square\square\square\square\ \geq tf(\beta_{i,t+1}) \tag{6}$$

where tf refers to a transfer function that is applied to scale the newly generated position. The variable rand represents a random number drawn from the range [0,1].

At the beginning of the HOA algorithm, the positions of the walkers $(\beta_{i,0})$ are randomly initialized within the defined boundaries of the problem, while in the BinHOA algorithm, values 0 and 1 are randomly generated for each dimension.

During each iteration, the fitness values for all hikers are computed based on the objective function, and the hiker with the best fitness is identified as the lead hiker. This process is repeated for a predetermined number of iterations.

4. PROPOSED APPROACH

The proposed approach in this study leverages the complementary strengths of the BinHOA and GP to generate mathematical functions in binary search spaces. The integration of these two methods allows for a more efficient exploration of the search space while maintaining the evolutionary process required to discover optimal mathematical expressions. The goal of BinHOA is to discover the optimal sequence of instructions chosen from the instruction list. Each binary string represents a potential set of functions and terminals to be used in the GP framework, which is then tested and refined through multiple iterations. The steps involved in this method are outlined as follows:

i. **Binary Representation of Functions**: In the proposed approach, each potential mathematical expression is represented as a binary string. This binary string encodes the sequence of instructions, such as addition, multiplication, or swapping. Each block of the binary string corresponds to a specific instruction, allowing BinHOA to search through various combinations.

   Each block of the binary string consists of 5 bits, where each 5-bit block corresponds to a specific instruction. Since 30 instructions are defined in this study, 5 bits are required to encode each instruction number. The total length of the chromosome is determined by the number of instructions used, multiplied by 5 bits per instruction. If a 5-bit block consists entirely of zeros, it indicates that no operation is applied in that position. The order of the instructions in the chromosome represents the sequence in which the operations are executed. This structure allows BinHOA to explore various combinations of functions, optimizing the mathematical expressions generated.

ii. **Fitness Evaluation**: The candidate solutions may generally represent a mathematical expression, a logical expression, or an algorithm. In this study, each binary string generated by BinHOA represents a mathematical function, and it is read from the r0 after each instruction has been executed sequentially. The fitness of each solution is evaluated by comparing the output of the generated function with the target dataset. Specifically, the error between the predicted values and the actual data points is used to guide the optimization process. The objective function used to measure the error is calculated by using Eq. (2).

iii. **Exploration of Function Space**: One of the key features of this approach is that BinHOA helps explore a vast and diverse set of function combinations by operating in a binary space. While GP handles the evolutionary aspects of function refinement,

BinHOA ensures that novel and potentially optimal combinations of functions and terminals are continuously introduced into the search process.

To adapt BinHOA for binary spaces, transfer functions are employed, which map continuous values to binary ones. In the literature, various transfer functions have been proposed for this purpose, including S-shaped, V-shaped, and Taper-shaped functions, among others. These transfer functions control the probability of flipping bits in the binary chromosome, thereby guiding the search through the binary function space.

In this study, the S1 transfer function, a commonly used S-shaped transfer function, is applied within BinHOA. The S1 transfer function is defined as follows:

$$S1(x) = \frac{1}{1 + e^{-2x}} \tag{7}$$

This function converts continuous values into probabilities, which are then used to determine whether a bit in the binary string should be flipped. The use of the S1 function allows for a smooth and adaptive transition between different binary states, enhancing the exploration capabilities of the algorithm by balancing local and global search efforts.

By utilizing the S1 transfer function within BinHOA, this approach ensures efficient exploration of the binary search space, leading to the discovery of optimal combinations of functions and terminals in Genetic Programming.

iv. **Iterative Optimization**: The entire process is iterative, with BinHOA generating new binary strings (function combinations) in each iteration and evaluating the performance of these combinations. The best-performing functions are retained, and the exploration of new regions in the search space continues until the optimization process converges or a predefined stopping criterion (such as a maximum number of iterations) is reached.

v. **Mathematical Formula Generation**: The output of the proposed approach is a mathematical formula that best approximates the target function. This formula is expressed as a simplified combination of functions and terminals, optimized through the effort of BinHOA's exploratory capabilities.

In summary, the proposed approach capitalizes on the ability of BinHOA to efficiently explore binary search spaces. By combining this method with the usage logic of the register-based instruction list used in LGP, the proposed approach offers a robust solution for generating accurate and optimized mathematical expressions, particularly in binary domains where traditional methods may struggle.

5. STEPWISE EXECUTION OF THE BINHOA-GP APPROACH

The BinHOA-GP approach was tested on a custom dataset consisting of 120 samples, shown in Table 2. The goal is to discover a mathematical equation that accurately approximates the curve representing this dataset.

Table 2. A part of sample dataset used in this study

	x_1	x_2	y
1	7	32	1521
2	16	40	3136
3	7	18	625
…	…	…	…
119	15	35	2500

120	14	21	1225

In the given approach, each solution consists of binary strings divided into 5-bit blocks. Each block represents a specific instruction from a predefined set of instructions, and there are 32 possible instructions. If a 5-bit block evaluates to zero, this means that no function is applied. Each non-zero block specifies an instruction according to its binary value, and this value determines which instruction to apply. The sequence of instructions determines the order in which they are executed. This process creates a mathematical expression by applying some mathematical functions, such as summation, subtraction, multiplication and division, to the variables x_1, x_2, r_0, r_1, r_s or intermediate results from previous operations. Here, x_1 and x_2 represent the input parameters in the dataset considered in this study, while r_0, r_1 and r_s are the registers.

As an example, the structure of a 25-bit candidate solution created to model the dataset by considering 5 potential instructions sequentially is given in Fig. 2. This binary chromosome is divided into 5-bit blocks.

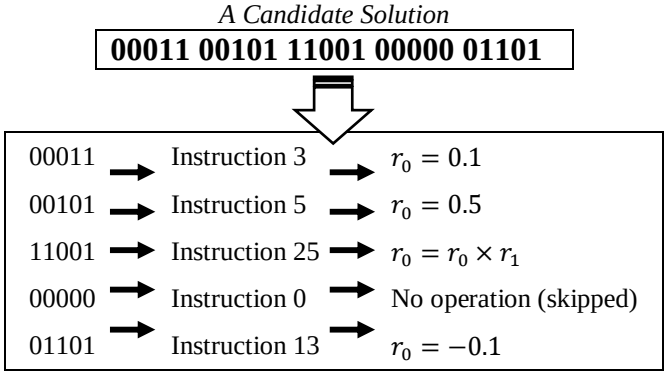

Figure 2. The structure of a candidate solution consisting of 25-bits

The operation of the program is given step by step below for this sample candidate solution.

Step 0: The program initializes r_0, r_1 and r_s as zero arrays.
$r_0 = 0, r_1 = 0, r_s = 0$

Step 1: Instruction 3: $r_0 = 0.1$
r_0 is updated to 0.1 for each element in the Y-vector (the target values).

Step 2: Instruction 5: $r_0 = 0.5$.
r_0 is now overwritten by 0.5. Equation: $r_0 = 0.5$.

Step 3: Instruction 25: $r_0 = r_0 \times r_1$
At this point, since r_1 is still zero, multiplying r_0 (which is 0.5) by r_1 results in r_0 being zero. Equation: $r_0 = 0.5 \times 0 = 0$.

Step 4: Instruction 0: No operation.
This block indicates no function should be applied, so the state remains unchanged.

Step 5: Instruction 13: $r_0 = -0.1$
The final step assigns $r_0 = -0.1$ across all elements. Equation: $r_0 = -0.1$.

After evaluating the entire solution, the result is that $r_0 = -0.1$ for each element in the output, as the solution dictated the final function (Function 13) to be an assignment of −0.1. In

the proposed approach, the binary string not only encodes the sequence of mathematical functions but also defines the order in which these functions are applied to the variables x_1, x_2, and intermediate results. In this case, the solution leads to a final output of −0.1, but for other solutions, the combination of operations could result in more complex mathematical expressions involving x_1, x_2, and other constants like 0.5 or 0.1.

In this study, the experimental setup consisted of a population of 50 members, each represented by 100 bits (20x5), and 100 iterations were performed. Additionally, 30 functions were defined for use in evaluating the objective function and constructing the mathematical equation. The best result, achieving a zero fitness value for the objective function, was obtained at the end of the 18th iteration. The convergence graph is shown in Fig. 3. The formula for the processed dataset is generated as "(0 + x1 + x2)^2". This is simplified using the symbolic math toolbox and is defined as $f(x) = (x_1 + x_2)^2$.

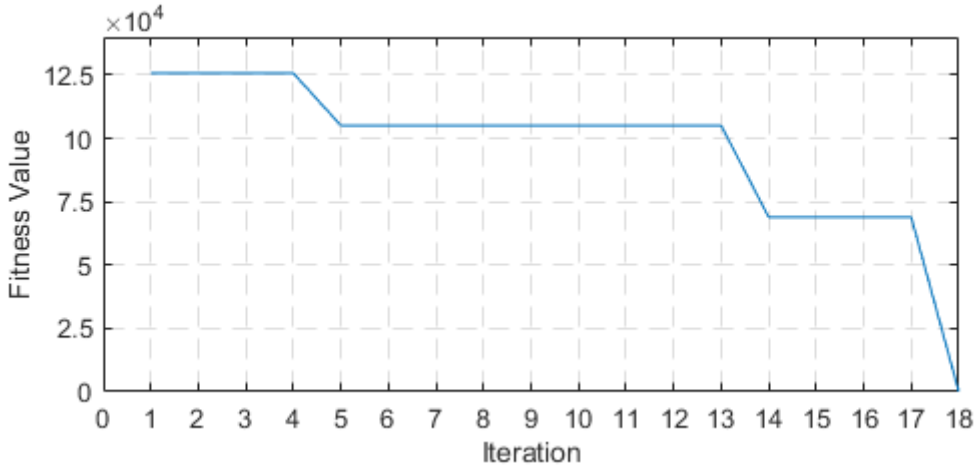

Figure 3. The convergence graphic of the proposed BinHOA-GP approach

6. CONCLUSION AND FUTURE WORKS

In this study, we introduced a novel approach that combines the BinHOA with the use of the instruction list element of LGP for generating mathematical equations in binary search spaces. The experimental results demonstrated the effectiveness of this approach in discovering optimal mathematical models. By leveraging BinHOA's capability to explore the search space efficiently and the register-based symbolic representation of the GP, the proposed method was able to generate complex symbolic equations with improved precision.

The synergy between BinHOA and LGP enabled the generation of a zero-fitness solution after only 18 iterations, as evidenced by the convergence graph. The approach successfully generated the mathematical formula "(0 + x1 + x2)^2", simplified to $f(x) = (x_1 + x_2)^2$ highlighting the efficiency of the method in symbolic regression tasks.

Future research could expand on this work by applying the BinHOA-GP method to larger and more diverse datasets. Additionally, exploring its performance in multi-objective optimization problems, real-world applications, and the integration with other evolutionary algorithms may further enhance its capabilities and broaden its applicability in various optimization domains.

7. REFERENCES

Brameier, M. F., & Banzhaf, W. (2007). *Basic concepts of linear genetic programming*: Springer New York, NY.

Hasanzadeh, H., Bashiri, M., & Amiri, A. (2018). A new approach to optimize a hub covering location problem with a queue estimation component using genetic programming. *Soft Computing, 22*(3), 949-961. doi:10.1007/s00500-016-2398-1

Koza, J. R. (1990). *Genetic programming: A paradigm for genetically breeding populations of computer programs to solve problems* (Vol. 34): Stanford University, Department of Computer Science Stanford, CA.

Koza, J. R. (1994). Genetic programming as a means for programming computers by natural selection. *Statistics and Computing, 4*(2), 87-112. doi:10.1007/BF00175355

Li, X. B., Jin, Z., Li, S. Q., Yu, D. W., Zhang, J., & Zhang, W. J. (2024). Li-ion battery state of health prediction through metaheuristic algorithms and genetic programming. *Energy Reports, 12*, 368-380. doi:10.1016/j.egyr.2024.06.038

Miller, J., & Turner, A. (2015). *Cartesian Genetic Programming*. Paper presented at the Proceedings of the Companion Publication of the 2015 Annual Conference on Genetic and Evolutionary Computation, Madrid, Spain. https://doi.org/10.1145/2739482.2756571

O'Neill, M. (2009). Riccardo Poli, William B. Langdon, Nicholas F. McPhee: A Field Guide to Genetic Programming. *Genetic Programming and Evolvable Machines, 10*(2), 229-230. doi:10.1007/s10710-008-9073-y

Oladejo, S. O., Ekwe, S. O., & Mirjalili, S. (2024). The Hiking Optimization Algorithm: A novel human-based metaheuristic approach. *Knowledge-Based Systems, 296*, 111880. doi:https://doi.org/10.1016/j.knosys.2024.111880

Onyelowe, K. C., Ebid, A. M., Egwu, U., Onyia, M. E., Onah, H. N., Nwobia, L. I., . . . Firoozi, A. A. (2022). Erodibility of Nanocomposite-Improved Unsaturated Soil Using Genetic Programming, Artificial Neural Networks, and Evolutionary Polynomial Regression Techniques. *Sustainability, 14*(12), 19. doi:10.3390/su14127403

Russo, I. L. S., Bernardino, H. S., & Barbosa, H. J. C. (2018). Knowledge discovery in multiobjective optimization problems in engineering via Genetic Programming. *Expert Systems with Applications, 99*, 93-102. doi:10.1016/j.eswa.2017.12.008

Sağ, T. (2024). *Binary Hiking Optimization Algorithm*. In: Bagnoli, F., Baetens, J., Bandini, S., Matteuzzi, T. (eds) Cellular Automata. ACRI 2024. Lecture Notes in Computer Science, vol 14978. Springer, Cham. https://doi.org/10.1007/978-3-031-71552-5_19

Whigham, P. A. (1995). *Grammatically-based genetic programming*. Paper presented at the Proceedings of the workshop on genetic programming: from theory to real-world applications.

CHAPTER 5

CURRENT PROBLEMS AND PROSPECTS IN SUNFLOWER PRODUCTION IN AZERBAIJAN

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1.INTRODUCTION

Sunflower is a priority crop, having strategic importance and also very important oily crop. Black chestnut soils and gray forest soils are suitable for growing sunflowers. It grows poorly on sandy and saline soils and soils with heavy mechanical content that heat up late.

(Mammadov and Ismayilov, 2012) The sunflower has a well-developed 2-3 m and very deep root system. Although this plant is drought-resistant, it requires a certain amount of moisture in the soil for high yields. Its water consumption rate is 600m^3. The sunflower uses the largest amount of moisture (about 60% of the total amount) during the flowering period and during the intensive growth of the stem and leaves.

The high yield of sunflower is achieved after winter crops, after corn and cereals. Spring wheat, oats and potatoes are not bad predecessors for corn. The total amount of nutrients used by the sunflower for the formation of the crop becomes much larger when the productivity of intensive varieties reaches 40-60 centners per hectare.

Sunflower absorbs nutrients unevenly during the vegetation process. Organic fertilizers have a positive effect on sunflower grain yield. Manure is given either directly under the sunflower crop, or its crops are placed after fertilized predecessors. In these cases, the yield increase is approximately the same. If they place the sunflower after the predecessors that were not given manure, then they definitely give mineral fertilizers. Therefore, manure and mineral fertilizers should be given separately to the sunflower.

Agriculture, including sunflower, has a special share in the social and economic development of our republic. As in other fields, in the fields of genetics, plant breeding and seed production, multi-faceted scientific and research works are carried out in the direction of increasing the productivity of agricultural crops.

The productivity and oil quality of sunflower depends on the biological and morphological characteristics of the variety, the irrigation scheme, plant density and the correct and timely application of fertilizer to the field, the correct placement of plants in the field, the timely application of irrigation and etc.

The work experience of specialized sunflower growers in our country and the information of scientific-research institutions show that there are inexhaustible opportunities to improve the agriculture of the republic. Wide application of scientific achievements and advanced farms to production plays a big role in solving this issue.

Abasov (2010) Farmers and landowners use scientifically based optimal options to increase productivity according to their business plans. Their main goal is to obtain varieties that are resistant to diseases and pests and have high productivity.

Each sunflower variety differs from each other in terms of biological and morphological characteristics. That is, varieties do not have the same potential under any soil and climate conditions. Each of the applied agrotechnical measures affects the structural indicators and genetic characteristics of the varieties in a different way.

When choosing varieties, agronomists should know in advance that it has been tested in that area and the agrotechnics required for it (growth dynamics, amount and weight of baskets, oil yield, leaf shape, leaf surface, etc.).

Humbatov and Khalilov (2010) Depending on the morphological and biological characteristics of the variety, its attitude to environmental factors is also different. Acceleration of processes in the plant, speed of height and development, accumulation of organic substances are determined by temperature. The optimum temperature for growth and development is 25-30°C, including seed germination.

Pre-sowing cultivation is carried out differently according to the characteristics of each field, but options that produce maximum and organized sprouts are preferred.

At this time, inter-row cultivation should be done in different order.

As a result of applying each agrotechnical measure in the optimal time according to the calendar plan, scientific and technical works are being carried out in the direction of preparing more optimal and efficient agrotechnics for farmers.

The sunflower production is important for meeting the food demand and provides the country with vegetable oil and animal feed. Due to the ongoing war between Russia and Ukraine, the main suppliers of sunflower products to the world market, difficulties have arisen in supplying the market with this product. Meeting the demand for sunflower products is closely related to the development of the value chain in this area.

In the article, were analyzed through this approach the current problems and prospects in the field of sunflower production in the country. At the same time, were also given the results of the research that, we conducted in order to study the effect of complex agrotechnical measures on the quality indicators of ecologically clean sunflower products.

The issues of development of sunflower production and processing areas are reflected in our country by the government, adopted in the agricultural policy, on strategic documents, as well as regulatory acts. Thus, in the "Strategic Roadmap on the production and processing of agricultural products" approved by the head of the country, the issues of stimulating the production of sunflower and sunflower oil for grain, as well as evaluating the possibilities of increasing the local production of raw materials used in the production of vegetable oils, including sunflower, have been reflected (Anonymous, 2015).

Taking into account that the issues of sunflower production and processing are considered a priority in the state's agricultural policy, it can be concluded that the development of sunflower production can be implemented by defining systematic measures.

Recently, against the background of climate changes, production and logistical difficulties related to the coronavirus pandemic, and local conflicts, the price of agricultural and food products has been steadily increasing in global markets. In particular, the Russian-Ukrainian conflict has led to the shortage and increase in prices of a number of products, including grain products and "oily" crops, specifically sunflower seeds and oil. Thus, Russia and Ukraine, which hold a leading position in the world in the production and export of these products, provide 53 % of global grain production (Anoymous, 2024), and respectively 33% and 22 % of oil and grain exports (Anoymous, 2024a).

This trend in the global markets has led to the increase in the prices of vegetable oils, including sunflower products, in Azerbaijan. This has brought to the fore the issue of reducing the level of dependence on imports by increasing production and productivity in terms of strengthening the country's food security.

Currently, the country cultivates 2 local varieties, ordinary and "Yerarmudu", characterized by different genetic characteristics (Anonymous 2024e), as well as imported from different countries "Gigant-549", improved "VNIIMK-883", "Kazio", "Alazan", "Oreshka" (Anoymous, 2024b).

The regions where sunflowers are most cultivated in Azerbaijan are Shamkir (81,6%), Goranboy (26,4%), Tartar (24,4%), Samukh (17,5%) and Agstafa (6,6%) regions.

Over the past 20 years, the sunflower cultivation area in Azerbaijan has increased and reached 9.89 thousand hectares in 2023. As of 2023, the yield of sunflower in the country was 25.9 cents/ha, and in the last 20 years, it is observed that the yield has increased by 2 and 3 times (Table 1, 2) (Anoymous, 2024c)

Table 1. Areas for growing sunflower, ha (Anoymous, 2024c)

	2019	**2020**	**2021**	**2022**	**2023**
Republic of Azerbaijan	16551	11016,6	11095,1	11538,5	9898,5
Ganja-Dashkasan Economic district	6826	4966,0	4746,0	4821,1	3984,4
Samukh district	3329	1943,5	1851,0	2202,5	1318,9

Table 2. Productivity of sunflower by regions, cents/ha (Anoymous, 2024c)

	2019	**2020**	**2021**	**2022**	**2023**
Republic of Azerbaijan	21,6	22,4	22,3	23,0	25,9
Ganja-Dashkasan Economic district	23,0	24,3	24,0	24,8	27,3
Samukh district	22,2	23,4	22,1	23,2	28,9

Growing sunflower for seeds, refined sunflower oil and its fractions, as well as sunflower oilcake , and other processing residues are produced from the main processing products of sunflower in Azerbaijan (Anoymous, 2024d).

During 2015-2020, the maximum volume of production in the country was 99.7 thousand tons (2019) of growing sunflower for seeds, 37.4 thousand tons of refined sunflower oil and their fractions (2017), and 859.7 thousand tons of processing residues from sunflower seeds (2017) (https://www.stat.gov.az/source/industry/). While the demand for sunflower seeds is mostly covered by local production, the main part of the demand for sunflower oil and processing residues is met by imports.

So, according to the results of the calculation, although this indicator for growing sunflower for seed reached the level of 70.9% with an increasing trend, it settled at the level of 44.6% with a decreasing trend for sunflower oil during 2015-2020. The demand for sunflower oil accounts for 57.4% of the demand for vegetable oils in the country. The level of self-sufficiency in vegetable oils also decreased during these years and was 34.8% in 2020.

Despite the increase in sunflower production and productivity in our country in recent years, the production of processing products in this sector is not stable, and at the same time, it is observed that the domestic industry is highly dependent on imported raw materials. This determines the high dependence on imports in the indicators of self-sufficiency in general. The issue of increasing the depth of processing has become a necessity in the direction of self-sufficiency with sunflower products .

The research conducted in the direction of assessing the current situation in sunflower production in Azerbaijan showed that there is a need to increase the production potential in this area.

In order to increase the production potential of the sunflower area in the country, first of all, favorable areas should be determined based on the agrotechnical parameters required for the cultivation of this plant and the country's soil and climate characteristics.

The implementation of agrotechnical measures in the optimal period of cultivation of sunflower, which is one of the leading fields of agrarian economy in our republic, temporarily declined after the agrarian reforms, but now special attention is paid to increasing sunflower production every year in farms.

However, in order to meet the ever-increasing demand of the industry for vegetable oils, it is very important to create new varieties with high productivity that will meet modern requirements and to study them in different agrotechnical conditions. The variety plays a special biological role in the implementation of intensive technology in the production of modern agricultural crops. Depending on the soil and climatic conditions, the agrotechnical measures required must be properly followed for any variety to produce a high and quality product. Under abnormal agrotechnical conditions, even cultivated varieties and hybrids are damaged and fail after a few generations. In order multi-disciplinary scientific research works are being conducted to increase the productivity and oil quality of the plant, which has such a strategic importance.

The researches show that, taking into account the required agrotechnical parameters and soil-climate characteristics, approximately 236 thousand hectares of land are suitable for sunflower cultivation in Azerbaijan, approximately 536 thousand hectares are less favorable, and the remaining areas are unfavorable. As it can be seen, there are enough favorable areas for the expansion of the sunflower cultivation area in Azerbaijan.

It is possible to meet the demand of the processing enterprises operating in the country with local sunflower raw materials by increasing the volume of production due to the existing potential, that is, the expansion of sunflower cultivation areas

At the same time, it should be taken into account that in addition to increasing production by extensive methods, higher productivity can be obtained due to the organization of sunflower production by intensive methods.

Currently, the average yield of sunflower in Azerbaijan is 25.9 centners/ha, but the results of the conducted survey show that there are farms that obtain productivity up to 40-50 centners per hectare with properly selected productive varieties and at the same time following agrotechnical rules.

Humbatov and Bashirov's researches indicated that when the yield of sunflower grain is 25 cents/ha,it is possible to obtained 1.2 tons of oil, 0.9 tons of sunflower oilcake, 0.5 tons of husk (0.7 centner of yeast), 30 kg of honey from 1 ha of cultivated land. (Humbatov et al.,2016).

However, discussions with market participants showed that 1 kg of oil can be bought from 2.86 kg of sunflower seeds. Thus, if we assume the average yield of sunflower field to be 40 cents/ha, it is possible to obtain even 1.4 tons of oil from 1 ha of cultivated area.

According to the calculations, in order to increase the level of self-sufficiency with sunflower grain under actual productivity conditions, it is necessary to expand sunflower cultivation areas by approximately 65 thousand ha.

Domestic demand for sunflower raw materials in our country is 170 thousand tons. 144.2 thousand tons (84.8%) of this demand is met by imports.

Valiyeva and Khalilov (2020) When the average yield of sunflower in our country is 40 cents/ha, it is necessary to expand the existing area by 2.8 times to 42.5 thousand hectares in order to be fully self-sufficient with sunflower seeds.

As a result of the expansion of the field to 50 thousand hectares, it is possible to produce 200 thousand tons of sunflower seeds, which creates a prospect for the export of 30 thousand tons of raw mater ials.

At the same time, the full realization of the capacity of the processing plants suggests that there is a potential for the production of approximately 62,000 tons of crude vegetable oil during oil processing. It should also be noted that the actual total production capacity of plants for potential sunflower oil processing is not enough.

In the Strategic Roadmap "On the production and processing of agricultural products" it is emphasized that there are opportunities to increase the export of products such as sunflower oil and sunflower seed within the priorities aimed at strengthening the production potential of competitive agricultural and processing industry products in both domestic and foreign markets (Anonymous, 2016).

In order to ensure the development of sunflower production in our country, it is appropriate to improve the relevant regulatory mechanisms, including stimulation mechanisms, for the realization of the established directions.

In order to achieve successful results in the field of sunflower production, should be studied all important issues, current situation and should be implemented strategic actions. One of these important issues is the organization of ecologically safe sunflower production. As we mentioned, among vegetable oils in Azerbaijan, the consumption of sunflower oil is at the forefront. However, as a result of the improper use of chemicals in sunflower cultivation, the residues of pesticides and mineral fertilizers in the sunflower crop exceed the norm. In the Western region of Azerbaijan, Samukh district is considered to be the region specialized in sunflower production. Our research in this region shows that farmers use excessive pesticides and mineral fertilizers in the production of sunflowers, are unaware of alternative methods that replace chemical means, and all this leads to the

production of products contrary to sanitary and hygienic norms for human health. If we take into account that the residues of chemicals, especially pesticides, form new stable metabolites after the hydrothermal process and they can remain in sunflower oil for a long time, then it becomes clear this problem is how urgent. Taking into account the above, we have conducted research to produce ecologically friendly sunflowers, incorporating nature-friendly approaches.

We have set ourselves the goal of studying the effect of complex agrotechnical measures on the quality indicators of the ecologically safe sunflower product under the conditions of the Ganja-Dashkasan economic region.

2.MATERIALS AND METHODS

In our experiment, we have studied the effect of plant density, irrigation, application of organic fertilizer norms, delivery method on the quality indicators of ecologically safe sunflower product.

The research is carried out on "Oreshka", "Kazio" and "Alazan" varieties of sunflower in Samukh region.

Alazan- It is a two-line hybrid created by French breeders. Its height is 160-172 cm, the diameter of the basket is 17-18 cm, it is thin, flat, and not inclined. The oil content of the seed is 46.0-52.0%. It has high technological characteristics as an equal height, regular yielding, simultaneous maturing hybrid. It is highly productive. In 2004-2006, it gave a seed yield of 30.5 s/ha in the competitive variety test in the demonstration field. Oil yield per hectare is 14.1 cents on average in 4 years. 54-59 thousand plants are kept per hectare. Vegetation period is 94-101 days.

Oreshka- Obtained from the local variety grown in Mariopol, Ukraine at the Armavir experimental station of the All-Union Scientific-Research Institute of Oil Plants (VNIIMK) through repeated individual selection. It yields 34.8 centners of grain per hectare. Oil content is 53%. It is possible to buy 16.6 centners of oil per hectare. The height of the plant is 175-215 cm. The vegetation period is 90-94 days. It is a medium maturing variety resistant to drought, sunflower blight and verticillium wilt.

Kazio- Was obtained by individual selection from plants obtained from free pollination of several varieties of different origin with the Zelyonka 63 variety at the Belgorod experimental station of the Scientific-Research Institute of Oil Plants (VNIIMK). It yields 28.2-34.5 centners of grain per hectare. Fat content is 51.8-54%. It is possible to buy 13.2 - 16.8 centners of oil per hectare. The height of the plant is 170 cm on average, the vegetation period is 90-105 days. It is a medium maturing variety, resistant to sunflower moth and verticillium wilt.

In the experiment were applied in each of the varieties, Control-5 tons of manure, 10 tons of manure, 15 tons of manure, 42, 47 and 56 thousand plant density per hectare, 3, 4 and 5 irrigations.

It is known that the implementation of each agrotechnical measure in the optimal time makes it possible to obtain abundant and high-quality products.

The experiment consists of 9 variants and each variant has 4 repetitions. In the experimental field, each replicate is 50 meters long and 2.8 meters wide (4 rows, 70 cm between rows), the area of one replicate is 140 m^2, the area of one option is 560 m^2, and the total area of the experimental field is 5040m^2.

Table 3. The following agrotechnical measures were implemented in the experimental field

№	Agrotechnical measures and time of their implementation	Time of implementation
1	Cleaning plant residues from the field	10.11.2022
2	Applying organic fertilizers under the plough	12.11.2022
3	The late ploughing	26.11.2022
4	Opening the irrigation furrow	03.12.2022
5	Conducting the frost irrigation	24.12.2022
6	Harrowing of the irrigated field	01.02. 2023
7	Bed preparation for sowing	03.03. 2023
8	Harrowing	07.03. 2023
9	Sowing	11.03. 2023
10	Thinning	30.03.2023
11	1st irrigation	05.04.2023
12	Conducting the 1st cultivation	08.04.2023
13	1st hoeing	12.04. 2023
14	2nd irrigation	23.04. 2023
15	Conducting the 2nd cultivation	28.04. 2023
16	2nd hoeing	01.05.2023
17	3rd irrigation	17.05. 2023
18	4th irrigation	04.06.2023
19	Harvesting the yields	06.07.2023

3. RESULT AND DISCUSSION

In 2023, the following results were obtained due to the effect of the agrotechnical measures we applied in the cultivation of the sunflower plant in the study area.

1. Complex agrotechnical measures had a different effect on the general development dynamics of sunflower varieties. In all three varieties, the development stages were observed a few days earlier, which variants were applied 70X30-1 (47 thousand plants) sowing scheme and plant density, 10 tons of manure per hectare and 4 irrigations.

2. The height of the main stem in different development stages of the studied varieties was as follows. In the flowering stages, the height of the main stem in the "Alazan" variety was 43-75 cm in the control variant, 59-85 cm in basket formation and 82-102 cm in maturity. Those indicators vere higher in the 70X30-1 (47 thousand plants) sowing scheme, 10 tons of manure per hectare and 4 irrigations variant, varying between 82-107,135-162 and 168-203 cm. Oreshka and Kazio varieties also achieved a higher result in the 70X30-1 (47 thousand plants) sowing scheme, 10 tons of manure per hectare and 4 times irrigation. In general, the indicators of the Oreshka variety were higher, varying between 252,2-272,4 cm.

3. In the Alazan variety, the number of baskets in one bush is 2-4, depending on the variety, the weight of the grains in the basket is 425-660 grams, in the Oreshka variety, the number of baskets in one bush is 2-4, depending on the variety, the weight of the grains in the basket is 570-642 grams, in

the Kazio variety, the number of baskets in one bush is 2-4, depending on the variety, the weight of the grains in the basket was 566-680 grams.

4. The weight of 1000 seeds per variant was higher in each 3 varieties in the 70X30-1 (47 thousand plants) sowing scheme, 10 tons of manure per hectare and 4 times irrigation. The weight of 1000 seeds was in the variants of the Alazan variety is 45-61, 73-82 and 75-85 grams, in the Oreshka variety 58-70, 78-85 and 77-83 grams, in the Kazio variety 56-73, 76-88 and 74-84 grams.

5. The effect of organic fertilizer rates, sowing scheme, plant density and irrigation were different on the productivity of sunflower varieties. The productivity per hectare in the variants varied in the Alazan variety between 23,2-27,1 centners, in the Oreshka variety 28,2-31,7 centners and in the Kazio variety between 26,7-28,8 centners. The yield was higher in varieties with 70X30-1 sowing scheme, 10 tons of manure, 47 thousand plant density per hectare and 4 times irrigation.

6. The effects of organic fertilizer rates, sowing scheme, plant density and irrigation were different on oil extraction and oil content of sunflower varieties. The oil content of the seeds was between 42,4-45,7% in the Alazan variety, and the oil extraction was 810- 1240 liter/ha. In the Oreshka variety, the oil content of the seeds was between 44,1-46,2%, and the oil yield extraction 1210- 1370 liter/ha. In Kazio variety, the oil content of the seeds was between 43,4-44,5%, and the oil extraction was 1110- 1260 liter/ha. In all three varieties, seed oil content and oil extraction were higher in the 70X30-1 sowing scheme, 10 tons of manure, 47 thousand plant density per hectare and 4 times irrigation.

7. The impact of complex agrotechnical measures on the economic efficiency of sunflower varieties was different. In all options, the highest indicators were obtained from the option with 10 tons of manure, 70X30-1 sowing scheme, 47,000 plant density per hectare and 4 irrigations. So, in the mentioned variant, the net income of the Alazan variety was 2730 manats and the level of profitability was 218,4%. In the Oreshka variety, the net income was 3405 manats, and the profitability was 272,4%, and in the Kazio variety, the net income was 3015 manats, and the profitability was 241,2%.

The results of the study are shown in more detail in tables 4 and 5.

Based on the results obtained from experience, we can say that due to the effect of complex agrotechnical measures applied in all 3 varieties, the highest indicators in all options were obtained from 10 tons of manure, 70X30-1 sowing scheme, 47 thousand plant density per hectare and 4 irrigation options.

From all that has been said, it is clear that there is a great need to meet the demand for sunflower products through local production, and to develop the field of sunflower production and processing. Bu istiqamətdə aşağıdakı tədbirlərin həyata keçirilməsi məqsədəuyğundur:

In this direction, it is appropriate to implement the following measures:

- Detection of potential areas for sunflower production in the country through the GIS system and, as a result, continuation of measures in the direction of maximum use of the production potential;

-Creation of seed farms for cultivation of new productive seed varieties, establishment of processing enterprises in the territories of agroparks operating in regions with favorable conditions for sunflower production;

- In order to increase and modernize the production capacity of existing processing enterprises, replacement of outdated equipment with techniques and equipment that meet modern standards;

- Simplification of procedures and lowering of state fees during sunflower oil certification;

- Taking measures to ensure that the packaging and labeling of sunflower oil meet international standards;

- Educating farmers through information and advisory services to increase seed productivity and agrarian literacy.

Table 4. Complex agrotechnical measures of sunflower varieties effect on productivity and oil extraction

Varieties	Sowing scheme and plant density, thousand units/hectare	Organic fertilizer rates	Irrigations	Seed productivity cent/ha	Oil content, in %	Oil extraction, liter/ha
Alazan	70X35-1(42 thousand plants)	Control-5 tons of manure	3 times	23,2	42,4	810
	70X30-1(47 thousand plants)	10 tons of manure	4 times	27,0	45,7	1240
	70X25-1(56 thousand plants)	15 tons of manure	5 times	27,1	44,4	1110
Oreshka	70X35-1(42 thousand plants)	5 tons of manure	3 times	28,2	44,1	1220
	70X30-1(47 thousand plants)	10 tons of manure	4 times	31,7	46,2	1370
	70X25-1(56 thousand plants)	15 tons of manure	5 times	30,6	45,3	1210
Kazio	70X35-1(42 thousand plants)	5 tons of manure	3 times	26,9	43,4	1110
	70X30-1(47 thousand plants)	10 tons of manure	4 times	28,9	44,5	1260
	70X25-1(56 thousand plants)	15 tons of manure	5 times	28,4	43,8	1160

Table 5. Complex agrotechnical measures of sunflower varieties impact on economic efficiency

Varieties	Sowing scheme and plant density, thousand units/hectare	Organic fertilizer rates	Irrigations	Seed productivity, cent/ha	Total income, manats	Production costs, manats	Net income, manats	Profitability, in %
Alazan	70X35-1(42 thousand plants)	Control-5 tons of manure	3 times	23,2	3480	1250	2230	178,4
	70X30-1(47 thousand plants)	10 tons of manure	4 times	27,0	4050	1320	2730	218,4
	70X25-1(56 thousand plants)	15 tons of manure	5 times	27,1	4065	1350	2715	217,2
Oreshka	70X35-1(42 thousand plants)	5 tons of manure	3 times	28,2	4410	1250	3160	252,8
	70X30-1(47 thousand plants)	10 tons of manure	4 times	31,7	4755	1350	3405	272,4
	70X25-1(56 thousand plants)	15 tons of manure	5 times	30,6	4590	1320	3270	261,6
Kazio	70X35-1(42 thousand plants)	5 tons of manure	3 times	26,9	4035	1250	2785	222,8
	70X30-1(47 thousand plants)	10 tons of manure	4 times	28, 9	4335	1320	3015	241,2
	70X25-1(56 thousand plants)	15 tons of manure	5 times	28,4	4260	1350	2910	232, 8

REFERENCES

Abasov, I.D. (2010). Agriculture of Azerbaijan. "Science and education" publishing. Baku, 589 p.

Humbatov, H.S., Bashirov V.V., Mohumayev M.M. (2016). "Oil and essential oil plants". Baku, "Science and education" publishing polygraphy LLC, 248 p.

Humbatov, H.S., Khalilov X.Q. (2010).Technical plants.-Baku, "Aytac", 415 p.

Mammadov, Q.Y., Ismayilov M.M. (2012). Crop production. Baku, 355 p.

Anonymous (2016)"Strategic Roadmap for the production and processing of agricultural products in the Republic of Azerbaijan" (2016)- approved by Decree No. 1138 of the President of the Republic of Azerbaijan dated December 6, 2016. Baku, "Law", 177 p.

Anonymous (2015)"The State Program on the reliable supply of food products to the population in the Republic of Azerbaijan in 2008-2015" - approved by the Decree of the President of the Republic of Azerbaijan No. 3004. Baku, 17 p.

Valiyeva M.A., Khalilov E.A. (2020). "Sunflower plant". Ganja, "Aytac Publishing Polygraph" LLC, 370 p.

Anonymous, (2024c) https://www.stat.gov.az/source/agriculture/ - Agriculture, forestry and fisheries / State Statistics Committee.

Anonymous, (2024d) https://www.stat.gov.az/source/industry/ - Azerbaijan industry / State Statistics Committee.

Anonymous (2024) https://www.fao.org/faostat/en/#data/MK - FAO statistical database / FAO.

Anonymous (2024a) https://www.trademap.org/Index.aspx - Trade statistics for international business development / International Trade Center.

Anonymous (2024e), https://az.wikipedia.org/sunflower.

Anonymous (2024b) http://axa.gov.az/ plant-varieties-registration-and-seed-selling-places-214.

CHAPTER 6

SIMULATION TECHNOLOGIES IN INDUSTRY 4.0 ERA: ENHANCING EFFICIENCY AND DECISION-MAKING IN MANUFACTURING AND SUPPLY CHAIN MANAGEMENT

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1. INTRODUCTION

Integrating simulation methodologies into industrial systems has become essential in the age of Industry 4.0 and the Internet of Things (IoT), where digitalization and connectivity drive continuous improvement and operational efficiency. Simulation is a powerful enabler in these interconnected landscapes. It offers detailed analytical tools that allow industries to explore hypothetical changes and assess their impacts on complex systems (de Paula Ferreira et al., 2020; Carothers et al., 2017; Koch, 2024). As computational power advances and costs decrease, simulation has become increasingly accessible, extending its utility to large and small businesses (Teerasoponpong & Sopadang, 2021; Escoto et al., 2022). This accessibility has led to a surge in simulation adoption, fostering the development of sophisticated software solutions tailored to diverse industrial needs. These applications incorporate traditional functionalities while introducing cutting-edge features, such as advanced 3D modeling and immersive interfaces, further enhancing the realism and accuracy of simulations.

The convergence of simulation with Industry 4.0 technologies amplifies its impact across manufacturing, logistics, supply chain management, and service sectors. Simulation is critical in supporting real-time scenario analysis, optimizing resource allocation, and streamlining operations by identifying bottlenecks and testing solutions before implementation (Nimmagadda, 2021; Qureshi et al., 2020). Companies can dynamically model their operations by integrating simulation with IoT, big data, and machine learning and gain predictive insights into potential challenges. This integration empowers professionals to make data-driven decisions that enhance productivity, reduce costs, and improve operational resilience (Uslu & Fırat, 2021; Uslu, 2023).

Simulation's theoretical foundations are frequently complemented by practical case studies demonstrating its successful application across industries. These case studies not only validate the utility of simulation but also highlight essential skills needed by simulation experts to keep pace with rapid technological advancements. For instance, e-commerce growth has increased the need for accurate simulation models to optimize warehouse layouts, streamline logistics, and minimize capital expenditures in system implementation (Zhu, 2020). Through iterative model development, verification, and rigorous analysis, simulation experts ensure that their models are valid and reliable—critical factors in managing the complexities of large-scale, dynamic industrial environments.

Simulation methodologies are increasingly varied, reflecting the diverse needs of modern industry. Simulations can operate at multiple levels, ranging from high-level, enterprise-wide applications that target strategic opportunities to localized, process-specific models in production or logistics. In the Industry 4.0 era, simulation types such as discrete-event, agent-based, and hybrid models incorporate AI, optimization techniques, and IoT integration, allowing for more detailed, flexible, and scalable models. These advanced simulations enable companies to model operations on an unprecedented scale, providing insights that support strategic decision-making, cost reduction, and enhanced productivity—critical advantages for sustainable and competitive operations (Nagy et al., 2023).

Enterprise-level simulations often focus on opportunities relevant to management and design teams engaged in supply chain and manufacturing planning. Simulation tools at this level can function independently or integrate with larger systems, sharing data and models to provide a comprehensive view of interconnected processes. For example, a global supply chain model may require simulation to identify efficiency gains in lead times or inventory management. At a more localized level, process-specific models can be used to optimize

workflows in production or logistics, targeting improvements in cycle time, resource allocation, or bottleneck management.

This chapter delves into simulation technologies and their role in industrial applications, focusing on three primary methods: Discrete Event Simulation (DES), Agent-Based Simulation (ABS), and Monte Carlo Simulation (MCS). In Section 2.1, DES is introduced as a method ideal for modeling systems with discrete changes, such as production scheduling and inventory management. Section 2.2 covers ABS, highlighting its effectiveness in simulating individual entity interactions within a system, useful for scenarios involving human decision-making and autonomous processes. Section 2.3 examines MCS, focusing on its application in assessing risks and uncertainties within manufacturing contexts. Chapter 3 explores these simulation methods' practical applications in manufacturing, from resource allocation to process optimization. Chapter 4 provides an in-depth analysis of the benefits and challenges of implementing these technologies, including integration with Industry 4.0 and IoT environments. Finally, Chapter 5 summarizes key insights and future directions for simulation technologies in enhancing industrial efficiency and resilience. In sum, this chapter provides a comprehensive look at simulation as a driver for efficiency and process improvement in manufacturing and supply chain contexts, emphasizing its critical role in the digitally connected environments of Industry 4.0 and IoT.

2. SIMULATION TECHNOLOGIES IN INDUSTRIAL APPLICATIONS

Simulation technologies have become indispensable in industrial applications, providing sophisticated tools for analyzing, optimizing, and predicting complex system behaviors. These methodologies support decision-makers by offering detailed insights into various industrial processes, from manufacturing to supply chain management. With data collection and computational power advancements, modern simulation techniques can now model the multifaceted dynamics of Industry 4.0 environments. This chapter explores three primary simulation methods that have each evolved to address different aspects of industrial complexity. Discrete Event Simulation (DES) enables detailed analysis of process flows and resource management, while Agent-Based Simulation (ABS) captures the nuanced decision-making and interactions of individual entities within the system. Additionally, Monte Carlo Simulation (MCS) provides a statistical framework to assess risks and uncertainties inherent in many industrial settings. Together, these methods form a robust toolkit, allowing for comprehensive and adaptable simulation approaches that align with efficiency, productivity, and resilience goals in modern industrial contexts.

To identify the main topics and associated literature related to discrete event simulation, agent-based simulation, Monte Carlo simulation, manufacturing, industrial applications, Industry 4.0, and IoT, an automated search is conducted using the Web of Science database. The search keywords included "Discrete Event Simulation," "Agent-Based Simulation," "Monte Carlo Simulation," "Manufacturing," "Industrial Applications," "Industry," "Industry 4.0," and "IoT." Utilizing VOSviewer software, a cluster map is generated to categorize and visualize the thematic areas and research focuses within these domains (see Figure 1). This aims to highlight the interconnections among these clusters and provide a comprehensive view of the literature related to simulation technologies and their applications in modern industrial and manufacturing contexts.

Discrete Event Simulation (DES) - Pink and Blue Clusters: Blue capture is the primary application and discussion around discrete event system simulations. It includes central topics in DES like system control and data integration, which are key aspects of discrete event systems within manufacturing and process control environments. Although closely related to the DES

cluster, this separate pink cluster focuses on discrete-event simulation's broader conceptual and methodological aspects. It includes keywords like emergent behavior and modeling issues, reflecting this simulation method's theoretical and computational challenges.

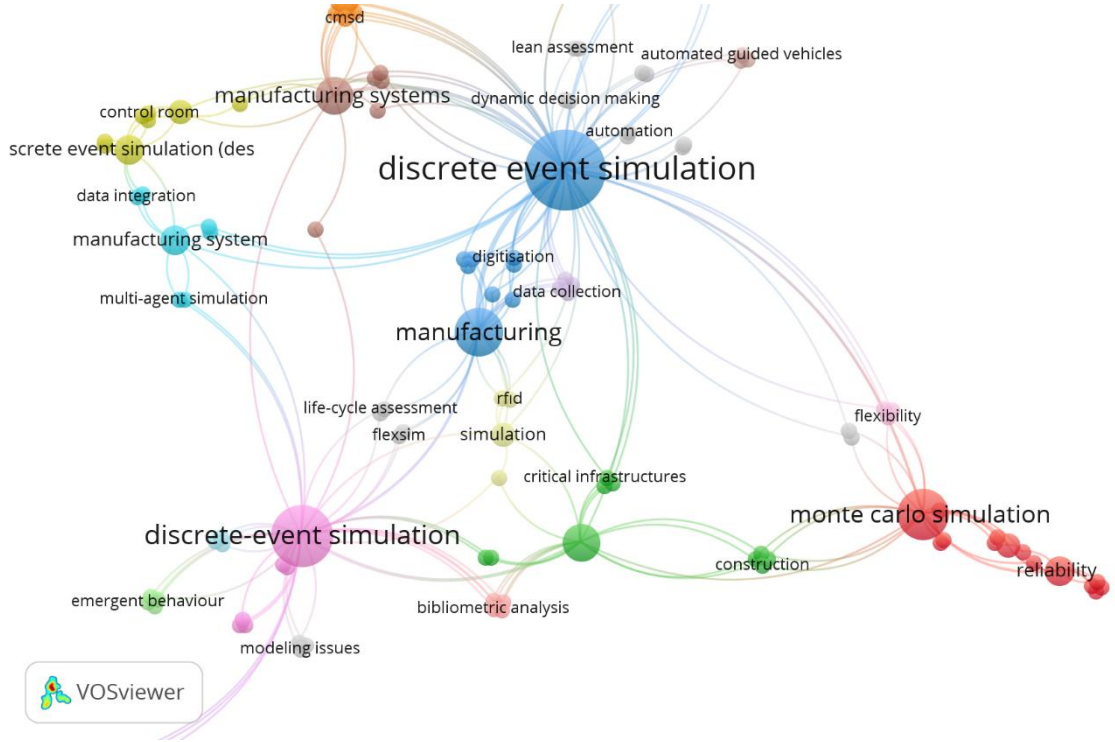

Figure 1. Cluster Map of Key Research Topics in Simulation Technologies for Industry 4.0 and IoT Applications

Manufacturing Systems—Brown and Light Blue Clusters: The brown cluster focuses on manufacturing systems and includes keywords such as lean assessment, automated guided vehicles, and dynamic decision-making. The presence of these terms indicates a focus on optimizing manufacturing processes, integrating automation, and evaluating system performance through simulation. This distinct manufacturing system cluster in light blue encompasses broader themes within the manufacturing context. It includes topics such as multi-agent simulation and life-cycle assessment, signifying a comprehensive manufacturing simulation approach that considers the full lifecycle of products and systems.

Monte Carlo Simulation - Red Cluster: The red cluster, dominated by Monte Carlo simulation, encompasses terms like reliability, construction, and flexibility. Monte Carlo simulation is widely known for its application in risk assessment and reliability analysis, especially in sectors requiring precise probability modeling. The association with reliability and flexibility indicates that Monte Carlo simulations are valuable in construction and manufacturing settings, where they are employed to predict potential failures and optimize resource allocation under uncertainty. The connection between Monte Carlo simulation and construction suggests a cross-disciplinary relevance, where Monte Carlo methods extend beyond manufacturing to support areas like construction project planning, where uncertainty management is crucial. This highlights the adaptability of Monte Carlo simulation in different industrial contexts, providing a robust approach for decision-making under variability.

Agent-based Simulation - Green Cluster: The green cluster represents agent-based simulation, which models individual agents with autonomous behaviors. This type of

simulation is particularly suited to complex and dynamic systems where individual components interact in a decentralized manner, making it applicable in manufacturing settings that require adaptive responses.. Bibliometric analysis in this cluster suggests that research is extensively analyzed and reviewed, indicating a well-documented and studied application area. Flexibility and modeling issues within this cluster highlight the challenges of developing adaptable simulation models that accurately represent complex infrastructure systems. The clusters revolve around multi-agent simulation and emergent behavior, suggesting an interest in agent-based models that simulate interactions between autonomous entities. Multi-agent simulation is particularly valuable in scenarios where individual elements (such as robots or automated machines) operate independently but contribute to collective system behaviors. Emergent behavior focuses on observing how individual agent interactions result in complex system-wide phenomena, a concept relevant in manufacturing and service operations. This modeling approach allows researchers and practitioners to analyze and predict how small-scale interactions influence overall system performance, especially in decentralized environments. This cluster may also emphasize the need for robust, flexible models that can accommodate the unique requirements of critical infrastructure management, such as resource allocation and system resilience.

2.1. Discrete Event Simulation

In recent decades, discrete event simulation (DES) has gained prominence among industry professionals as a critical methodology for modeling production and supply chain systems. This simulation approach has demonstrated substantial effectiveness in uncovering insights into the behavior and performance of complex systems. Early explorations, such as the "Belt Conveyor Crew" problem, laid foundational work in understanding and optimizing production system dynamics (Akparibo & Normanyo, 2020; Neagoe et al., 2021). However, traditional DES models, which often focus on a single flow of jobs or manufacturing orders requiring resources, may lack the capacity to capture the intricate complexities of modern industrial systems, particularly those aligned with Industry 4.0 principles. These limitations, especially in handling extreme or high-demand scenarios, have motivated researchers to advance DES by incorporating elements of continuous modeling alongside IoT, cyber-physical systems, and digital twins (Leng et al., 2021).

Integrating discrete and continuous models—often termed discrete-continuous or hybrid models—enhances DES's capabilities by comprehensively examining industrial systems. Through IoT sensors and data collection, cyber-physical systems enable real-time monitoring and data-driven adjustments that inform discrete event models (Karakra et al., 2022). Digital twin technology further augments this integration by offering a virtual representation of the production environment, which mirrors real-world manufacturing conditions. These twins can continuously synchronize with the actual system via IoT devices, providing up-to-date information on system states, resource conditions, and job progress. As a result, DES combined with digital twins allows a dynamic and accurate reflection of system interdependencies and operational dynamics, supporting more robust scenario analysis and optimization strategies (Gejo-García et al., 2022).

A critical step in developing effective models for these complex, IoT-enhanced manufacturing environments involves aggregating real-time data about resources and individual orders into actionable statistics. Metrics like job completion times, resource utilization rates, and order flow across different stages of the production life cycle become key insights in identifying bottlenecks and inefficiencies. Digital twins and cyber-physical systems further enrich this data aggregation, providing a continuous feedback loop that enhances DES's

ability to develop adaptive and responsive strategies for system productivity and efficiency improvement (Villalonga et al., 2021).

Moreover, statistical methods, such as Monte Carlo simulations, play a vital role in modeling the range of values for random variables within production systems integrated with IoT. These methods allow for detailed studies across various life cycle stages, where data from sensors inform Adjusted Production Functions that dynamically adapt to real-time conditions. By including correction and rework phases, DES provides a thorough analysis of production processes at multiple operational levels, from initiation to completion, supported by a digital infrastructure that facilitates continuous monitoring and adjustment ().

The depth of DES analysis is further enhanced through discrete-time algorithms that capture specific aspects of production flows (Lee, 2019; Topcu et al., 2021). Techniques such as the Uniformization method for Markovian processes offer more precise representations of system dynamics, while algorithms tailored for distributed, IoT-enabled models add layers of complexity and control to the analysis (Almutairi et al., 2024). By leveraging IoT data streams and digital twins, these advanced methodologies empower researchers and practitioners to gain a granular understanding of production flows, refine optimization processes, and implement strategies for sustained efficiency and productivity. Incorporating these advanced techniques and technologies into DES positions it as an indispensable tool for production and supply chain modeling within Industry 4.0 frameworks. Enhanced by IoT, cyber-physical systems, and digital twins, DES offers a more dynamic and adaptive approach to operational excellence. By leveraging comprehensive data aggregation, sophisticated algorithms, and real-time digital feedback, DES supports robust decision-making and continuous improvement within complex industrial environments (Serper et al., 2022; Perera & Uslu, 2022).

2.2. Agent-Based Simulation

Agent-based simulation (ABS) has emerged as a crucial tool in industrial applications, particularly for modeling complex decision-making processes, often focusing on human activities. Unlike traditional simulation approaches that primarily model resource flows and process sequences, ABS leverages agent technologies to represent individual entities—referred to as agents—with unique behaviors, preferences, and decision-making abilities (Uslu, 2023; Carayannis et al., 2016; Gao et al., 2024). This simulation methodology allows modeling the interactions between various system components and human participants' decision-making processes. By simulating these intricacies, ABS provides a nuanced and layered understanding of human-related activities and their broader implications on industrial systems.

One of the core strengths of ABS lies in its capacity to go beyond the relatively straightforward bottom-up modeling typical of traditional simulations. Conventional models often prioritize resource allocation and process flow, yet they fall short in capturing the higher-level, abstract decisions made by humans. Decisions in an industrial environment, such as prioritizing specific tasks or reacting to dynamic changes, occur at multiple levels of abstraction, influencing the system's behavior as a whole. ABS bridges this gap by introducing decision-making layers that account for agents' characteristics, including their priorities, adaptive responses, and potential biases (Mazzetto, 2024). This is particularly valuable for scenarios where human decisions drive process performance and outcomes, such as in manufacturing environments where workers make real-time choices that affect production flow and resource allocation.

For instance, in manufacturing, ABS enables workers to model their decisions on the shop floor by considering individual preferences and situational factors. Unlike traditional simulations focusing solely on task scheduling or resource distribution, ABS can incorporate

factors like task urgency, individual workload, or personal goals influencing workers' decisions (van de Merwe et al., 2024). This leads to a more comprehensive representation of the complex trade-offs and interactions in real-world environments. By simulating these decisions as they occur on the shop floor, ABS can reveal patterns of behavior that affect overall productivity and efficiency, making it possible to design interventions that address specific challenges faced by workers and management alike.

Furthermore, ABS excels at capturing emergent behaviors—patterns and trends arising from multiple agents' interactions. In complex industrial systems, individual decisions and actions can create feedback loops and dependencies, collectively shaping the system's behavior in unexpected ways. For example, ABS can model how production delays caused by a few agents may create cascading bottlenecks throughout the entire workflow, highlighting potential vulnerabilities in the system (D'Angelo & Ferretti, 2022). Through these insights, ABS provides a robust framework for investigating the interconnectedness and heterogeneity of agents, enabling decision-makers to anticipate challenges and optimize processes more effectively.

The flexibility of ABS makes it ideal for exploring a range of "what-if" scenarios. By adjusting agents' behaviors and environmental parameters, ABS allows researchers and practitioners to test various strategies and identify the most effective solutions under different conditions. This capability is beneficial for proactive decision-making, enabling companies to explore potential bottlenecks, inefficiencies, and disruptions before they occur. For instance, in a supply chain context, ABS can simulate how individual suppliers might respond to demand fluctuations (Namany et al., 2020), revealing vulnerabilities in the supply chain and suggesting strategies for improving resilience (Lohmer et al., 2020).

Another significant advantage of ABS is its ability to adapt to complex industrial environments that require constant interaction among agents with distinct goals (Haki et al., 2020). By simulating agents that operate based on their unique set of rules, ABS can mimic real-world scenarios where individual behaviors diverge, converge, or even conflict (Belik et al., 2024). This quality makes ABS a powerful tool for understanding the collective outcomes of autonomous, decentralized decision-making processes (Bucchiarone et al., 2020), which are increasingly relevant in modern, collaborative industrial settings.

Agent-based simulation is an indispensable methodology for studying human-centric activities in industrial applications (Lakmali et al., 2024). By capturing the nuanced aspects of individual decision-making and simulating the interactions of diverse agents, ABS offers unparalleled insights into the dynamics of complex systems. The ability of ABS to model emergent behaviors, simulate diverse scenarios, and facilitate a deep exploration of agent interactions empowers decision-makers with actionable insights, leading to informed strategies that drive organizational improvement. Through its emphasis on adaptability and detailed behavioral representation, ABS continues to elevate the potential for understanding and optimizing complex industrial systems, making it a cornerstone of modern simulation technology.

2.3. Monte Carlo Simulation

Monte Carlo simulation is a powerful numerical technique rooted in probability and statistics, designed to model and analyze systems characterized by inherent randomness. At its core, this method leverages sequences of random numbers or pre-defined probabilistic distributions to evaluate possible outcomes, enabling a detailed exploration of uncertainty within complex scenarios (Aoufi et al., 2024). Monte Carlo simulation has become a cornerstone in fields such as management technology, demand forecasting, production

planning, and risk management, where it supports decision-makers in navigating unpredictable conditions with greater precision.

One prominent application of Monte Carlo simulation is in financial modeling, where it helps companies maximize profits by projecting potential financial outcomes (Tobisova et al., 2022). For example, when a company aims to optimize its budget to achieve profit growth, Monte Carlo simulation can be used to simulate various financial scenarios, offering insights into expected net growth and potential fluctuations. This tool is equally valuable in sales analysis, enabling analysts to evaluate market demand uncertainties and assess the probability of meeting production goals under various marketing strategies. By providing a statistical basis for estimating demand variability, Monte Carlo simulation helps firms make informed production and marketing decisions that align with market trends (Divyaa et al., 2024).

In quality control, Monte Carlo simulation plays a crucial role by enabling analysts to assess production risks, inspect shipment quality, evaluate inventory loss risks, and predict product return rates (Momani & Khrais, 2024; Khodabandeh-Yalabadi et al., 2024; Zhu et al., 2024). As supply chain management continues to gain importance in production and inventory sectors, the Monte Carlo simulation has proven to be invaluable. Warehouses and inventory managers can apply this method to predict item availability, optimize stock levels, and reduce the costs associated with safety stocks. By simulating various demand scenarios, Monte Carlo analysis supports more accurate and cost-effective inventory planning, ultimately enhancing supply chain resilience (Khodabandeh-Yalabadi et al., 2024; Suryawanshi et al., 2021).

Monte Carlo simulation is also widely used in project management. It enables project managers to evaluate the potential impacts of uncertainties on schedules, budgets, and resources (Zygiaris et al., 2022). Through probabilistic analysis, Monte Carlo simulation allows managers to assess the likelihood of completing projects on time and within budget, enabling them to allocate resources more efficiently and plan for delays. This capability gives project managers a clearer understanding of risk and empowers them to make strategic adjustments to keep projects on track (Jin et al., 2023). In engineering, Monte Carlo simulation aids in evaluating the failure probabilities of complex systems, such as bridges, dams, and aerospace components (Xu & Pang, 2024). By simulating numerous scenarios and estimating failure likelihoods, engineers can enhance the reliability and safety of these systems, allowing for the development of structures that are more resilient to unforeseen stressors. This application is precious in sectors where system reliability is paramount, as it supports the design of safer and more robust structures. The healthcare sector also benefits from Monte Carlo simulation, as it enables the evaluation of treatment strategies based on probabilistic models of patient outcomes (Fum et al., 2021; Muraro et al., 2020). By simulating different treatment paths and patient responses, healthcare professionals can make data-driven decisions to determine the most effective and cost-efficient treatment plans.

Monte Carlo simulation is similarly indispensable in finance and investment. It enables investors to simulate market conditions and incorporate various risk factors into portfolio assessments (Senova et al., 2023). By evaluating potential returns and risks associated with different investment strategies, investors can make more informed choices, balancing risk and return to build robust portfolios. This application is instrumental in managing portfolio risk, particularly in volatile markets, where understanding probabilistic outcomes is essential for strategic decision-making. Therefore, Monte Carlo simulation is a versatile, powerful tool that facilitates decision-making, risk assessment, and optimization across various fields, including finance, project management, engineering, healthcare, and supply chain management. Its capacity to model complex scenarios and assess probabilistic outcomes makes it an invaluable resource for analyzing uncertainties and predicting results. As Monte Carlo simulation

continues to be applied across industries, its role in improving operational efficiency, enhancing predictive accuracy, and reducing risks underscores its enduring relevance and adaptability.

3. APPLICATIONS IN MANUFACTURING

In contemporary manufacturing, simulation technologies have become essential tools for optimizing operations, managing resources, and addressing complex industry challenges (Mourtzis, 2020; Gadde, 2022; Nwosu et al., 2024). These technologies provide critical insights into process behavior, resource allocation, and decision-making dynamics, supporting sectors as diverse as garment production, aerospace, automotive, and electronics (Ordu et al., 2021; Rane et al., 2024; do Rêgo et al., 2024; Sokolovska et al., 2023; Wang & Yang, 2024). Monte Carlo simulation is widely applied for risk assessment and decision-making under uncertainty. In supply chain management, Monte Carlo models are used to simulate disruptions in supplier availability or demand fluctuations, enabling manufacturers to develop more resilient plans. For inventory management, Monte Carlo simulations assist in setting optimal safety stock levels by simulating variations in demand and lead times. This application is precious for industries with high demand variability, such as consumer electronics and seasonal goods. Additionally, Monte Carlo simulation aids in production planning by assessing the probability of meeting deadlines, allowing companies to mitigate potential delays and proactively optimize scheduling.

Agent-based simulation (ABS) is particularly useful in manufacturing settings where human decision-making and collaboration are critical. In collaborative robotics, ABS models interactions between human operators and robots on the production floor, enhancing safety, optimizing workflows, and improving overall efficiency. ABS also plays a valuable role in assembly lines, where worker decisions directly influence workflow. By simulating individual preferences, task priorities, and adaptive behaviors, ABS provides insights into how human factors affect overall system performance, improving labor allocation and coordination.

Simulation technologies also significantly impact supply chain optimization and logistics management (Tordecilla et al., 2021). Discrete-event and agent-based simulations allow manufacturers to model supply chain flows and analyze potential disruptions (Brewer, 2023; Fauadi et al., 2022). In logistics, simulations support route optimization, demand forecasting, and warehouse management. By modeling different scenarios, manufacturers can optimize transportation costs, reduce carbon footprints, and meet customer demands efficiently—a critical need for fast-paced sectors like e-commerce and retail.

Production planning and scheduling are other essential areas in manufacturing, involving the organization and sequencing of machine tasks to meet delivery deadlines. Integrating simulation methodologies with advanced scheduling rules is crucial for addressing complex scheduling challenges, a topic widely researched in production planning (Houssein et al., 2021; Parente et al., 2020; Sheikhkhoshkar et al., 2023). Though effective in smaller scheduling environments, traditional combinatorial optimization methods face limitations in large-scale or dynamic job shops. Modern approaches combine forecasting with sophisticated algorithms to bridge the gap between exact and heuristic techniques, achieving a balance of precision and flexibility for complex setups. Industrial engineering, computer science, and mathematics researchers have developed innovative algorithms, including genetic algorithms, ant colony optimization, and neural networks, to manage this complexity. By simulating these scheduling strategies, manufacturers can explore potential outcomes and evaluate performance across diverse operational scenarios (Serrano-Ruiz et al., 2021). Machine learning (ML) further enhances these methodologies by utilizing historical data to improve scheduling accuracy (Usuga Cadavid et al., 2020). ML models learn from past scheduling decisions to predict task

durations and machine availability, creating efficient schedules that minimize makespan and maximize resource utilization. This adaptability is especially valuable in dynamic environments, where real-time data and predictive analytics enable rapid adjustments based on current demand and resource availability.

Inventory management is another crucial area, ensuring that manufacturing systems meet customer demand by effectively tracking and managing the various goods used throughout production. Key objectives in inventory management include balancing supply with demand and minimizing associated costs, such as holding costs, setup costs, and penalties for late deliveries. Efficient inventory management often involves addressing complex issues framed as mixed-integer problems, covering aspects like multi-echelon distribution, location assignments, minimum order quantities, and setup policies. Simulation models have become essential tools for addressing these challenges, enabling manufacturers to predict the performance of different inventory policies (Buschiazzo et al., 2020; Sridhar et al., 2021). For instance, by simulating order assignment rules, companies can evaluate uniform service policies in scenarios where demand history may be sparse or centralized.

The simulation also allows for a comparative analysis of supportability impacts across alternative demand data transmission formats, highlighting how each approach influences inventory efficiency and responsiveness. The integration of simulation and analytical techniques offers valuable insights for inventory management, particularly in understanding how information systems influence safety stock levels (Zhao & Tu, 2021; Buschiazzo et al., 2020). Simulation enables managers to identify and quantify the costs associated with suboptimal policies, providing a foundation for aligning inventory strategies with real-time operational needs. This alignment helps mitigate the risks associated with insufficient safety stock and enables a more flexible response to fluctuating demand.

Manufacturing quality control and inspection processes have greatly advanced through integrating simulation and modeling techniques. These applications emphasize precision, calibration, and the sensitivity of sensing systems, as well as optimal sample size selection to enhance the quality, accuracy, and robustness of inspection and evaluation processes. By leveraging these tools, manufacturers are able to fine-tune their inspection processes, ensuring consistent quality across production stages and increasing overall efficiency.

In recent years, automated and semi-automated inspection and measurement methods have made significant strides, largely due to advancements in real-time system models (Carvalho et al., 2020; Lin et al., 2022; Nwankpa et al., 2021). These models facilitate effective feedback control, sensor and sampling design, and defect detection and analysis, improving quality and cost efficiency. Inspection techniques can be refined further by integrating simulation methodologies and conducting targeted simulation studies. Simulation studies provide insights that support the optimization of key parameters and variables, enhancing inspection systems' precision and reliability. This combination has led to substantial improvements in quality outcomes and cost reductions, making it an essential tool for modern manufacturing.

Simulation-based inspection systems have proven particularly effective in various industrial applications, including automotive, rail, semiconductor, and bearing manufacturing sectors (Peres et al., 2021; Kumar & Cao, 2021; de Souza Souza et al., 2021). Engineers can accurately determine optimal sensor placements through simulation, design effective sensing environments, and develop sensor fusion and non-contact measurement algorithms. This approach facilitates more accurate measurements and supports the detection of outliers,

providing a comprehensive view of the system that traditional discrete sensor methods may overlook.One significant benefit of simulation in quality control is its contribution to root cause analysis, particularly in understanding factors that affect yield and cost loss (Hassan et al., 2023).

Simulation technology has become a critical asset in supply chain management, allowing companies to conduct in-depth analyses and explore improvements within a predictive virtual environment (Lohmer et al., 2020). As supply chains grow more complex due to technological advances and shifting market dynamics, effective management becomes increasingly challenging. Modern competition often extends beyond individual companies to entire supply chains, highlighting the need for robust systems that handle intricate interactions and risks (Tordecilla etn al., 2021)

A key area in supply chains is the integration of demand and supply networks through software systems that enable real-time responses to market changes and supply disruptions. However, many current supply chain management tools rely on basic deterministic models, covering only standard parameters like lead times and order quantities. These models lack the depth to capture the complexities of today's interconnected supply chains, characterized by dynamic demand, market variability, and complex supplier networks.

Integrating simulation technologies with ERP (Enterprise Resource Planning) systems offers a solution to enhance supply chain management (Park & van der Aalst, 2021). This combination would create an advanced decision support tool, allowing companies to model scenarios, forecast outcomes, and make informed decisions based on real-time data. Such integration requires efficient data synchronization and processing, enabling seamless interaction between ERP systems and simulation tools, ultimately leading to more responsive and agile supply chains (Syed et al., 2024).

Demand forecasting, which estimates future product demand using historical data, now extends to include various business metrics like sales, production, and operational costs. Forecasting applies at both individual product and product line levels, aiming to guide efficient planning. Companies achieve dynamic, flexible, and accurate predictions by integrating simulation into forecasting, especially in complex, fluctuating markets (Grznár et al., 2020; Mittal & Panchal, 2023). The forecasting process typically includes eight stages: defining the problem, data collection and processing, graphical plotting, methodology selection, statistical analysis, forecast verification, and forecast application. Simulation models enhance these stages, offering a virtual environment for testing different scenarios. For example, in statistical analysis, simulation allows for modeling demand under varying conditions, helping understand the effects of seasonality or market volatility.

Forecasting methods like time series analysis, trend extrapolation, and expert judgment can be combined with simulation for greater accuracy and adaptability. This approach enables scenario analysis, helping companies prepare for new product launches, seasonal spikes, or market shifts. Simulation-enhanced forecasting supports proactive decision-making, providing a flexible, robust framework that adapts to changing demands. Despite advancements, many transportation systems still rely on partial manual support, limiting efficiency and driver engagement in strategic planning. A proposed solution is to install sensors on vehicles to collect and transmit data to a central system, categorized for user-specific insights. This approach enhances precision and user engagement by integrating simulation-based estimation and optimization. Simulation models centralize data and support real-time decision-making, such as route optimization and adaptive responses to changing conditions. By tracking vehicle

locations, simulation enables quick rerouting in traffic and prioritizes tasks for optimal resource use. Combined with a centralized control structure, simulation enhances efficiency, collaboration, and accountability among drivers and carriers, offering a comprehensive framework for improved decision-making and operational efficiency in transportation.

According to the findings obtained from the literature, Table 1 provides a comparative analysis of key simulation technologies used in industrial applications, detailing their primary benefits and application areas. Discrete Event Simulation (DES) is highlighted for its precision in modeling sequential processes and bottlenecks, especially useful in manufacturing environments. Monte Carlo Simulation excels in risk analysis and uncertainty modeling, making it ideal for financial risk forecasting and resource planning. Agent-based simulation (ABS) captures decentralized decision-making and human interactions, which supports dynamic supply chain modeling. Each simulation type is linked with suitable software tools, such as Arena for DES, MATLAB for Monte Carlo, and AnyLogic for ABS, demonstrating their alignment with specific industrial needs and applications.

4. BENEFITS AND CHALLENGES OF IMPLEMENTING SIMULATION TECHNOLOGIES

The rapid advancement of simulation technologies has transformed how complex systems are modeled and analyzed across various industries. As manufacturing environments become increasingly interconnected, especially within the frameworks of Industry 4.0 and IoT, the need for effective simulation models that capture these systems' intricate interactions and dynamic behaviors has intensified. Simulation provides essential tools for capturing stochastic elements, enabling businesses to monitor and adapt to changes in real-time while accurately modeling system behaviors under fluctuating conditions.

While traditional optimization and analytical techniques serve specific needs, they often fail to accommodate modern industrial systems' fast-paced and unpredictable nature. Simulation bridges this gap by enabling comprehensive analysis, offering flexibility in modeling the interdependencies of multi-layered systems. Today’s simulation technologies are also enhanced by automated data handling and streamlined interfaces, increasing accessibility and efficiency. These capabilities allow industries to make data-driven decisions based on real-time insights, adapting quickly to changing demands and operational complexities. However, simulation has its limitations. It is not universally optimal for every scenario, mainly when deterministic models can handle simpler processes with predictable outputs.

Process mapping or mathematical programming methods may be more efficient in such cases. Combining simulation and deterministic methods often provides the most thorough approach to complex challenges. However, as systems grow more complex with continuous data flows from IoT devices and increased automation, simulation remains indispensable for modeling real-world variability and supporting decision-making. Simulation empowers companies to identify bottlenecks, optimize workflows, and allocate resources with a precision that promotes both operational excellence and resilience in rapidly evolving industrial landscapes.

In addition, simulation offers a safe environment for testing hypothetical scenarios, enabling companies to explore potential solutions and assess risks without impacting real-world operations.

Table 1. Comparative analysis of simulation technologies for industrial applications.

Simulation Type	Key Benefits	Quality Control	Production Planning	Supply Chain Management	Distributed Network Design	Risk Analysis	Strategic Implications / Use Cases	Application Example	Suitable Software
Discrete Event Simulation (DES)	Allows detailed modeling of step-by-step processes and events, enabling the identification of bottlenecks and performance issues.	Suitable; ideal for detailed process and control analysis.	Suitable; effective in analyzing process steps and identifying bottlenecks.	Moderate; suitable for simulating specific events in complex supply chains but limited for broader networks.	Moderate; valid for static network events but limited in dynamic networks.	Moderate; adequate for event-based risk analysis but limited for uncertainties.	It helps analyze time-specific processes in manufacturing, logistics, and operations management. It is ideal in structured systems with defined event sequences.	Manufacturing line efficiency analysis for automotive parts to identify bottlenecks.	Arena, Simul8, FlexSim, AnyLogic, Siemens Tecnomatix
Monte Carlo Simulation	Excellent for modeling uncertainty and variability in high-risk environments, supporting robust risk analysis.	Moderate: It can be used to analyze quality variability but is limited to event-based control.	Limited; supportive in uncertainty analysis but lacks detailed planning capabilities.	High; ideal for risk analysis and uncertainty management, efficacious in stock levels and demand forecasting.	Low; more focused on stock levels and risk management in supply chains, limited in network applications.	High; most suitable for modeling risks and uncertainties.	Widely used in financial risk analysis, demand forecasting, and resource planning where uncertainty is high. Ideal for unpredictable demand.	Inventory demand forecasting for consumer goods with high seasonal variability.	MATLAB, @RISK, Simul8, AnyLogic, Oracle Crystal Ball
Agent-Based Simulation (ABS)	Captures decentralized decision-making and human interactions, enabling realistic modeling of supply chain dynamics.	Moderate; valuable in applications involving human behaviors or decision-making processes.	Moderate; can analyze individual or team impacts in production but limited for general planning.	High; effective in analyzing individual or group behaviors in complex supply chains.	High enables dynamic optimization by simulating collaboration among independent units.	Moderate; suitable for agent-based risk analysis but limited for broader risk analysis.	It is best for systems involving human behavior, market dynamics, or autonomous decision-making, such as last-mile delivery in logistics.	Simulating last-mile delivery in e-commerce to account for driver behaviors and route selection.	AnyLogic, NetLogo, GAMA Platform, Repast Simphony, Swarm

As industries continue to integrate simulation with IoT and other digital technologies, they gain an invaluable tool for sustainable growth and continuous improvement. With its comprehensive capacity for modeling dynamic systems, simulation is a fundamental component of modern industry, driving informed decision-making and supporting a competitive edge.

As technology and automation continue to shape the manufacturing landscape, simulation has become pivotal for advancing complex systems' efficiency, reliability, and adaptability. The increasing complexity of manufacturing environments demands detailed analysis and innovative solutions to ensure systems meet stringent efficiency and safety standards. Companies leverage cutting-edge simulation technologies with advanced computational power to address these evolving challenges, enabling in-depth insights into system performance and operational optimization.

One major trend in simulation is the shift toward a systems-level approach that integrates various complementary technologies, such as statistical analysis, optimization, data mining, and AI-driven decision support systems. This multidisciplinary approach provides a holistic view of manufacturing operations by capturing the full scope of interconnected processes, allowing for local and global optimization. Integrating simulation with parallel and distributed computing capabilities also enables real-time responsiveness, enhancing the overall effectiveness of manufacturing systems. Additionally, localized analytical capabilities on the shop floor facilitate quick adjustments, mirroring the networked efficiency of an interconnected smart factory.

The growing integration of simulation with technologies like AI, IoT, and virtual modeling further exemplifies how simulation shapes the industry's future. By bridging continuous and discrete dynamics, simulation creates a unified framework that reflects the complexities of real-world manufacturing. This integration supports adaptive, flexible manufacturing environments where systems can self-optimize based on real-time data. Advanced applications, such as intelligent control of flexible manufacturing systems and GIS-integrated electronic manufacturing systems, showcase the potential of simulation to create more responsive and intelligent production environments, providing companies with a competitive advantage.

5. CONCLUSION

This chapter has provided an in-depth look at the role of advanced simulation technologies within industrial applications, emphasizing their impact on enhancing resource allocation, process optimization, and decision-making processes. In the Industry 4.0 context, simulation technologies have evolved into essential tools for handling complex systems, allowing industry professionals to model scenarios, analyze operational flows, and predict outcomes with a higher degree of accuracy. Integrating simulation with IoT, big data analytics, and machine learning has further strengthened its role, enabling dynamic adjustments based on real-time data, which is critical for today’s fast-paced and interconnected industrial environments.

Simulation is also increasingly intertwined with other technology fields, providing crucial links to new trends in digital representation, human-centered design, and virtual modeling. By enabling the coupling of continuous and discrete dynamics, simulation bridges disciplines, creating unified frameworks that incorporate the complexities of real-world systems. Modern simulation tools are now integrated with interdisciplinary frameworks, knowledge engineering, and artificial intelligence (AI) platforms, further expanding their applicability in advanced manufacturing. For example, simulation plays a central role in the

intelligent control of flexible manufacturing systems, enabling real-time adaptability and optimization. Another emerging application is the integration of mathematical programming with simulation or Geographic Information Systems (GIS), enhancing the automation of electronic manufacturing systems. These advances pave the way for more intelligent, efficient, and responsive manufacturing processes, providing companies with a competitive edge.

Despite these advancements, a notable gap persists between academic research in simulation methodologies and the practical requirements of the industry. While academia has developed a wide range of sophisticated simulation models and techniques, their practical application in industrial settings often faces challenges due to issues in automation, integration, and adaptability to real-world conditions. Bridging this gap will require a more collaborative approach between academia and industry, where both sectors contribute to creating simulation solutions that are not only innovative but also tailored to address specific operational needs. By promoting such cooperation, simulation technologies can become more accessible and practical for companies, allowing them to leverage these tools fully to enhance productivity and resilience.

The transition from Industry 4.0 to Industry 5.0 introduces a new paradigm emphasizing human-centric and sustainable industrial systems. Unlike Industry 4.0, which primarily focuses on digitalization and responding to existing demand, Industry 5.0 aims to proactively create value by anticipating and addressing users' unarticulated needs. In this context, simulation technologies are expected to play a pivotal role. They will support organizations in optimizing processes and fostering a deeper understanding of market trends, allowing for innovations that align with evolving user expectations and environmental sustainability goals.

Looking toward the future, many design and planning activities are expected to integrate into customized designer systems. These systems will function as interactive agents, engaging directly with designers to translate ideas into digital formats, such as graphic desktop publishing systems. This integration will enable seamless interfacing between design outputs, factory scheduling systems, and manufacturing networks. Consequently, simulation technology will allow for a streamlined workflow where design and scheduling integrate smoothly with the wider manufacturing architecture.

As industries strive to become more adaptive and resilient, simulation will continue to serve as a strategic asset that empowers decision-makers to test scenarios, identify bottlenecks, and develop solutions in a risk-free virtual environment. The capability to simulate complex interactions within interconnected systems enables companies to prepare for future uncertainties, ensuring long-term competitiveness. With continuous advancements in simulation tools and techniques, industries can expect even greater integration of artificial intelligence, predictive analytics, and real-time monitoring, all of which will drive the next wave of industrial innovation.

In conclusion, simulation technologies represent more than just a means for operational efficiency—they are a foundational component of modern industry strategies, crucial for navigating the complexities and opportunities of the digital era. As industries evolve within the framework of Industry 5.0, the strategic use of simulation will be instrumental in achieving human-centered, intelligent, and sustainable production environments that meet present needs and proactively shape the future of industrial operations.

REFERENCES

Almutairi, R., Bergami, G., & Morgan, G. (2024). Advancements and Challenges in IoT Simulators: A Comprehensive Review. *Sensors*, 24(5), 1511.

Akparibo, A. R., & Normanyo, E. (2020). Application of resistance energy model to optimising electric power consumption of a belt conveyor system. *Int. J. Electr. Comput. Eng*, 10, 2861-2873.

Aoufi, B., Ameddah, H., Slamani, M., & Arslane, M. (2024). An advanced framework for tolerance analysis of cam-clamping devices integrating unified Jacobian–Torsor model, Monte Carlo simulation, and bootstrap technique. *The International Journal of Advanced Manufacturing Technology*, 1-18.

Belik, I., Bhattacharya, P., & Knudsen, E. S. (2024). A case for simulated data and simulation-based models in organizational network research. *Research Policy*, 53(8), 105058.

Brewer, L. L. (2023). Distruptions in Supply Chain: An Agent-Based Model Simulation to Measure Resiliency and Performance During Disasters *(Doctoral dissertation, The University of North Carolina at Charlotte)*.

Bucchiarone, A., De Sanctis, M., & Bencomo, N. (2020). Agent-based framework for self-organization of collective and autonomous shuttle fleets. *IEEE Transactions on Intelligent Transportation Systems*, 22(6), 3631-3643.

Buschiazzo, M., Mula, J., & Campuzano-Bolarin, F. (2020). Simulation optimization for the inventory management of healthcare supplies. *International Journal of Simulation Modelling*, 19(2), 255-266.

Carayannis, E. G., Provance, M., & Grigoroudis, E. (2016). Entrepreneurship ecosystems: An agent-based simulation approach. *The Journal of Technology Transfer*, 41, 631-653.

Carothers, C., Ferscha, A., Fujimoto, R., Jefferson, D., Loper, M., Marathe, M., ... & Vakilzadian, H. (2017). Computational challenges in modeling and simulation. *Research Challenges in Modeling and Simulation for Engineering Complex Systems*, 45-74.

Carvalho, R., Nascimento, R., D'Angelo, T., Delabrida, S., GC Bianchi, A., Oliveira, R. A., ... & Uzeda Garcia, L. G. (2020). A UAV-based framework for semi-automated thermographic inspection of belt conveyors in the mining industry. *Sensors*, 20(8), 2243.

D'Angelo, G., & Ferretti, S. (2022). Adaptive parallel and distributed simulation of complex networks. *Journal of Parallel and Distributed Computing*, 163, 30-44.

de Paula Ferreira, W., Armellini, F., & De Santa-Eulalia, L. A. (2020). Simulation in industry 4.0: A state-of-the-art review. *Computers & Industrial Engineering*, 149, 106868.

de Souza Souza, L. M. A., da Silva, A. M., de Souza, J. M., Bueno, R. C., Machado, S. T., & Tanaka, W. Y. (2021). A simulation-based approach to identify bottlenecks in the bearing manufacturing process. *Independent Journal of Management & Production,* 12(9), s843-s855.

Divyaa, S., Saravanane, R., & Kumar, M. (2024, April). Predicting Macro-Economic Factors of WTI Crude Oil Using Monte Carlo Simulation. I*n 2024 International Conference on Advances in Data Engineering and Intelligent Computing Systems (ADICS)* (pp. 1-7). IEEE.

do Rêgo, G. G. M., de Lima Carneiro, F. L., Pereira, J. R. L. A., Pereira, M., Neto, A. T. P., & da Silva Júnior, H. B. (2024). Implementation and Analysis of a Digital Twin for Propylene

Glycol Production: Dynamic Simulation and Process Statistical Control. *Revista de Gestão Social e Ambiental*, 18(3), e04467-e04467.

Escoto, X., Gebrehewot, D., & Morris, K. C. (2022). Refocusing the barriers to sustainability for small and medium-sized manufacturers. *Journal of Cleaner Production*, 338, 130589.

Fauadi, M. M., Damanhuri, A. M., Yahaya, S. H., Noor, A. M., & Hao, X. (2022). AGENT-BASED discrete event simulation–system dynamics approach to optimize manufacturing system with maintenance activities. *Journal of Advanced Manufacturing Technology (JAMT*), 16(2).

Fum, W. K., Wong, J. H. D., & Tan, L. K. (2021). Monte Carlo-based patient internal dosimetry in fluoroscopy-guided interventional procedures: A review. *Physica Medica*, 84, 228-240.

Gadde, H. (2022). AI-Enhanced Adaptive Resource Allocation in Cloud-Native Databases. *Revista de Inteligencia Artificial en Medicina,* 13(1), 443-470.

Gao, C., Lan, X., Li, N., Yuan, Y., Ding, J., Zhou, Z., ... & Li, Y. (2024). Large language models empowered agent-based modeling and simulation: A survey and perspectives. *Humanities and Social Sciences Communications,* 11(1), 1-24.

Gejo-García, J., Reschke, J., Gallego-García, S., & García-García, M. (2022). Development of a system dynamics simulation for assessing manufacturing systems based on the digital twin concept. *Applied Sciences,* 12(4), 2095.

Grznár, P., Gregor, M., Krajčovič, M., Mozol, Š., Schickerle, M., Vavrík, V., ... & Bielik, T. (2020). Modeling and Simulation of Processes in a Factory of the Future. *Applied sciences*, 10(13), 4503.

Haki, K., Beese, J., Aier, S., & Winter, R. (2020). The evolution of information systems architecture: An agent-based simulation model. *MIS Quarterly*, 44(1).

Hassan, Y. B., Orabi, M., & Gaafar, M. A. (2023). Failures causes analysis of grid-tie photovoltaic inverters based on faults signatures analysis (FCA-B-FSA). *Solar Energy*, 262, 111831.

Houssein, E. H., Gad, A. G., Wazery, Y. M., & Suganthan, P. N. (2021). Task scheduling in cloud computing based on meta-heuristics: review, taxonomy, open challenges, and future trends. *Swarm and Evolutionary Computation*, 62, 100841.

Jin, L., Yin, Y., Du, F., Yuan, H., & Zheng, C. (2023). Impact of Engineering Changes on Value Movement in Fund Flow: Monte Carlo-System Dynamics Modeling Approach. *Buildings*, 13(9), 2218.

Karakra, A., Fontanili, F., Lamine, E., & Lamothe, J. (2022). A discrete event simulation-based methodology for building a digital twin of patient pathways in the hospital for near real-time monitoring and predictive simulation. *Digital Twin*, 2, 1.

Khodabandeh-Yalabadi, A., Sheikhalishahi, M., Torabi, S. A., Naderpour, M., & Radmankian, A. (2024). Enhancing supply chain resilience under disruption: analysis of the farmed data by Monte Carlo simulation. I*nternational Journal of Systems Science: Operations & Logistics,* 11(1), 2398573.

Koch, J. (2024). Modeling and Simulation of Internet of Things Infrastructures for Cyber-Physical Energy Systems (*Doctoral dissertation, Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau*).

Kumar, G. M. S., & Cao, S. (2021). Simulation-based techno-economic feasibility study on sector coupled net-zero/positive energy metro railway system in Hong Kong. *Energy Conversion and Management*, 248, 114786.

Lakmali, R. G. N., Genovese, P. V., & Abewardhana, A. A. B. D. P. (2024). Evaluating the Efficacy of Agent-Based Modeling in Analyzing Pedestrian Dynamics within the Built Environment: A Comprehensive Systematic Literature Review. *Buildings*, 14(7), 1945.

Lee, H. (2019). Real-time manufacturing modeling and simulation framework using augmented reality and stochastic network analysis. *Virtual Reality*, 23(1), 85-99.

Leng, J., Wang, D., Shen, W., Li, X., Liu, Q., & Chen, X. (2021). Digital twins-based smart manufacturing system design in Industry 4.0: A review. J*ournal of manufacturing systems*, 60, 119-137.

Lin, C., Rahman, A. A., & Maropoulos, P. (2022, August). Reconfiguration of quality inspection approach to the food processing industry. *In Proceedings of the 38th International Manufacturing Conference (IMC38)* (pp. 207-214). University College Dublin. School of Mechanical and Materials Engineering.

Lohmer, J., Bugert, N., & Lasch, R. (2020). Analysis of resilience strategies and ripple effect in blockchain-coordinated supply chains: An agent-based simulation study. *International journal of production economics*, 228, 107882.

Mazzetto, S. (2024). Interdisciplinary Perspectives on Agent-Based Modeling in the Architecture, Engineering, and Construction Industry: A Comprehensive Review. *Buildings*, 14(11), 3480.

Mittal, U., & Panchal, D. (2023). AI-based evaluation system for supply chain vulnerabilities and resilience amidst external shocks: An empirical approach. *Reports in Mechanical Engineerin*g, 4(1), 276-289.

Momani, A., & Khrais, S. (2024). Managing Risk and Uncertainty in Machine Replacement Decisions Using Real Options Analysis and Monte Carlo Simulation. *Management Systems in Production Engineering*, 32(3), 326-338.

Mourtzis, D. (2020). Simulation in the design and operation of manufacturing systems: state of the art and new trends. *International Journal of Production Research*, 58(7), 1927-1949.

Muraro, S., Battistoni, G., & Kraan, A. C. (2020). Challenges in Monte Carlo simulations as clinical and research tool in particle therapy: a review. *Frontiers in Physics*, 8, 567800.

Namany, S., Govindan, R., Alfagih, L., McKay, G., & Al-Ansari, T. (2020). Sustainable food security decision-making: an agent-based modelling approach. J*ournal of Cleaner Production*, 255, 120296.

Nimmagadda, V. S. P. (2021). Artificial Intelligence for Real-Time Logistics and Transportation Optimization in Retail Supply Chains: Techniques, Models, and Applications. *Journal of Machine Learning for Healthcare Decision Support*, 1(1), 88-126.

Nwankpa, C. E., Ijomah, W., & Gachagan, A. (2021). Design for automated inspection in remanufacturing: a discrete event simulation for process improvement. *Cleaner Engineering and Technology*, 4, 100199.

Nwosu, N. T., Babatunde, S. O., & Ijomah, T. (2024). Enhancing customer experience and market penetration through advanced data analytics in the health industry. *World Journal of Advanced Research and Reviews*, 22(3), 1157-1170.

Ordu, M., Demir, E., Tofallis, C., & Gunal, M. M. (2021). A novel healthcare resource allocation decision support tool: A forecasting-simulation-optimization approach. *Journal of the operational research society*, 72(3), 485-500.

Parente, M., Figueira, G., Amorim, P., & Marques, A. (2020). Production scheduling in the context of Industry 4.0: review and trends. *International Journal of Production Research*, 58(17), 5401-5431.

Park, G., & van der Aalst, W. M. (2021, June). Towards reliable business process simulation: A framework to integrate erp systems. *In International Conference on Business Process Modeling, Development and Support* (pp. 112-127). Cham: Springer International Publishing.

Perera, T. S., & Uslu, B. Ç. (2022). Simulation Analysis of a Neonatal Unit with Complex Patient Flow Patterns–An Enhanced Model for Capacity Planning. *South African Journal of Industrial Engineering*, 33(4), 94-108.

Peres, R. S., Guedes, M., Miranda, F., & Barata, J. (2021). Simulation-based data augmentation for the quality inspection of structural adhesive with deep learning. *IEEE Access*, 9, 76532-76541.

Qureshi, M. S., Qureshi, M. B., Fayaz, M., Mashwani, W. K., Belhaouari, S. B., Hassan, S., & Shah, A. (2020). A comparative analysis of resource allocation schemes for real-time services in high-performance computing systems. I*nternational Journal of Distributed Sensor Networks*, 16(8), 1550147720932750.

Rane, N. L., Choudhary, S. P., & Rane, J. (2024). Artificial Intelligence-driven corporate finance: enhancing efficiency and decision-making through machine learning, natural language processing, and robotic process automation in corporate governance and sustainability. *Studies in Economics and Business Relations*, 5(2), 1-22.

Senova, A., Tobisova, A., & Rozenberg, R. (2023). New approaches to project risk assessment utilizing the Monte Carlo method. *Sustainability*, 15(2), 1006.

Serper, N., Şen, E., & Çalış, B. (2022). Discrete event simulation model performed with data analytics for a call center optimization. *Istanbul Business Research*, 51(1), 189-208.

Serrano-Ruiz, J. C., Mula, J., & Poler, R. (2021). Smart manufacturing scheduling: A literature review. *Journal of Manufacturing Systems*, 61, 265-287.

Sheikhkhoshkar, M., Bril El-Haouzi, H., Aubry, A., & Hamzeh, F. (2023). Functionality as a key concept for integrated project planning and scheduling methods. *Journal of Construction Engineering and Management*, 149(7), 04023053.

Sokolovska, Z., Klepikova, O., Ivchenko, I., & Ivchenko, O. (2023, June). Models-Simulators in Business Decision-Making Processes for Pharmaceutical Enterprises. *In International Conference on Information and Knowledge Systems* (pp. 3-18). Cham: Springer Nature Switzerland.

Sridhar, P., Vishnu, C. R., & Sridharan, R. (2021). Simulation of inventory management systems in retail stores: A case study. *Materials Today: Proceedings*, 47, 5130-5134.

Suryawanshi, P., Dutta, P., Varun, L., & Deepak, G. (2021). Sustainable and resilience planning for the supply chain of online hyperlocal grocery services. *Sustainable Production and Consumption*, 28, 496-518.

Teerasoponpong, S., & Sopadang, A. (2021). A simulation-optimization approach for adaptive manufacturing capacity planning in small and medium-sized enterprises. *Expert Systems with Applications*, 168, 114451.

Tobisova, A., Senova, A., & Rozenberg, R. (2022). Model for sustainable financial planning and investment financing using Monte Carlo method. *Sustainability*, 14(14), 8785.

Topcu, G., Çağıl, ., Susoy, Y., & Çalış Uslu, B. (2021). Supply chain risk management: A literature review on definition, theory, and the role of simulation and existing optimization methods. 19*th Logistic and Supply Chain Congress*, Gaziantep, Türkiye, 21-22 Ekim, ss. 401-415

Tordecilla, R. D., Juan, A. A., Montoya-Torres, J. R., Quintero-Araujo, C. L., & Panadero, J. (2021). Simulation-optimization methods for designing and assessing resilient supply chain networks under uncertainty scenarios: A review. Simulation modelling practice and theory, 106, 102166..

Uslu, B. Ç. (2023).The role of multi-agent systems (MAS) interoperability in IoT applications: A study on recent developments in manufacturing systems. J*ournal of the Faculty of Engineering & Architecture of Gazi University*, 38(2).

Uslu, B. Ç., & Fırat, S. Ü. O. (2021). A comprehensive study on internet of things based on key artificial intelligence technologies and industry 4.0. In Research Anthology on Cross-Industry Challenges of Industry 4.0 (pp. 171-191). *IGI Global*.

Usuga Cadavid, J. P., Lamouri, S., Grabot, B., Pellerin, R., & Fortin, A. (2020). Machine learning applied in production planning and control: a state-of-the-art in the era of industry 4.0. *Journal of Intelligent Manufacturing*, 31, 1531-1558.

Van de Merwe, K., Mallam, S., & Nazir, S. (2024). Agent transparency, situation awareness, mental workload, and operator performance: A systematic literature review. *Human Factors*, 66(1), 180-208.

Wang, X., & Yang, B. (2024, February). A Review of Semi-Physical Simulation Techniques for Aircraft Ring Control Systems. *In 2024 International Conference on Electrical Drives, Power Electronics & Engineering (EDPEE)* (pp. 476-481). IEEE.

Zhu, L. (2020). Optimization and Simulation for E-Commerce Supply Chain in the Internet of Things Environment. Complexity, 2020(1), 8821128.

Zhu, Y., Garai, A., Karmakar, R., Sarkar, B., & Mazumder, S. (2024). Customer-centric policies for environmentally sustainable manufacturing of deteriorating items with varying quality control practices under disruptions. *Computers & Industrial Engineerin*g, 189, 109895.

Zygiaris, S., Velu, S., & Alqatari, M. A. (2022). The role of Monte Carlo simulation in optimizing uncertainty: Project management in construction contract. *Cent. Eur. Manag. J*, 30, 1016-1038.

CHAPTER 7

DAMAGE MODES AND CRACK PROPAGATION ANALYSIS IN FIBER-REINFORCED POLYMER COMPOSITES USING DIGITAL IMAGE CORRELATION

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1. INTRODUCTION

Polymer composite materials are utilized in aerospace, automotive, construction, and defense industries due to their lightweight nature, high mechanical strength, and excellent corrosion resistance. Polymer composites are typically formed by combining fabric materials with a matrix material. These fabrics consist of high-strength materials such as carbon, glass, Kevlar, and basalt, among others (De Santis, de Felice, Napoli, & Realfonzo, 2016; Kwiecień, 2014; Pellegrino & Sena-Cruz, 2016; Tekieli, De Santis, de Felice, Kwiecień, & Roscini, 2017).

The increasing use of fiber-reinforced composites across various fields necessitates a thorough understanding of damage formation and rehabilitation. To build the required knowledge base, numerous experimental studies have been conducted. Evaluating the tensile strength performance and identifying the damages in composite materials guide the implementation of reinforcing additives to these composites. In some cases, detecting elongation and stress in polymer composite materials under tensile strength can be challenging. To identify damage in polymer composites, whether initiated as notched or unnotched, and to determine crack propagation and propagation rates, several methods have been developed. However, non-destructive testing (NDT) has been found to be the most effective approach. Due to the variety of materials used in polymer composites, applying the most suitable NDT technique is of critical importance (Tekieli et al., 2017). NDT techniques can be categorized into eight main groups: density measurements, ultrasonic waves, hardness loss, micrography, cyclic stress amplitudes, tertiary creep, and microhardness (Awaja, Zhang, Tripathi, Nikiforov, & Pugno, 2016; Gholizadeh, 2016; Hild, Bouterf, & Roux, 2015). The detection of damage in materials**,** including hardness and stiffness losses as well as the effects of physical and chemical changes on the material, can be monitored through NDT techniques. In laminated composites, the damage progression scenario during the mechanical fatigue life occurs in three stages (Montesano, Fawaz, & Bougherara, 2015; Peng, Liu, Saxena, & Goebel, 2015). The first stage occurs within the initial 5% of the fatigue life, ending with a rapid decrease in performance. The second stage progresses more slowly but significantly reduces the material's stiffness. The third stage occurs within 5% to 15% of the remaining life of the composite. In laminated composites, potential fiber fractures, matrix cracks, and interlayer delamination can be identified through NDT techniques(Hild et al., 2015). In composites produced with chopped fibers, delamination damage does not occur. This is due to the random distribution of the chopped fibers, which prevents the formation of a layered structure. Damage progression in chopped fiber-reinforced composites generally consists of four main stages: dominant transverse cracking, multiple transverse cracking, debonding, and dominant debonding damage (Yu, Blanc, Soutis, & Withers, 2016).

The digital image correlation (DIC) method is widely utilized across various fields. Its application provides more effective results, especially in areas requiring precise damage analysis, where composite materials are extensively used, such as high-tech industries. Composite materials are among the most critical materials in the aerospace and aviation sectors. However, the significant increase in usage within these sectors also emphasizes the importance of effective composite repair. A review of previous studies reveals a limited number of works on detecting damage in notched structures and monitoring crack propagation using the DIC method.(Caminero, Lopez-Pedrosa, Pinna, & Soutis, 2014; Grediac, 2004; Lagattu, Lafarie-

Frenot, Lam, & Brillaud, 2005; Pierron, Green, & Wisnom, 2007) . Various methods have been developed to overcome errors encountered in many of the measurements conducted so far. Digital image correlation (DIC) offers a non-contact damage analysis approach for materials. DIC is an optical technique used to measure 2D or 3D areas under static and dynamic loads(Benaarbia, Chrysochoos, & Robert, 2014; Duchene, Chaki, Ayadi, & Krawczak, 2018; Mahal, Blanksvärd, Täljsten, & Sas, 2015; Tableau, Aboura, Khellil, Marcin, & Bouillon, 2017).

To apply the digital image correlation (DIC) technique, images of the damage occurring in polymer composite materials must be obtained. Using these images, damaged areas can be distinguished from undamaged regions with the necessary DIC techniques. However, to acquire images of the damaged areas, various NDT imaging techniques are utilized.

2. DIC IN X-Ray IMAGING

Recent studies have focused on analyzing damaged areas obtained from X-ray images. X-ray imaging and image processing methods can help prevent errors in examining damage in composite structures(Castaneda, Wisner, Cuadra, Amini, & Kontsos, 2017; Djabali, Toubal, Zitoune, & Rechak, 2019; Duchene et al., 2018). Djabali et al. combined acoustic emission, X-ray computed tomography, and digital image correlation to investigate fatigue damage in thick laminates. Through these three non-destructive testing (NDT) methods, they enhanced the damage development mechanism in composites, enabling more detailed and precise analysis(Barile, Casavola, Pappalettera, & Kannan, 2020; Zhuang & Yan, 2006). X-ray images of composites in different layers are shown in Figure 1.

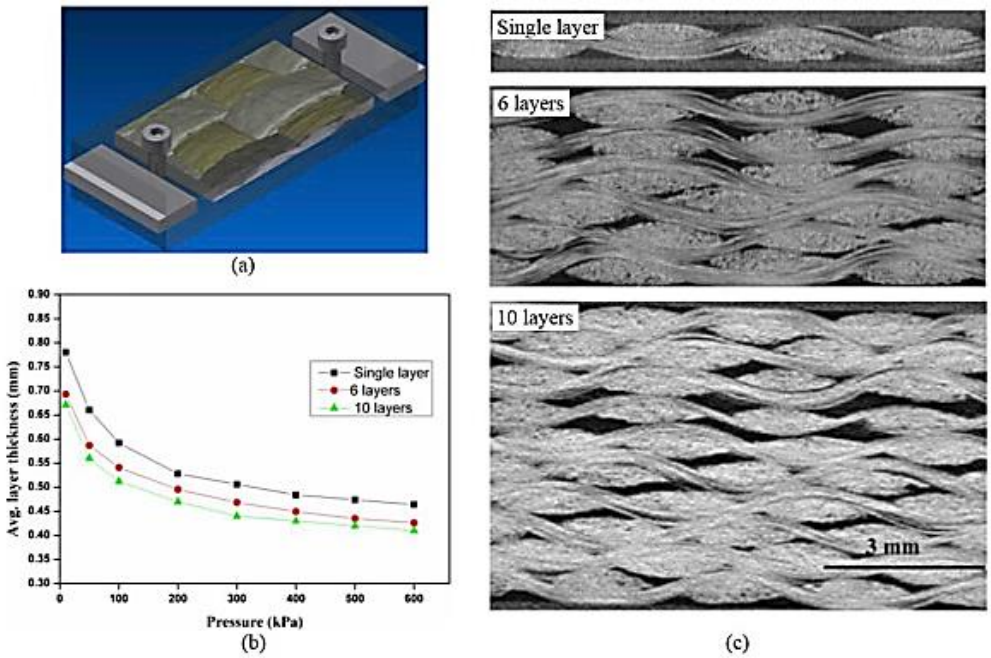


Figure 1. a) A fixture schematic for in-situ compression loading on plain-woven E-glass fabrics, b) average fabric layer thickness obtained as a function of pressure and number of layers, and c) X-ray CT slice images of single-layer, 6-layer, and 10-layer weft cross-sections showing the nesting phenomenon in multi-layer fabric stacks.(Garcea, Wang, & Withers, 2018)

3. DIC IN ULTRASONIC WAVES

3.1. Ultrasonic Testing (UT) of Polymer Composites: A Comprehensive Overview

Ultrasonic testing (UT) is a non-destructive acoustic inspection technique used to evaluate engineering materials, including polymer composites. This method measures the reflection, transmission, or backscattering of elastic waves and operates over a broad frequency range, spanning from 20 kHz to beyond 1 GHz, depending on the application. For most industrial non-destructive testing (NDT) purposes, frequencies between 0.5 and 10 MHz are typically utilized. Three distinct types of elastic waves can propagate in materials during UT:

- **Bulk waves**, which include compression (longitudinal) and shear (transverse) waves.
- **Surface waves**, also known as Rayleigh waves, confined to the material's surface.
- **Lamb waves**, which propagate in a guided manner within thin plates.

Various scanning modes are employed in UT, such as:

- **A-scan**, displaying amplitude versus time, suitable for depth measurements.
- **B-scan**, providing a one-dimensional amplitude display along a single axis.
- **C-scan**, presenting a planar amplitude map through biaxial scanning.
- **D-scan**, visualizing time-of-flight data from biaxial scans.

3.2. Ultrasonic Testing in Composite Materials

Composite materials, despite their anisotropic nature, can be effectively characterized using UT. The anisotropic properties of composites influence wave propagation due to the varying elastic properties in different material directions (Kinra, Ganpatye, & Maslov, 2006). These variations enable UT to reveal important internal features of the material.

3.3. Application of Impact-Echo C-Scan in GFRP

The **impact-echo C-scan technique** has been used to study damage in [0°/90°]S glass fiber-reinforced polymer (GFRP) laminates. This method monitored damage occurring perpendicular to the loading direction under varying levels of tensile stress. Density change mapping and image segmentation techniques were applied to analyze the material, enabling the identification of damage zones.

The differences between maps generated for unloaded and loaded specimens illustrated the heterogeneity in fiber distribution and the presence of porosity within the material, which are considered macroscopic outcomes (Harizi, Chaki, Bourse, & Ourak, 2015). These damage characteristics were further examined by analyzing density changes at the pixel level (Duchene et al., 2018).

3.4. Ultrasonic Imaging in Composite Materials

Ultrasonic images, such as those obtained through C-scan techniques, provide detailed insights into internal material structures. These images can reveal fiber alignment irregularities, voids, and other defects, supporting advanced material analysis and quality control. Such techniques

play a vital role in ensuring the reliability and performance of polymer composites in various engineering applications.

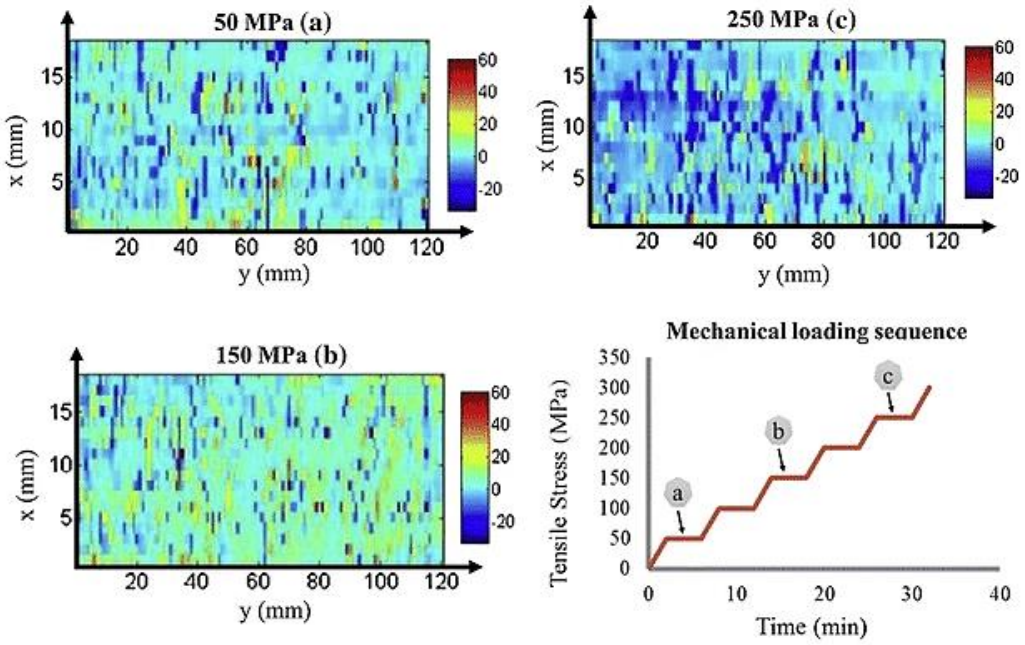


Figure 2. Acquisition of damage images using ultrasonic waves (Duchene et al., 2018)

4. IMAGE PROCESSIG TECHNIQUES

Digital image processing is a computer-based operation integrated with many industrial applications. Through image processing techniques, digital image data can be enhanced or transformed into images of different qualities, and object recognition can be performed. Image processing consists of a series of steps, beginning with image capture and continuing with the application of various techniques for specific objectives. This process, which combines mathematics and computer science, is widely used in fields such as design, manufacturing, security, medicine, electronics, mechanical engineering, architecture, and geodesy. In this study, image processing and example studies where these methods are applied across different fields are evaluated.

Image processing is distinct from “signal processing,” which aims to capture, measure, and evaluate data before converting it into a format readable by another device or transferring it from one electronic environment to another. Images consist of different content derived from a source with a specific purpose; examples of such images include those from ultrasound, electron microscopy, and computer-aided imaging. In the preprocessing phase of image processing, noise (blur, lack of clarity, low quality) in the image is reduced. For this purpose, low, medium, and high-level processes are applied. Low-level processes rely on filtering to ensure the accuracy of input and output images. Medium-level processes involve segmentation and recognition of objects in the images, while high-level processes focus on object identification and image analysis. Analyzing images in a computer environment allows for detailed examination of the objects within the content, thereby completing the image processing sequence (Jähne, 2005).

5. APPLICATIONS OF IMAGE PROCESSING TECHNIQUES

The benefits of image processing vary depending on the techniques used. Each technique applied during the image processing process approaches the image from a different perspective, allowing for a variety of outcomes. The foundation of studies in image processing lies in analyzing and digitizing images, and today this field stands out as a broad area of application across many different domains, including design, manufacturing, security, medicine, electronics, mechanical engineering, architecture, and geodesy. Given the diversity of applications, the number of studies in image processing is increasing daily, making it challenging to provide a comprehensive assessment of all studies in this field. In this work, however, key studies in a few specific areas are evaluated.

5.1. Application of Image Processing Techniques in Manufacturing

Image processing is used in many applications and control systems, from manufacturing to the design process. Depending on the area of application, it offers advantages such as improving quality, saving time, enhancing practicality, and contributing to the formation of new business units. Image processing techniques used in manufacturing and pre-manufacturing stages also aid in new product designs, helping reduce production costs. Zhou developed a fundamental recognition method using model-matching interpretation in computer-aided design and line photometry measurement systems. This study utilized interpretation angle, graphic angle, and model matching. The generated graphics included the hierarchical structure and primary graphical features of the object, creating computer-aided design elements by matching the averages, model graphic angles, and image graphic angles of classified objects (Zhou, 1997).
Ying-dong and colleagues succeeded in measuring spray deposition size in real-time during the process using image processing techniques. The spray forming process involves spraying particles from liquid metal with high-speed gas. Image processing algorithms are generally used for accurate measurement of deposition sizes (Lawrynowicz et al., 1995). Another technique, edge detection, is essential in many image processing applications such as object recognition and motion analysis. New edge detection processes utilize neural network and fuzzy logic techniques (Ghosal & Mehrotra, 1993).

In this study, a new image processing technique was developed to measure the deposition size in spray forming. First, an adapted plane operator and image source are analyzed to capture an image. In the second step, the Sobel-Zernike moment operator, an edge detection technique, is used to determine the edges of the deposition image. Finally, qualitative information, such as the outer diameter of the tubular deposit, is used to calculate the deposit size.

The designed system allows for easy measurement of deposit sizes through the developed image processing algorithm and edge detection technique. A standard CCD camera was used for these measurements. The system consists of three stages: noise reduction in images obtained by the camera, edge detection, and deposit size calculation.
New techniques in image processing are expanding its scope of application. Bellaire and colleagues performed object recognition by utilizing color values. This study presents a two-

and three-dimensional object recognition system derived from data obtained from colored images. Edge and color distribution information in colored images was obtained using a model centered on the image and the relationships between defined image points. By interpreting the images, real image data was matched with result data, and image features were identified with labels in various studies, with edges detected through these labels.
Uras and colleagues conducted a study on detecting wear in plowshares using image processing techniques. To identify wear factors seen in plowshares, which lead to various adverse effects, the study utilized not only measurement methods such as precision scales and planimeters but also computerized image processing techniques(Uras & Okursoy, 2007).

5.2. Application of Image Processing Techniques in Polymer Composites

Composite materials exhibit complex anisotropic properties and various forms of damage progression when loaded, due to the influence of their different components. Woven composites, in particular, present additional complexity in deformation and damage response because of their architectural complexity and the interactions between warp and weft crimped fiber tows.(Gorbatikh & Lomov, 2016; Quaresimin & Ricotta, 2015).
Despite these challenges, woven fiber-reinforced thermoplastic composites are becoming increasingly popular due to their ability to be rapidly produced through thermoforming(Deng et al., 2021; Long & Clifford, 2007; Zheng et al., 2019).
For more efficient utilization**,** accurate characterization of these materials is essential to enable precise simulations during the design phase, ensure quality assurance checks during production, and predict progressive fatigue damage development. Digital Image Correlation (DIC) is increasingly preferred for providing valuable insights into deformation and damage by observing heterogeneous surface displacement and strain fields during testing (Dong & Pan, 2017; Pan, 2018; Sutton, Orteu, & Schreier, 2009). However, the internal structure and architecture of the composite play a critical role in damage development, naturally limiting the ability of surface-based techniques to provide comprehensive data in this regard (Ali, Umer, & Khan, 2020; Maire & Withers, 2014). Therefore, it is necessary to extend surface characterization to 3D internal examination to gain further insight into the effects of internal damage, deformation, and structure on the observed surface response. Image processing procedures are shown in Figure 3.

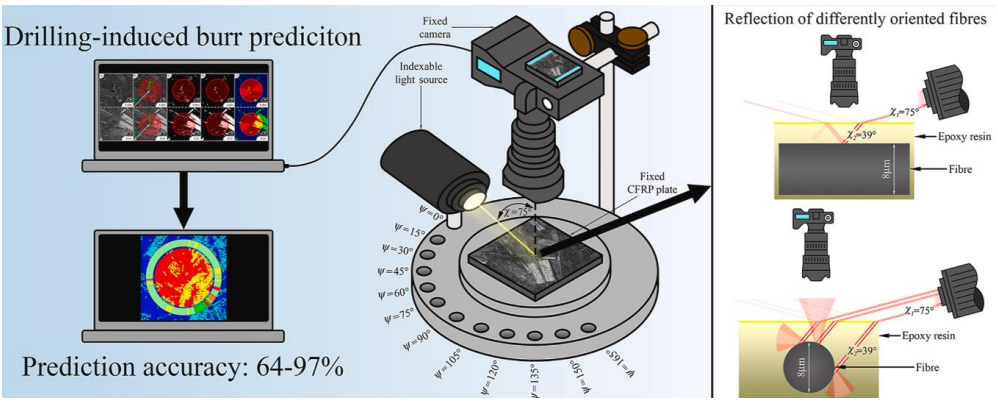


Figure 3. Diagram of damage analysis in composite structures using image processing(Geier, Póka, Jacsó, & Pereszlai, 2022)

Burr measurement and analysis are typically conducted using digital image processing (DIP) applied to two-dimensional images, as burrs predominantly form at the entry and exit edges of drilled holes. Studies by Hrechuk, Bushlya, and Ståhl (2018) and Pereszlai and Geier (2020) evaluated hole quality in carbon fiber-reinforced polymers (CFRPs) using DIP, identifying segmentation, contour detection, and triangulation algorithms as effective methods for analyzing geometric defects caused by drilling. They highlighted the need to minimize the influence of human factors in defect evaluation, which still plays a significant role. Hrechuk and colleagues introduced a novel metric called "implenarity," which evaluates the uniformity of hole contour shapes through Delaunay triangulation, offering a promising parameter for objective defect assessment. Additionally, Stokes-Griffin and Compston (2015) examined the optical properties of CFRP composites, noting that the polymer matrix is highly transparent while carbon-reinforced fibers are the primary contributors to anisotropic scattering behavior, strongly influenced by fiber orientations. These findings were experimentally validated by Meister, Stüve, and Groves (2022), who confirmed the anisotropic scattering properties. Consequently, Geier et al. (2022) suggested that a camera-based inspection system could be an effective tool for characterizing chopped CFRP composites. Microscope images of drilled holes and their corresponding binary images after image processing are shown in Figures 4 and 5, illustrating defect detection and evaluation.

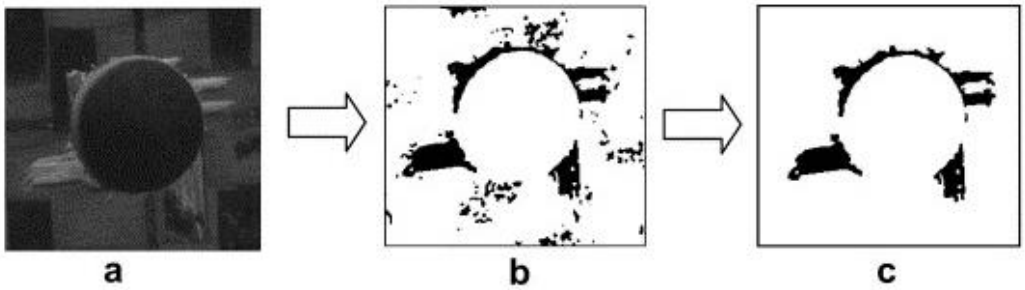
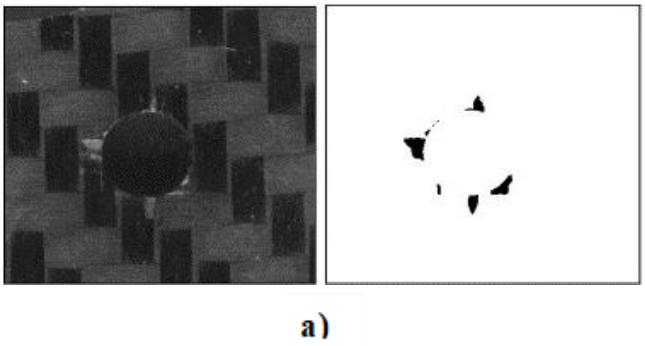
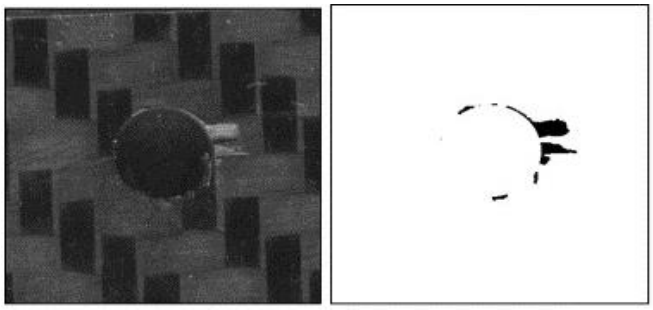
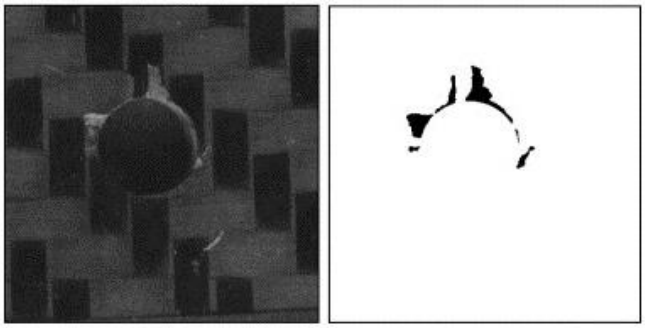


Figure 4. Image processing operations to determine the damage zone final form: (a) digital image, (b) initial processing and (c) end resulting image (Davim, Rubio, & Abrao, 2007)





b)



c)

Figure 5. Captured and processed images at the hole exit in CFRP (Davim et al., 2007)

Various techniques are used to analyze and calculate the damage area in drilled composites (Arul, Vijayaraghavan, Malhotra, & Krishnamurthy, 2006; Davim & Reis, 2003a, 2003b; Hocheng & Tsao, 2006; Koenig, Grass, Heintze, Okcu, & Schmitz-Justin, 1984; Piquet, Ferret, Lachaud, & Swider, 2000).

These techniques are crucial for providing a detailed characterization of damage and assessing the structural integrity of the material. For example, Gao and Kim presented a study comparing destructive and non-destructive methods for evaluating impact damage in carbon fiber-reinforced composites (Gao & Kim, 1999). The study revealed that visual inspection methods are insufficient for accurately determining the profile and depth of damage, highlighting the need for more advanced image processing techniques. In this research, digital images were used to identify the damage area, and the extent of damage at the drill entry and exit points was analyzed.

A digital image can be thought of as a matrix of rows and columns, where each cell represents a point in the image and indicates the brightness intensity of the corresponding pixel. Image processing yields satisfactory results for observing and analyzing the details of this digital data. Using the discrete processing technique, the image is converted into a rectangular grid defined by coordinate pairs, taking the top left corner as the origin.

The damage area is determined by processing digital images. The flow diagram of the image processing procedure used to calculate the damage area around a drilled hole is shown. To enhance image quality, parameters such as brightness intensity adjustments, noise reduction

(speckle removal), image enhancement, and edge detection must be carefully selected. To obtain a binary image, the grayscale image is processed with a threshold filter, separating black and white regions for precise measurement of the damage area.

Such digital image processing techniques facilitate post-drilling damage analysis of composite materials, minimize human error, and provide a reliable foundation for automated evaluation systems. Binary imaging and edge detection techniques, in particular, allow for a comprehensive assessment of the damage, enhancing our understanding of material performance and durability. These methods are highly beneficial for improving the reliability of composites and preventing potential damage during the design phase.

6. CONCLUSIONS

This study evaluated the effectiveness of damage analysis in polymer composite materials using digital image processing techniques. The findings indicate that image processing methods offer a reliable and effective approach for detecting and analyzing damage in composite materials. Basic image processing techniques, such as edge detection, segmentation, and digitization, accurately identified the size and location of damage, providing faster and more cost-effective analysis compared to traditional methods.

The techniques used in the research successfully differentiated various types of damage, including cracks, delamination, and fiber breakage on composite surfaces. Moreover, digital image processing accurately detected microscopic damage that is undetectable by the human eye, providing detailed insights into damage size and propagation. Specifically, binary imaging and pixel-based analyses offered high-resolution and precise assessment of the extent of damage.

In conclusion, digital image processing techniques stand out as a powerful tool for damage analysis in polymer composite materials. Integrating these methods into the design and manufacturing processes is likely to be beneficial in enhancing composite performance, reducing damage risk, and ensuring long-term reliability. Future studies are encouraged to apply advanced algorithms for analyzing more complex types of damage and multilayer composites. This approach will enable a more comprehensive understanding of damage analysis in composite materials and foster the development of new design strategies.

REFERENCES

Ali, M. A., Umer, R., & Khan, K. A. (2020). *CT Scan Generated Material Twins for Composites Manufacturing in Industry 4.0*: Springer.

Arul, S., Vijayaraghavan, L., Malhotra, S. K., & Krishnamurthy, R. (2006). The effect of vibratory drilling on hole quality in polymeric composites. *International Journal of Machine Tools and Manufacture, 46*(3-4), 252-259.

Awaja, F., Zhang, S., Tripathi, M., Nikiforov, A., & Pugno, N. (2016). Cracks, microcracks and fracture in polymer structures: Formation, detection, autonomic repair. *Progress in Materials Science, 83*, 536-573.

Barile, C., Casavola, C., Pappalettera, G., & Kannan, V. P. (2020). Application of different acoustic emission descriptors in damage assessment of fiber reinforced plastics: A comprehensive review. *Engineering Fracture Mechanics, 235*, 107083.

Benaarbia, A., Chrysochoos, A., & Robert, G. (2014). Kinetics of stored and dissipated energies associated with cyclic loadings of dry polyamide 6.6 specimens. *Polymer Testing, 34*, 155-167.

Caminero, M. A., Lopez-Pedrosa, M., Pinna, C., & Soutis, C. (2014). Damage assessment of composite structures using digital image correlation. *Applied Composite Materials, 21*, 91-106.

Castaneda, N., Wisner, B., Cuadra, J., Amini, S., & Kontsos, A. (2017). Investigation of the Z-binder role in progressive damage of 3D woven composites. *Composites Part A: Applied Science and Manufacturing, 98*, 76-89.

Davim, J. P., & Reis, P. (2003a). Drilling carbon fiber reinforced plastics manufactured by autoclave—experimental and statistical study. *Materials & Design, 24*(5), 315-324.

Davim, J. P., & Reis, P. (2003b). Study of delamination in drilling carbon fiber reinforced plastics (CFRP) using design experiments. *Composite Structures, 59*(4), 481-487.

Davim, J. P., Rubio, J. C., & Abrao, A. M. (2007). A novel approach based on digital image analysis to evaluate the delamination factor after drilling composite laminates. *Composites Science and Technology, 67*(9), 1939-1945.

De Santis, S., de Felice, G., Napoli, A., & Realfonzo, R. (2016). Strengthening of structures with Steel Reinforced Polymers: A state-of-the-art review. *Composites Part B: Engineering, 104*, 87-110.

Deng, T., Zhang, W., Jiang, W., Zhou, H., Huang, Z., Peng, X., . . . Li, D. (2021). A hybrid lamination model for simulation of woven fabric reinforced thermoplastic composites solid-state thermo-stamping. *Materials & Design, 200*, 109419.

Djabali, A., Toubal, L., Zitoune, R., & Rechak, S. (2019). Fatigue damage evolution in thick composite laminates: Combination of X-ray tomography, acoustic emission and digital image correlation. *Composites Science and Technology, 183*, 107815.

Dong, Y. L., & Pan, B. (2017). A review of speckle pattern fabrication and assessment for digital image correlation. *Experimental Mechanics, 57*, 1161-1181.

Duchene, P., Chaki, S., Ayadi, A., & Krawczak, P. (2018). A review of non-destructive techniques used for mechanical damage assessment in polymer composites. *Journal of materials science, 53*(11), 7915-7938.

Gao, S.-L., & Kim, J.-K. (1999). Scanning acoustic microscopy as a tool for quantitative characterisation of damage in CFRPs. *Composites Science and Technology, 59*(3), 345-354.

Garcea, S. C., Wang, Y., & Withers, P. J. (2018). X-ray computed tomography of polymer composites. *Composites Science and Technology, 156*, 305-319.

Geier, N., Póka, G., Jacsó, Á., & Pereszlai, C. (2022). A method to predict drilling-induced burr occurrence in chopped carbon fibre reinforced polymer (CFRP) composites based on digital image processing. *Composites Part B: Engineering, 242*, 110054.

Gholizadeh, S. (2016). A review of non-destructive testing methods of composite materials. *Procedia structural integrity, 1*, 50-57.

Ghosal, S., & Mehrotra, R. (1993). Orthogonal moment operators for subpixel edge detection. *Pattern recognition, 26*(2), 295-306.

Gorbatikh, L., & Lomov, S. V. (2016). Damage accumulation in textile composites. In *Modeling damage, fatigue and failure of composite materials* (pp. 41-59): Elsevier.

Grediac, M. (2004). The use of full-field measurement methods in composite material characterization: interest and limitations. *Composites Part A: Applied Science and Manufacturing, 35*(7-8), 751-761.

Harizi, W., Chaki, S., Bourse, G., & Ourak, M. (2015). Mechanical damage characterization of glass fiber-reinforced polymer laminates by ultrasonic maps. *Composites Part B: Engineering, 70*, 131-137.

Hild, F., Bouterf, A., & Roux, S. (2015). Damage measurements via DIC. *International Journal of Fracture, 191*, 77-105.

Hocheng, H., & Tsao, C. C. (2006). Effects of special drill bits on drilling-induced delamination of composite materials. *International Journal of Machine Tools and Manufacture, 46*(12-13), 1403-1416.

Hrechuk, A., Bushlya, V., & Ståhl, J.-E. (2018). Hole-quality evaluation in drilling fiber-reinforced composites. *Composite Structures, 204*, 378-387.

Jähne, B. (2005). *Digital image processing*: Springer Science & Business Media.

Kinra, V. K., Ganpatye, A. S., & Maslov, K. (2006). Ultrasonic ply-by-ply detection of matrix cracks in laminated composites. *Journal of Nondestructive Evaluation, 25*, 37-49.

Koenig, W., Grass, P., Heintze, A., Okcu, F., & Schmitz-Justin, C. (1984). Developments in drilling and contouring composites containing kevlar. *Production Engineer, 63*(8), 56-61.

Kwiecień, A. (2014). Shear bond of composites-to-brick applied with highly deformable, in relation to resin epoxy, interface materials. *Materials and Structures, 47*, 2005-2020.

Lagattu, F., Lafarie-Frenot, M. C., Lam, T. Q., & Brillaud, J. (2005). Experimental characterisation of overstress accommodation in notched CFRP composite laminates. *Composite Structures, 67*(3), 347-357.

Lawrynowicz, D. E., Wolfenstine, J., Lavernia, E. J., Nutt, S. R., Bailey, D. E., Sickinger, A., & Hirt, A. M. (1995). Reactive synthesis and characterization of MoSi [sub 2]/SiC using low-pressure plasma deposition and 100% methane. *Scripta Metallurgica et Materialia;(United States), 32*(5).

Long, A. C., & Clifford, M. J. (2007). Composite forming mechanisms and materials characterisation. *Composites forming technologies*, 1-21.

Mahal, M., Blanksvärd, T., Täljsten, B., & Sas, G. (2015). Using digital image correlation to evaluate fatigue behavior of strengthened reinforced concrete beams. *Engineering Structures, 105*, 277-288.

Maire, E., & Withers, P. J. (2014). Quantitative X-ray tomography. *International materials reviews, 59*(1), 1-43.

Meister, S., Stüve, J., & Groves, R. M. (2022). Optical material characterisation of prepreg CFRP for improved composite inspection. *Applied Composite Materials, 29*(2), 871-887.

Montesano, J., Fawaz, Z., & Bougherara, H. (2015). Non-destructive assessment of the fatigue strength and damage progression of satin woven fiber reinforced polymer matrix composites. *Composites Part B: Engineering, 71*, 122-130.

Pan, B. (2018). Digital image correlation for surface deformation measurement: historical developments, recent advances and future goals. *Measurement Science and Technology, 29*(8), 082001.

Pellegrino, C., & Sena-Cruz, J. (2016). Design procedures for the use of composites in strengthening of reinforced concrete structures. *State-of-the-art Report of the RILEM Technical Committee*, 392.

Peng, T., Liu, Y., Saxena, A., & Goebel, K. (2015). In-situ fatigue life prognosis for composite laminates based on stiffness degradation. *Composite Structures, 132*, 155-165.

Pereszlai, C., & Geier, N. (2020). Comparative analysis of wobble milling, helical milling and conventional drilling of CFRPs. *The International Journal of Advanced Manufacturing Technology, 106*(9), 3913-3930.

Pierron, F., Green, B., & Wisnom, M. R. (2007). Full-field assessment of the damage process of laminated composite open-hole tensile specimens. Part I: Methodology. *Composites Part A: Applied Science and Manufacturing, 38*(11), 2307-2320.

Piquet, R., Ferret, B., Lachaud, F., & Swider, P. (2000). Experimental analysis of drilling damage in thin carbon/epoxy plate using special drills. *Composites Part A: Applied Science and Manufacturing, 31*(10), 1107-1115.

Quaresimin, M., & Ricotta, M. (2015). Fatigue response and damage evolution in 2D textile composites. In *Fatigue of textile composites* (pp. 193-221): Elsevier.

Stokes-Griffin, C. M., & Compston, P. (2015). Optical characterisation and modelling for oblique near-infrared laser heating of carbon fibre reinforced thermoplastic composites. *Optics and Lasers in Engineering, 72*, 1-11.

Sutton, M. A., Orteu, J. J., & Schreier, H. (2009). Image correlation for shape, motion and deformation measurements: basic concepts, theory and applications. *Springer Science & Business Media.*

Tableau, N., Aboura, Z., Khellil, K., Marcin, L., & Bouillon, F. (2017). Accurate measurement of in-plane and out-of-plane shear moduli on 3D woven SiC-SiBC material. *Composite Structures, 172*, 319-329.

Tekieli, M., De Santis, S., de Felice, G., Kwiecień, A., & Roscini, F. (2017). Application of Digital Image Correlation to composite reinforcements testing. *Composite Structures, 160*, 670-688.

Uras, A., & Okursoy, R. (2007). Determination of wear on plough end bars using image processing technique. *Journal of Agricultural Sciences, 13*(03), 253-260.

Yu, B., Blanc, R., Soutis, C., & Withers, P. J. (2016). Evolution of damage during the fatigue of 3D woven glass-fibre reinforced composites subjected to tension–tension loading observed by time-lapse X-ray tomography. *Composites Part A: Applied Science and Manufacturing, 82*, 279-290.

Zheng, B., Gao, X., Li, M., Deng, T., Huang, Z., Zhou, H., & Li, D. (2019). Formability and failure mechanisms of woven CF/PEEK composite sheet in solid-state thermoforming. *Polymers, 11*(6), 966.

Zhou, G. (1997). Primitive recognition using aspect-interpretation model matching in both CAD-and LP-based measurement systems. *ISPRS Journal of Photogrammetry and Remote Sensing, 52*(2), 74-84.

Zhuang, X., & Yan, X. (2006). Investigation of damage mechanisms in self-reinforced polyethylene composites by acoustic emission. *Composites Science and Technology, 66*(3-4), 444-449.

CHAPTER 8

EVALUATION OF PHENOLIC AND FLAVONOID LEVELS AND IN VITRO ANTIOXIDANT CAPACITY OF *Sargassum acinarium*

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I. INTRODUCTION

A large part of the Earth's surface is covered with saltwater, while freshwater resources, such as rivers and lakes, are much rarer. (Moss, 2010). Algae typically live in water, which can be freshwater, saltwater, or brackish. They serve as primary producers in their habitats, generating organic matter using water, carbon dioxide, and sunlight,. Apart from being the primary source of food in the food chain, they also generate the oxygen required for organisms that consume them (Lee, 2008; Aşıkkutlu and Akköz, 2022). Greenhouse gases resulting from increasing environmental pollution are driving climate change (Gümüş and Buluş, 2020). In the context of climate change, it has become increasingly important to define the biological characteristics of algae, which are among the first aquatic organisms to be affected (McCormick and Cairns, 1994).

In recent years, algae have become one of the natural resources utilized by humans for their benefit. (Yoldaş et al., 2003). Algae are significant sources of bioactive molecules used in human and animal nutrition. Numerous marine macroalgae possess both primary and secondary metabolites with distinctive structures (Keskinkaya et al., 2020; Aşıkkutlu and Akköz, 2022).

Macroalgae, in particular, contain reactive antioxidant molecules and secondary metabolites. These include carotenoids (such as fucoxanthin, astaxanthin, alpha- and beta-carotene), catechins (e.g., epigallocatechin, catechin), mycosporine-like amino acids (e.g., mycosporine-glycine), gallates, tocopherols, and eckol-type phlorotannins (e.g., phloroglucinol) (Kolsi et al., 2017). With the increase in scientific research on macroalgae, their commercial importance is growing, and their applications are expanding (Souza et al., 2011; Kran, 2013; Aşıkkutlu ve Akköz, 2022).

Recent studies, particularly in recent years, have shown that macroalgae are rich in compounds with high antioxidant properties. Additionally, many studies have proven that macroalgae contain certain secondary metabolites, such as phenolics and flavonoids, which are responsible for their antioxidant activity (Keskinkaya et al., 2023).

It is known that substances found in macroalgae, such as peptides, polysaccharides, pigments phenolic compounds, polyunsaturated fatty acids, proteins, , sterols, vitamins, pigments and terpenoid, exhibit antioxidant effects. *Sargassum* species are distributed in unpolluted areas and are commonly found in the Mediterranean waters of our country. In terms of antioxidant compounds, these species hold significant importance, alongside terrestrial plants. Due to the richness of active (primary and secondary) metabolites in aquatic organisms'

structures, their use in the pharmaceutical industry is increasing every day. (Lee and Kim, 2015).

Figure 1. *Sargassum acinarium*

The goal of this study was to assess the in-vitro antioxidant analysis. (DPPH, ABTS+, CUPRAC, and phosphomolybdenum activity) and total phenolic-flavonoid content of ethanol, methanol, and water extracts of the marine brown macroalga *Sargassum acinarium*, collected from the Üçadalar district in Antalya.

2. MATERIAL and METHOT

Sample Collection and Preparation

The *Sargassum acinarium* (Linnaeus) Setchell 1933, belonging to the Phaeophyceae division, found in the waters of Antalya (Figure 2), was collected from pre-determined coordinates (Table 1). The gathered samples were transferred into sterile glass containers and transported to the laboratory under cold chain conditions. In the laboratory, the algal samples were washed with distilled water or cleaned with scissors to remove foreign particles and epiphytic organisms, as well as necrotic fragments. The systematic categorization of the *Sargassum acinarium* species is as follows:

Kingdom: Chromista

Phylum: Ochrophyta

Class: Phaeophyceae

Subclass: Fucophycidae

Order: Fucales

Family: Sargassaceae

Genus: Sargassum

Species: *Sargassum acinarium (Linnaeus) Setchell 1933*

(https://www.algaebase.org/search/species/detail/?species_id=1359)

Table 1. Sampling Station Geographic Information.

Species name	**Divisio**	**Locality**	**Coordinate**	**Depth**
Sargassum acinarium	Ochrophyta	Antalya Üç Adalar	36°27'31.90"N 30°32'48.10"E	30 m

Figure 2. Satellite image of algae collected from Antalya

After the S. acinarium samples were dried under appropriate conditions, they were mechanically ground into a fine powder under aseptic conditions. A 10 g sample was weighed and subjected to extraction with 100 ml of solvent by stirring for 24 hours. The extracted solutions were filtered and subsequently evaporated under reduced pressure with a rotary

evaporator at 40 °C, until approximately 1-2 ml remained. (Kaufman et al., 1995). Afterward, any remaining algal extract in the flask was dissolved in a small amount (2-3 ml) of its solvent with the help of ultrasound and transferred to vials. Following this process, the samples were stored at -20 °.

Antioxidant Tests

The total phenolic content (TPC) of the macroalgae extracts was determined using the Folin-Ciocalteu method (Slinkard and Singleton, 1977). The results were calculated based on the equation derived from the standard gallic acid curve.

Absorbance = 0.0104 [gallic acid (μg)] - 0.0263, (r^2 = 0.9924)

The total flavonoid content (TFC) of the macroalgae extracts was determined using the aluminum nitrate method (Park et al., 1997). The results were calculated based on the equation derived from the standard quercetin calibration curve.

Absorbance = 0.0158 [quercetin (μg)] - 0.0306, (r^2 = 0.9993)

The antioxidant capacities of the macroalgae extracts were evaluated using several methods:, ABTS+ (2,2′-azinobis (3-ethylbenzothiazoline-6-sulfonic acid)) cation radical scavenging, CUPRAC (Cupric reducing antioxidant capacity), DPPH (2,2′-diphenyl-1-picrylhydrazyl) free radical scavenging and the Phosphomolybdenum assay (Çayan et al., 2019).BHA, ascorbic acid and BHT served as standard references.

The IC50 value (concentration required for 50% inhibition) was determined from the graph plotting antioxidant activity percentage (inhibition %) against extract concentration (μg/mL). The A0.50 value (concentration corresponding to 0.50 absorbance) was obtained from the graph of absorbance versus extract concentration (μg/mL).

The results were presented as IC50 values and inhibition percentages (%) for the radical scavenging assays at a concentration of 200 μg/mL, and as A0.50 values and absorbance for the CUPRAC and phosphomolybdenum assays at the same concentration of 200 μg/mL.

3. RESULTS AND DISCUSSION

The TPC and TFC results of S. acinarium's methanol, ethanol, and water extracts are provided in Table 2. The aim of this study was to evaluate the in vitro antioxidant capacity, total phenolic content (TPC), and total flavonoid content (TFC) of the different extracts (ethanol, methanol, and water) of S. acinarium. Antioxidant activity was assessed using DPPH scavenging activity, CUPRAC, ABTS+ and phosphomolybdenum assay. BHT, BHA, ascorbic acid wereused as standard substances in the total antioxidant activity assays.

The TPC and TFC values of the extracts were determined to be 5.85±0.34–10.89±0.11 µg GAEs/mg of extract and 5.79±0.17–21.94±1.17 µg QEs/mg of extract, respectively.

Table 2. Total phenolic (TPC) and flavonoid (TFC) contents of S.acinarium a extracts.

Extracts	Total phenolic content (TPC) (µg GAEs/mg extract[b])	Total flavonoid content (TFC) (µg QEs/mg extract[c])
SAE	10,89±0,11	21,94±1,17
SAM	10,48±0,22	5,79±0,17
SAS	5,85±0,34	11,37±0,09

[a]: Results are given as mean ±SD of 3 replicate measurements. SAE: SA Ethanol Extract, SAM: SA Methanol Extract, SAS: Water Extract
[b] GAEs, gallic acid equivalent, y=0,0104x-0,263 r^2=0,9924
[c] QEs, quercetin equivalent, y=0,0158x-0,0306 r^2=0,999

Given that antioxidants operate through various mechanisms, it is preferable to use multiple methods to assess antioxidant activity rather than relying on just one. The antioxidant activities of S. acinarium extracts were evaluated through DPPH free radical scavenging, CUPRAC and ABTS+ cation radical scavenging assays. The results are shown in Table 3.

Table 3. Antioxidant contents of S. acinarium extracts.

		Antioxidant Activity							
		DPPH˙ test		ABTS$^{\bullet+}$ test		CUPRAC test		Phosphomolybdenum test	
		Inhibition (%)[a]	IC_{50} (µg /mL)[b]	Inhibition (%)[a]	IC_{50} (µg/mL)[b]	Absorbance[c]	$A_{0.50}$ (µg/mL)[d]	Absorbance[c]	$A_{0.50}$ (µg/mL)[d]
Extracts	**SAE**	79,60±0,67	25,36±0,22	91,24±0,20	17,21±0,55	1,84±0,02	38,74±0,07	1,17±0,01	80,64±0,13
	SAM	48,±0,59	14,61±0,85	79,47±0,23	10,11±0,07	1,06±0,38	21,09±0,44	1,02±0,53	56, 41±0,53
	SAS	27,01±083	8,75±0,68	-	>200	-	>200	0,75±1,02	38,11 ±1,32
Standards	**BHT**	85,93±0,32	23,90±0,14	83,12±0,21	12,75±0,63	2,18±0,02	26,54±0,02	-	-
	BHA	86,64±0,12	22,80±0,59	86,41±0,16	12,05±0,97	2,02±0,03	28,21±0,01	-	-
	Ascorbic acid	84,32±0,18	6,68±0,22	84,56±0,41	5,24±0,18	3,35±0,01	20,67±0,01	3,74±0,01	13,66±0,01

SAE: SA Ethanol Extract, SAM: SA Methanol Extract, SAS: Water Extract

[a]: Inhibition % of extracts at 200 µg/mL concentration.

[b]: IC50 values are given as the mean ±SD of three parallel measurements.

[c]: Absorbance at 200 µg/mL concentration of extracts.

[d] : A0.50 values are given as the mean ±SD of three parallel measurements.

The highest phosphomolybdenum activity was observed in the ethanol extract of *S. acinarium* (A0.50: 80.64±0.13 µg/mL). The highest CUPRAC activity was also observed in the ethanol extract of *S. acinarium* (A0.50: 38.74±0.07 µg/mL). The DPPH radical scavenging activity values were again highest in the ethanol extract (IC50: 25.36±0.22 µg/mL).

Extraction methods and solvent changes increase TPC/TFC levels and enhance antioxidant potential (Silva et al., 2006).

In a research conducted by Baba and Malik (2015), the in vitro antioxidant potential of methanolic extracts from A. jacquemontii roots was examined. The total phenolic content of the methanolic root extract ($R^2 = 0.998$) was measured at 145.17 ± 1.70 gallic acid equivalents per gram, while the total flavonoid content ($R^2 = 0.999$) was 35 ± 2.20 rutin equivalents per gram. The methanolic root extract demonstrated significant antioxidant activity against all tested free radicals, with DPPH scavenging activity reaching 64.16% at a concentration of 500 µg/mL, compared to 84% for the control (ascorbic acid).

Rodríguez-Bernaldo de Quirós et al. (2010) analyzed the total phenolic and pigment content in edible seaweeds. The total phenolic content of four brown algae species (*Laminaria saccharina*, *Undaria pinnatifida*, *Himanthalia elongata* and *Laminaria sp*) was measured using the Folin-Ciocalteu method. The polyphenol content ranged from 1.3 to 10.0 g phloroglucinol per kg of weight. The pigments responsible for the algae's color, including carotenoids and chlorophylls, were assessed using spectrophotometric techniques.

In a 2022 study by Keskinkaya et al., antimicrobial activity results from green algae species (C. fragile-C. bursa) showed antimicrobial activation against *P. aeruginosa* strain. Similar results were obtained in our study.

There are both similarities and discrepancies between the findings of our study and those reported in the literature. In general, the quantity of phenolic compounds is affected by several factors, including the source of the sample, the extraction method employed, the particle size of the sample, storage conditions, duration, the analytical technique applied, and the presence of substances that may interfere with the extracts. Isolating phenolic compounds in a quantitative manner is difficult due to their size, molecular weight, structural resemblances, and their tendency to interact with other substances (Keskinkaya et al., 2022).

These differences between studies can be explained by different extraction conditions and reporting methods (Mekinic et al., 2019; Schoenwaelder, 2012). The significant differences and similarities between our results and previous studies may stem from several factors. First, this variation may be related to intraspecific variability in the production of secondary metabolites, which is sometimes linked to seasonal changes, as seen in other published reports (Lima-Filho et al., 2002; Moreau et al., 1988). Second, these variations might arise from the different solubility effects of secondary metabolites, influenced by the species' geographical and seasonal distribution, as well as differences in extraction protocols and analysis methods that could affect the recovery of active metabolites and the sensitivity of the target strains (Perez et al., 1990; Gonzalez et al., 2001).

Our study focused on evaluating the in vitro antioxidant potential of extracts derived from *S. acinarium*. The results of our study show that these extracts are particularly rich in flavonoids and phenolic compounds and exhibit significant antioxidant potential, consistent with findings from previous studies (Baharfar et al., 2015; Tungmunnithum et al., 2018; Huang et al.).

In conclusion, the results suggest that *S. acinarium* is a valuable source of antioxidant capacity and contains beneficial phenolic compounds.

4. CONCLUSION

The findings of this study emphasize that *S. acinarium*, which is considered a potential future food source, could contribute to the discovery of promising new natural antioxidants and anticancer agents critical for various industries such as medicine, food, and cosmetics. However, isolation studies need to be conducted to identify active components other than the phenolic compounds responsible for these biological activities. Considering Turkey's vast terrestrial and marine resources, we are faced with a great untapped treasure. In this context, research aimed at discovering new agents from both terrestrial and marine sources is gaining momentum. We believe this study could represent a new step in understanding the health benefits of algae and could be considered an important alternative for functional components in food and medicinal preparations.

REFERENCES

Aşıkkutlu, B. & Akköz, C. (2022). Determination of Pigment Content and Antioxidant Activities of Some Chlorophyta Species Isolated from Altınapa Dam Lake (Konya/Türkiye). *Anadolu Çev. ve Hay. Journal*, 7(2), 227-234.

Baba, S.A.& Malik,S.A. 2015. Determination of total phenolic and flavonoid content, antimicrobialand antioxidant activity of a root extract of *Arisaema jacquemontii* Blume. *Journal of Taibah University for Science* 9: 449–454 .

Baharfar, R., Azimi, R., & Mohseni, M. (2015). Antioxidant and antibacterial activity of flavonoid-, polyphenol- and anthocyanin-rich extracts from Thymus kotschyanus boiss & hohen aerialparts. *Journal of food science and technology, 52*(10), 6777–6783. https://doi.org/10.1007/s13197- 015-1752-0.

Çayan, F., Tel-Çayan, G., Deveci, E., Öztürk, M., & Duru, M.E. (2019). Chemical profile, in vitro enzyme inhibitory, and antioxidant properties of Stereum species (Agaricomycetes) from Turkey. International Journal of Medicinal Mushrooms, 21(11), 1075-1087. https://doi.org/10.1615/IntJMedMushrooms.2019032893.

Gümüş, B., & Buluş, A. (2020). International Environmental Problems and William Nordhaus' Contributions to Environmental Economics", *Alanya Academic View*, 4(3):1015-1031. Doi:10.29023/alanyaakademik.686110

Gonzalez, G., Brownlee, D., & Ward, P. (2001). The galactic habitable zone: galactic chemical evolution. *Icarus*, 152(1), 185-200.

Huang, B., Ke, H., He, J., Ban, X., Zeng, H., & Wang, Y. (2011). Extracts of Halenia elliptica exhibit antioxidant properties in vitro and in vivo. *Food and chemical toxicology: an international journal published for the British Industrial Biological Research Association, 49*(1), 185–190. https://doi.org/10.1016/j.fct.2010.10.015

Kaufman P.B, Wu W, Kim D and Cseke L.J (1995). Handbook of molecular and cellular methods in biology and medicine, CRC Press Inc., Corporate Blvd NW, Boca Raton, Florida, vol 33 (pp. 431-438)

Keskinkaya, H. B., Gümüş, N. E., Aşıkkutlu, B., Akköz, C., Okudan, E. Ş., & Karakurt, S. (2020). Macro and trace element levels of green algae codium fragile (suringar) hariot 1889 from dardanelles (Çanakkale/Turkey). *Anadolu Orman Araştırmaları Dergisi*, *6*(2), 55-61.

Keskinkaya, H. B., Deveci, E., Güneş, E., Okudan, E. Ş., Akköz, C., Gümüş, N. E., & Karakurt, S. (2022). Chemical composition, in vitro antimicrobial and antioxidant activities of

marine macroalgae Codium fragile (Suringar) Hariot. *Commagene Journal of Biology*, *6*(1), 94-104.

Keskinkaya, H. B., Deveci, E., Yılmaz Altınok, B., Gümüş, N. E. Okudan, E. Ş. Akköz, C., Karakurt, S. (2023) "HPLC-UV analysis of phenolic compounds and biological activities of Padina pavonica and Zanardinia typus marine macroalgae species," *Turkish Journal of Botany*: Vol. 47: No. 3, Article 6. https://doi.org/10.55730/1300-008X.2761

Kolsi, R. B. A., Salah, H. B., Jardak, N., Chaaben, R., Jribi, I., El Feki, A., ... & Belghith, K. (2017). Sulphated polysaccharide isolated from *Sargassum vulgare*: Characterization and hypolipidemic effects. *Carbohydrate polymers*, *170*, 148-159.

Kraan, S. (2013). Pigments and minor compounds in algae. In Functional ingredients from algae for foods and nutraceuticals (pp. 205-251). Woodhead Publishing. DOI: 10.1533/9780857098689.1.205

Lee, R.E. (2008). Phycology. Cambridge University Press, 614 pp.

Lee, J. H., & Kim, G. H. (2015). Evaluation of antioxidant activity of marine algae-extracts from Korea. *Journal of Aquatic Food Product Technology*, *24*(3), 227-240.

Lima-Filho, J.V.M., Carvalho, A.F., Freitas, S.M., & Melo, V.M. (2002). Antibacterial activity of extracts of six macroalgae from the northeastern Brazilian coast. *Brazilian Journal of Microbiology*, 33, 311-314. https://doi.org/10.1590/S1517-8382200200040000

McCormick, P.V. & Cairns, J. (1994). Algae as indicators of environmental change. Journal of Applied Phycology, 6(5), 509-526.

Mekinic, I.G., Skroza, D., Šimat, V., Hamed, I., Cagalj, M., & Perkovic, Z.P. (2019). Phenolic content of brown algae (Pheophyceae) species: extraction, identification, and quantification. Biomolecules, 9, 244. http://doi.org/10.3390/biom9060244

Moreau, J., Pesando, D., Bernard, P., Caram, B., & Pionnat, J. C. (1988). Seasonal variations in the production of antifungal substances by some dictyotales (brown algae) from the French Mediterranean coast. *Hydrobiologia*, 162(2), 157-162.

Moss, B. (2010). Ecology of fresh waters: a view for the twenty-first century. John Wiley & Sons, 480 pp.

Park, Y.K., Koo, M.H., Ikegaki, M., & Contado, J.L. (1997). Comparison of the flavonoid aglycone contents of Apis mellifera propolis from various regions of Brazil. Brazilian Archives of Biology and Technology, 40, 97-106.

Perez-Perez, G. I., Taylor, D. N., Bodhidatta, L., Wongsrichanalai, J., Baze, W. B., Dunn, B. E., ... & Blaser, M. J. (1990). Seroprevalence of Helicobacter pylori infections in Thailand. *Journal of Infectious Diseases*, 161(6), 1237-1241.

Rodrı´guez-Bernaldo de Quiro´s, A., Frecha-Ferreiro,S., Vidal-Pe´rez, A.M, Lo´pez-Herna´ndez,J.,(2010). Antioxidant compounds in edible brown seaweeds, Eur Food Res Technol 231:495–498.

Schoenwaelder, M.E.A. (2002). The occurrence and cellular significance of physodes in brown algae. Phycologia, 41, 125-139. https://doi.org/10.2216/i0031-8884-41-2-125.1

Silva, S., Gomes, L., Leitao, F., Coelho, A. V., & Boas, L. V. (2006). Phenolic compounds and antioxidant activity of Olea europaea L. fruits and leaves. *Food science and technology international*, *12*(5), 385-395.

Slinkard, K., & Singleton, V.L. (1977). Total phenol analyses: Automation and comparison with manual methods. American Journal of Enology and Viticulture, 28, 49-55. https://doi.org/10.5344/ajev.1977.28.1.49

Souza, B.W., Cerqueira, M.A., Martins, J.T., Quintas, M.A., Ferreira, A.C., Teixeira, J.A. & Vicente, A.A. (2011). Antioxidant potential of two red seaweeds from the Brazilian coasts. Journal of Agricultural and Food Chemistry, 59(10), 5589- 5594. DOI: 10.1021/jf200999n

Tungmunnithum, D., Thongboonyou, A., Pholboon, A., & Yangsabai, A. (2018). Flavonoids and Other Phenolic Compounds from Medicinal Plants for Pharmaceutical and Medical Aspects: An Overview. *Medicines (Basel, Switzerland)*, *5*(3), 93. https://doi.org/10.3390/medicines5030093

Yoldaş, M.A., Katırcıoğlu, H. ve Beyatlı, Y. (2003). Investigation of Poly-β-hydroxybutyrate (PHB) Production and Antimicrobial Activities of Some Blue-Green Algae (Cyanophyta- Cyanobacteria). *E.Ü.* J*ournal of Fisheries* 20.467-471.

CHAPTER 9

ADVANCES IN RESEARCH ON MEDICINAL AND AROMATIC PLANTS OF THE LAMIACEAE FAMILY USING MOLECULAR MARKER TECHNIQUES

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1. INTRODUCTION

Since ancient times, people have used plants not only for food and feed, but also for medicine and for scenting and flavoring purposes. Today, the medicines obtained from plants in different ways are widely used. Throughout history, people have relied on these plants for treating ailments and satisfying various needs. Of the 250,000 plant species documented worldwide, more than 80,000 are utilized for their medicinal benefits. These plants are essential not only for traditional medicine and the herbal industry but also play a significant role in supporting the livelihoods and health of millions of people globally (Jain, 1968; Uritu et al., 2018). The Lamiaceae family comprises a diverse range of plants, including annual and perennial herbs, shrubs and occasionally, woody species (Raja, 2012). It commonly known as the mint family includes a diverse range of aromatic herbs and plants. The Lamiaceae includes more than 245 genera and 7886 species, found across the globe (Kahraman et al., 2009; Selvi et al., 2022) Turkey serves as a vital gene center for the Lamiaceae family, featuring approximately 574 species within 45 genera. This positions it as the third most diverse plant family in the country (Kahraman et al., 2009). This family thrives in regions influenced by the Mediterranean climate (Celep and Dirmenci 2017; Xu et al., 2017), including Southwest Asia, the tropical areas of Australia and China, the Mexican region of North America, and the coastal regions of Chile. Many members of this family are valued for their aromatic qualities and are utilized in various fields, such as culinary, medicinal and ornamental uses. Common examples include mint, basil, oregano, and sage, all of which are not only important in cooking but also have recognized health benefits (Sadeghi et al.,2014; Bendif, 2021). The Lamiaceae family is highly valuable economically, with many of its plants cultivated as ornamental varieties or spices. Also, plants belonging to the *Lamiaceae* family are recognized for its medicinal properties, commonly utilized in both pharmacy and traditional medicine due to its richness in essential oils, aromatic compounds and secondary metabolites (Baser, 1992).

1. Some Important Plants in the Lamiaceae Family

Sage (*Salvia officinalis* L.)

Salvia officinalis is a perennial herb and it is among the most significant plant in the Lamiaceae family. Medicinal sage, known for its historical use, has been utilized since ancient times for various purposes. It finds applications in cooking, pharmaceuticals, perfumery and cosmetics, highlighting its versatility and importance in different industries.

Mint (*Mentha* spp.)

Mint (*Mentha*) is a perennial herb classified among medicinal and aromatic plants. It is highly valued for its essential oils, particularly menthol and tannins. Mint essential oil is classified as valuable oil and is used to treat various health conditions. Moreover, it plays a significant role in the food industry, as well as in medicine and cosmetics, reflecting its diverse applications and importance (Gupta, 2023).

Lavender (*Lavandula angustifolia*)

Lavender is a perennial plant species of flowering plant in the *Lamiaceae* family. It is cultivated for its fresh flowers, dried arrangements, and a range of other applications (Petkova et al., 2018). It is a well-known plant prized for its essential oils. The essential oil is widely used in the perfume and cosmetics sectors. Additionally, it is used in traditional and complementary medicine for its antidepressant, antiseptic, and analgesic effects, offering therapeutic benefits for a range of ailments (Karakaş and İzci, 2024).

2. Biotechnological Methods and Molecular Markers in the *Lamiaceae* Family

Plant breeding can be defined as the process of consciously changing and developing the genetic structure of economically valuable plant genera, species and varieties in line with the demands of producers and consumers, using genetic and cytogenetic information (Yorgancılar et al., 2015). For many years, it has been desired to improve the characteristics of plants through plant breeding, and in this process, efforts have been made to increase the yield, disease resistance, quality and adaptation abilities of plants by taking into account genetic, environmental and agronomic factors. Breeding of medicinal and aromatic plants has a great potential for both agricultural economy and health sector. Applications cover a wide range from traditional methods to modern biotechnological methods. As the research and development of various species in cultivation and breeding advance, the number of registered varieties is expected to rise. This increase will meet the growing demand for standardized production materials among diverse manufacturers, thereby facilitating improved standards and quality in production (Karık and Tunçtürk, 2019). Conventional breeding has played a key role in improving crop yields, yet many challenges persist that must be addressed to enhance plant productivity and adopt strategies for sustainable agricultural practices (Bakhsh, 2021). The time-consuming nature of conventional breeding processes and the possibility of not obtaining the desired characteristics are considered as its disadvantages (Pank, 2007). Breeding studies in the Lamiaceae family are of great importance both economically and ecologically. The new varieties developed increase the competitiveness in the agricultural sector and respond better to consumer demands. However, combining conventional methods with modern techniques can improve product varieties and increase plant productivity.

Biotechnology is defined as the branch of science and technology in which living organisms or biological systems derived from them are used to produce products or services. Biotechnology forms around utilizing living organisms or their molecular components, like cells, enzymes, and proteins, to design new products or enhance existing processes (Bentahar et al., 2023). Plant biotechnology is a technological process carried out at the molecular level and using cell and tissue culture methods to increase the yield and quality of plants and to reduce or eliminate the effects of diseases, pests and stress factors (Onay et al., 2012). Molecular biology studies, which gained momentum with the studies on the structure of DNA and the discovery of PCR, have gained a different dimension as techniques that complement and support classical plant breeding programs. Today, molecular markers are one of the most frequently used biotechnological methods that complement classical plant breeding programs.

Molecular markers are specific DNA fragments within the genome that are utilized in molecular biology to recognize and analyze unknown DNA sequences. Molecular marker systems are based on the detection of polymorphic regions in the DNA molecule. A gene or phenotypic trait is considered polymorphic if more than one form of that gene or trait is present in a population.

Polymorphism can occur at various levels, in the form of different variants of DNA sequence, amino acid sequence, chromosomal structure or phenotypic traits. Markers are found in all tissues, remain stable regardless of environmental influences, can be either codominant or dominant, and follow simple patterns of inheritance (Williams et al., 1990). Markers are considered effective for the selection of plant materials in breeding studies because they are numerous and can be easily observed at any stage of plant development (Ovesna, 2002). Currently, a wide range of molecular markers are used in molecular studies (Karakaş and Bayrıl, 2024).

RFLP (Restriction Fragment Length Polymorphism) is the oldest marker system based on hybridization. PCR-based markers, such as RAPD (Random Amplified Polymorphic DNA), AFLP (Amplified Fragment Length Polymorphism), SSR (Simple Sequence Repeats), ISSR (Inter Simple Sequence Repeats), SNP (Single Nucleotide Polymorphism), and SRAP (Sequence-Related Amplified Polymorphism), are frequently employed in plant molecular studies. RFLP is marker first and the most used technique that based on hybridization. This method uses restriction enzymes to cut specific regions of the DNA and then analyzes the length differences of these cut fragments. RFLP is frequently used in population and species genetic diversity and phylogenetic studies (Desplanque et al.,1999; Nadeem et al., 2018). Polymerase chain reaction (PCR) was developed by Kary B. Mullis to amplifying DNA in vitro based on enzymatic amplification (Mullis et al., 1986). With PCR, the amplification of a specific DNA fragment is possible millions of times through a sequence of enzymatic reactions. In time, a development of PCR research has made it a cornerstone in molecular marker technology and has led to the creation of numerous PCR-based markers. The RAPD is the first PCR-based marker system that based on random DNA fragment amplification using synthetic primers (usually 10 bases long) (Williams et al., 1990). RAPD analysis is simple and no sequence information is required to use the technique. Genetic diversity and population analyzes are the main usage area of RAPD markers because of its quick detection of polymorphism (Tonk et al. 2010).

AFLP is PCR- based marker system between RAPD and RFLP method. In AFLP, DNA fragments of 80–500 bp, which are digested with restriction enzymes, are ligated with adapters, two consecutive PCR reactions are carried out using selective primers in these reactions (Vos et al., 1995). Because of it is effective in evaluating intercultural variations or kinship degrees it is preferred in genetic diversity studies in plants. It provides an advantage to the researcher with its highly reproducible feature and being a rapid method in determining polymorphisms (Aykut, 2007; Filiz and Koç, 2011). SSR markers are known as microsatellite. In SSR marker system, if the flanking region is known, PCR is performed by designing primers suitable for those regions (usually 20–25 bp in length). The high levels of polymorphism and repeatability make them particularly advantageous for analyzing genetic diversity (Jones et al., 1997; Aykut, 2007). The ISSR technique employs primers with repeated nucleotide motifs to amplify the DNA between two microsatellites (Zietkiewicz et al., 1994). It provides high sensitivity and the ability to rapidly determine genetic diversity (Tonk et al. 2014). SRAP is a PCR-based molecular marker technique that amplifies gene-associated regions to detect polymorphisms. It provides the advantage of detecting genetic diversity with high resolution and is used in determining genetic relationships between plant species (Salazar et al., 2014). The selection of the marker to be used in plant breeding studies shall be made according to the desired features of the marker. In this context, the comparison of the properties of molecular markers is given in the Table 1. (Nadeem et al., 2018).

Table 1. Comparison of generally used molecular markers (Nadeem et al. 2018)

Characteristics	RFLP	RAPD	AFLP	SSR	ISSR	Retrotransposons
Codominant/ Dominant	Codominant	Dominant	Dominant	Dominant	Codominant	Dominant
Reproducibility	High	High	Intermediate	High	High	High
Polymorphism Level	Medium	High	High	High	High	High
Cost	High	Less	High	High	High	Cheapest
Sequencing	Yes	No	No	Yes	No	No
PCR Requirement	No	Yes	Yes	Yes	Yes	Yes
Visualization	Radioactive	Agarose Gel	Agarose Gel	Agarose Gel	Agarose Gel	Agarose Gel
Required DNA (ng)	10000	20	50-1000	50	50	25-50
Status	Past	Past	Past	Present	Present	Present

The fact that markers are fast and low cost makes them preferred especially in large-scale breeding studies. The reproducibility of molecular markers is also of great importance; this feature allows reliable results to be obtained in different laboratories and time periods. In addition, some markers show inter-species transferability, allowing genetic analyses to be spread over a wider range. These features allow molecular markers to be used as an effective tool in plant breeding (Bayrıl et al., 2023) to evaluate genetic diversity, select desired traits such as disease resistance or productivity, and rapidly develop new plant varieties (Mondini, 2009; Agarwal et al., 2008). Molecular markers are used to detect genetic variations in plants (Karakaş, 2024) and play an active role in selecting important traits such as agricultural productivity, disease resistance, and drought tolerance. With methods such as genetic mapping and marker-assisted selection (MAS), plants with the desired genetic traits can be produced more quickly, while losses due to harmful environmental effects or diseases can be minimized. In addition, marker technologies contribute to the development of more productive, durable, and high-quality plant varieties by enabling the emergence of traits in plants that cannot be obtained with traditional breeding methods (Appleby et al., 2009; Nadeem et al. 2018).

3. Molecular Marker Studies in Sage (*Salvia officinalis* L.)

Molecular marker studies in *Salvia officinalis* L. have become an essential tool for understanding the genetic diversity, improving breeding programs, and enhancing the selection of desirable traits in this medicinal plant. Various molecular marker techniques, such as RAPD, SSR, and AFLP, have been employed to analyze the genetic variation within sage populations (Table 2). These studies have helped identify genetic markers linked to important agronomic and medicinal traits, including antioxidant properties, essential oil composition, and disease resistance. Molecular markers have also facilitated the development of genetic maps, which are valuable for marker-

assisted selection (MAS) in sage breeding programs. Furthermore, these markers enable the assessment of genetic relationships between different sage cultivars, aiding in the conservation of genetic resources and the identification of genetically superior lines. Overall, molecular marker studies in *Salvia officinalis* L. can be crucial for improving both the quality and productivity of this valuable plant in a more efficient and precise manner (Karaca and İnce, 2017).

Table 2. Molecular Marker Studies in Sage (*Salvia officinalis* L.)

Scope of Application	Marker	Number of used primers	Polymorphism	References
Genetic diversity	RAPD	8 primers	50.84%	Liber et al., 2014
Genetic and chemical diversity	RAPD	39 primers	57.2%	Boszormenyi et al., 2009
DNA fingerprinting and essential oil profiling	AFLP	4 primers	50.6%	Rapposelli et al., 2015
Genetic diversity and population structure	SSR	6 primers	89%	Bahadirli and Ayanoglu, 2021
Genetic diversity and metabolic profile	ISSR	6 primers	51.26%	Sarrou et al., 2017
Genetic diversity	SRAP	32 primers	96%	Aghaei et al., 2017
Genetic diversity	SRAP	18 primers	90.91%	Çardaklı et al., 2017

4. Molecular Marker Studies in Mint (*Mentha* spp.)

Molecular marker studies in mint (*Mentha* spp.) are important areas of research that help scientists understand the genetic diversity, evolutionary relationships, and potential applications for improving mint species. Mint species exhibit considerable genetic diversity, and molecular markers, such as RAPD, SSR, AFLP, and SNPs, are commonly used to assess this variability, enabling the identification of distinct populations and species (Table 3). These marker systems also key in species authentication, preventing adulteration in essential oil production, and in developing high-quality cultivars. Beyond improving agronomic traits, these markers are used in phylogenetic studies to explore the genetic relationships between different mint species. These studies can not only enhance agricultural practices but also ensure the sustainability and profitability of mint cultivation globally (Dhawan, 2016).

Table 3. Molecular Marker Studies in Mint (*Mentha* spp.)

Scope of application	Marker	Number of used primers	Polymorphism	References
Genetic diversity and genetic similarity	RAPD	60 primers	93.5%	Khanuja et al., 2000
Genetic diversity	AFLP	3 primers	55.83%	Gobert et al., 2002
Genetic diversity	RAPD and ISSR	15 RAPD and 9 ISSR	99.03% 100%	Panjeshahin et al., 2018
Genetic diversity and population structure	SSR	12 primers	-	Fukui et al., 2022
Genetic diversity	ISSR	24 primers	90.5%	Roshanibakhsh et al., 2023
Molecular characterization	ISSR	23 primers	100%	Çelik et al., 2024

5. Molecular Marker Studies in Lavender (*Lavandula angustifolia*)

Molecular marker studies are an important tool for examining the genetic diversity of lavender, its biotechnological potential and its resistance to various diseases. The studies conducted offer great potential especially in areas such as the evaluation of genetic diversity, determination of resistance to diseases and pests, improvement of chemical contents and development of new varieties. Molecular markers used to determine genetic diversity (such as AFLP, SSR, RAPD and SRAP) help to understand interspecific relationships by revealing the differences between lavender species. Molecular markers also help to identify lavender plants that are naturally resistant to diseases and pests, allowing the development of more resistant and productive species (Ibrahim et al., 2017). All these studies pave the way for biotechnological applications of lavender plants and can also provide great advantages in gaining desired characteristics through genetic engineering (Table 4).

Table 4. Molecular Marker Studies in Lavender (*Lavandula angustifolia*)

Scope of application	Marker	Number of used primers	Polymorphism	Referans
Genetic diversity	RAPD	6	95.8%	Al-Qahtani., 2023
Genetic diversity	RAPD	20	68.19%	Hnia et al., 2013
Genetic diversity	SRAP	51	77.2%	Zagorcheva et al., 2020
Molecular characterization	ISSR	11	100%	Hmissi et al., 2024
Genetic stability	RAPD and ISSR	2 RAPD and 5 ISSR	85.4% and 63.02%	Babanina et al., 2023

6. CONCLUSION

Molecular marker techniques have become indispensable in contemporary plant research, agricultural development, and crop breeding. These studies involve the use of molecular markers, to identify genetic variation within and between plant populations. Recognizing how genetic variation distributes across the populations is essential for both plant breeding and conservation. In plant breeding, this knowledge is the foundation for developing and selecting plant genotypes that exhibit desired traits, such as disease resistance or higher yield. By identifying genetic diversity, breeders can select the most suitable genetic material to improve crops or create new plant varieties. At the same time, understanding the levels and distribution of genetic variation also provides insights into the historical processes that shaped that diversity. Overall, molecular marker studies not only contribute to a deeper understanding of Lamiaceae genetic makeup but also can facilitate the development of improved cultivars, better management practices, and enhanced quality.

REFERENCES

Agarwal, M., Shrivastava, N., & Padh, H. (2008). Advances in molecular marker techniques and their applications in plant sciences. *Plant cell reports*, *27*, 617-631.

Aghaei, Z., Talebi, M., & Rahimmalek, M. (2017). Assessment of genetic diversity within and among sage (*Salvia*) species using SRAP markers. *Plant Genetic Resources*, *15*(3), 279-282.

Al-Qahtani, K. A., & Al-Ghamdi, F. A. (2023). An Overview of Techniques Used for The Molecular Identification of Genus *Lavandula* L.Advances in Environmental Biology, 17(6): 8-14.

Appleby, N., Edwards, D., & Batley, J. (2009). New technologies for ultra-high throughput genotyping in plants. *Plant genomics: methods and protocols*, 19-39.

Aykut, F. (2007). Researches on molecular markers related to brown rust resistance genes in wheat. Ege University Institute of Science Doctoral Thesis. Bornova-İzmir.

Babanina, S. S., Yegorova, N. A., Stavtseva, I. V., & Abdurashitov, S. F. (2023). Genetic stability of lavender (*Lavandula angustifolia* Mill.) plants obtained during long-term clonal micropropagation. *Russian Agricultural Sciences*, *49*(2), 132-139.

Bahadirli, N. P., & Ayanoglu, F. (2021). Genetic diversity of Salvia species from Turkey assessed by microsatellite markers. *Journal of Applied Research on Medicinal and Aromatic Plants*, *20*, 100281.

Bakhsh, A., Sırel, I. A., Kaya, R. B., Ataman, I. H., Tillaboeva, S., Dönmez, B. A., ... & Duru, E. (2021). Contribution of Genetically Modified Crops in Agricultural Production: Success Stories. In *Policy Issues in Genetically Modified Crops* (pp. 111-142). Academic Press.

Baser, K. H. C. (1992, July). Essential oils of Anatolian Labiatae: a profile. In *WOCMAP I-Medicinal and Aromatic Plants Conference: part 1 of 4 333* (pp. 217-238).

Bayrıl, B. Y., Bakhsh, A., Nadeem, M. A., & Demirel, U. (2023). Elucidating the genetic diversity and population structure of international Cotton germplasm using iPBS Retrotransposon Marker System.

Bendıf, H. H. (2021). Phytochemical constituents of Lamiaceae family. *RHAZES: Green and Applied Chemistry*, *11*, 71-88.

BENTAHAR, S., ABADA, R., & Nadia, P. Y. Biotechnology: Definitions, types and main applications. *Ymer, 22 (4), 563, 575*.

Boszormenyi, A., Hethelyi, E., Farkas, A., Horvath, G., Papp, N., Lemberkovics, E., & Szoke, E. (2009). Chemical and genetic relationships among sage (*Salvia officinalis* L.) cultivars and Judean sage (*Salvia judaica* Boiss.). *Journal of agricultural and food chemistry*, *57*(11), 4663-4667.

Çardaklı, E., Bardak, A., & Özdemir, M. (2017). Determination of Genetic Diversity of Some Sage Species Collected From Eastern Mediterranean Region, *Turkish Journal Of Agriculture-Food Science And Technology*, *5*(6), 695-700.

Celep, F., & Dirmenci, T. (2017). Systematic and biogeographic overview of Lamiaceae in Turkey. *Natural Volatiles and Essential Oils*, *4*(4), 14-27.

Çelik, C., Seraj, N. A., Yasak, S., Karakurt, Y., Telci, İ., & Sevindik, E. (2024). Molecular Characterization and Genetic Relationships in Different Mint (Mentha L.) Species with ISSR Marker Technique. *Biology Bulletin*, 1-10.

Desplanque, B., Boudry, P., Broomberg, K., Saumitou-Laprade, P., Cuguen, J., & Van Dijk, H. (1999). Genetic diversity and gene flow between wild, cultivated and weedy forms of *Beta vulgaris* L.(Chenopodiaceae), assessed by RFLP and microsatellite markers. *Theoretical and Applied Genetics*, *98*, 1194-1201.

Dhawan, S. S. (2016). Role of molecular markers in assessing genetic diversity in mentha: a review. *Scientific Journal of Genetics and Gene Therapy*, *2*(1), 022-026.

Filiz, E., & Koç, İ. (2011). Bitki biyoteknolojisinde moleküler markörler. *Journal of Agricultural Faculty of Gaziosmanpaşa University (JAFAG)*, *2011*(2).

Fukui, Y., Saito, M., Nakamura, N., Mizuno, T., Sato, S., Tsukuda, M., ... & Kubo, N. (2022). Classification of Southeast Asian mints (*Mentha* spp.) based on simple sequence repeat markers. *Breeding Science*, *72*(2), 181-187.

Gobert, V., Moja, S., Colson, M., & Taberlet, P. (2002). Hybridization in the section *Mentha* (Lamiaceae) inferred from AFLP markers. *American Journal of Botany*, *89*(12), 2017-2023.

Gupta, S., Kumar, A., Gupta, A. K., Jnanesha, A. C., Talha, M., Srivastava, A., & Lal, R. K. (2023). Industrial mint crop revolution, new opportunities, and novel cultivation ambitions: A review. *Ecological Genetics and Genomics*, *27*, 100174.

Hmissi, S., Chograni, H., Yangui, I., Riahi, L., Boussaid, M., & Messaoud, C. (2024). Genetic diversity and population structure patterns in *Lavandula stoechas* L. wild germplasms using ISSR and EST-SSRs markers and implications for conservation. *Genetic Resources and Crop Evolution*, *71*(6), 2859-2876.

Hnia, C., Yosr, Z., & Mohamed, B. (2013). Genetic diversity of natural Tunisian *Lavandula multifida* L.(Lamiaceae) populations assessed by allozymes and random amplification of polymorphic DNA (RAPD). *African Journal of Biotechnology*, *12*(7).

Ibrahim, H., Salama, A. M., & Abou El-Leel, O. F. (2017). Analysis of genetic diversity of Lavandula species using taxonomic, essential oil and molecular genetic markers. *Sciences*, *7*(01), 141-154.

Jain, S. K. (1968). *Medicinal plants* (pp. 1-216). National Book Trust, India.

Kahraman, A., Celep, F., & Dogan, M. (2009). Morphology, anatomy and palynology of *Salvia indica* L.(Labiatae). *World Applied Sciences Journal*, *6*(2), 289-296.

Karaca, M., & Ince, A. G. (2017). Molecular markers in Salvia L.: past, present and future. *Salvia biotechnology*, 291-398.

Karakaş, İ. and Bayrıl, B. (2024). From Classical Selection to Marker Assisted Selection in Plant Breeding: Mas Approaches, *New Studies in Agriculture, Forestry and Water Sciences*, Chapter 5, Editor: Assoc. Prof. Dr. Burcu Tuncer, Duvar Publishing, p. 90. (in Turkish).

Karakaş, İ. (2024). Molecular Marker Techniques and Genotypic Characterization Approaches in Plant Breeding. *Turkish Journal of Agriculture-Food Science and Technology*, *12*(8), 1487-1498.

Karakaş, İ., & İzci, B. (2024). Effects of Rooting Mediums and Growth Regulating Agents on Rooting Parameters of Lavender and Lavandin Cuttings (*Lavandula* sp.). *Journal of Agricultural Production*, *5*(3), 138-152.

Karık, Ü., & Tunçtürk, M. (2019). Production, trade and future perspective of medicinal and aromatic plants in Turkey.

Khanuja, S. P. S., Shasany, A. K., Srivastava, A., & Kumar, S. (2000). Assessment of genetic relationships in Mentha species. *Euphytica*, *111*, 121-125.

Liber, Z., Židovec, V., Bogdanović, S., Radosavljević, I., Pruša, M., Filipović, M., ... & Šatović, Z. (2014). Genetic diversity of dalmatian sage (*Salvia officinalis* L.) as assessed by RAPD markers. *Agriculturae Conspectus Scientificus*, *79*(2), 77-84.

Mondini, L., Noorani, A., & Pagnotta, M. A. (2009). Assessing plant genetic diversity by molecular tools. *Diversity*, *1*(1), 19-35.

Mullis, K., Faloona, F., Scharf, S., Saiki, R., Horn, G., & Erlich, H. (1986, January). Specific enzymatic amplification of DNA in vitro: the polymerase chain reaction. In *Cold Spring Harbor symposia on quantitative biology* (Vol. 51, pp. 263-273). Cold Spring Harbor Laboratory Press.

Nadeem, M. A., Nawaz, M. A., Shahid, M. Q., Doğan, Y., Comertpay, G., Yıldız, M., ... & Baloch, F. S. (2018). DNA molecular markers in plant breeding: current status and recent advancements in genomic selection and genome editing. *Biotechnology & Biotechnological Equipment*, *32*(2), 261-285.

Onay, A., Yıldırım, H., Pirinç, V., Tilkat, E., Çiftçi, Y. Ö., Akdemir, H., ... & Kılınç, F. M. (2012). Commercial propagation of plants by biotechnological methods; current and future status. Batman University Journal of Life Sciences,, *1*(2), 11-28.

Ovesna, J., Poláková, K. & Leišová, L. (2002). DNA analyses and their applications in plant breeding. *Czech Journal of Genetics and Plant Breeding*, *38*(1), 29-40.

Panjeshahin, Z., Sharifi-Sirchi, G. R., & Samsampour, D. (2018). Genetic and morphological diversity of wild mint. *Journal of Medicinal plants and By-Products*, *7*(1), 105-115.

Pank, F. (2007). Use of breeding to customise characteristics of medicinal and aromatic plants to postharvest processing requirements. *Stewart Postharvest Rev*, *4*(1).

Petkova, M., Tahsin, N., Yancheva, S., & Yancheva, H. (2018, April). Development of the production ofaromatic oil crops in Bulgaria. In *China-Bulgaria Rural Revitalization Development Cooperation Forum* (p. 71).

Raja, R. R. (2012). Medicinally Potential Plants of Labiatae (Lamiaceae) Family: An. *Research journal of medicinal plant*, *6*(3), 203-213.

Rapposelli, E., Melito, S., Barmina, G. G., Foddai, M., Azara, E., & Scarpa, G. M. (2015). AFLP fingerprinting and essential oil profiling of cultivated and wild populations of Sardinian *Salvia desoleana*. *Genetic resources and crop evolution*, *62*, 959-970.

Roshanibakhsh, F., Samsampour, D., Askari Seyahooei, M., & Bagheri, A. (2023). Strong relationship between molecular and morphological attributes in Iranian mentha populations (*Mentha mozaffarianii* Jamzad). *Genetic Resources and Crop Evolution*, *70*(6), 1721-1745.

Sadeghi, Z., Akaberi, M., & Valizadeh, J. (2014). *Otostegia persica* (Lamiaceae): A review on its ethnopharmacology, phytochemistry, and pharmacology. *Avicenna journal of phytomedicine*, *4*(2), 79.

Salazar, J. A., Rasouli, M., Moghaddam, R. F., Zamani, Z., Imani, A., & Martínez-Gómez, P. (2014). Low-cost strategies for development of molecular markers linked to agronomic traits in Prunus. *Agricultural Sciences*, *2014*.

Sarrou, E., Ganopoulos, I., Xanthopoulou, A., Masuero, D., Martens, S., Madesis, P., ... & Chatzopoulou, P. (2017). Genetic diversity and metabolic profile of *Salvia officinalis* populations: implications for advanced breeding strategies. *Planta*, *246*, 201-215.

Selvi, S., Polat, R., Çakilcioğlu, U., Celep, F., Dirmenci, T., & Ertuğ, Z. F. (2022). An ethnobotanical review on medicinal plants of the Lamiaceae family in Turkey. *Turkish Journal of Botany*, *46*(4), 283-332.

Tonk, F. A., Yüce, S., Bayram, E., Akçali Giachino, R. R., Sönmez, Ç., Telci, I., & Furan, M. A. (2010). Chemical and genetic variability of selected Turkish oregano (*Origanum onites* L.) clones. *Plant systematics and evolution*, *288*, 157-165.

Tonk, F. A., Tosun, M., Ilker, E., Istipliler, D., & Tatar, O. (2014). Evaluation and comparison of ISSR and RAPD markers for assessment of genetic diversity in triticale genotypes. *Bulgarian Journal of Agricultural Science*, *20*(6), 1413-1420.

Uritu, C. M., Mihai, C. T., Stanciu, G. D., Dodi, G., Alexa-Stratulat, T., Luca, A., ... & Tamba, B. I. (2018). Medicinal plants of the family Lamiaceae in pain therapy: A review. *Pain Research and Management*, *2018*(1), 7801543.

Vos, P., Hogers, R., Bleeker, M., Reijans, M., Lee, T. V. D., Hornes, M., ... & Zabeau, M. (1995). AFLP: a new technique for DNA fingerprinting. *Nucleic acids research*, *23*(21), 4407-4414.

Williams, J. G., Kubelik, A. R., Livak, K. J., Rafalski, J. A., & Tingey, S. V. (1990). DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nucleic acids research*, *18*(22), 6531-6535.

Xu, Z., Chang, L., Xu, Z., & Chang, L. (2017). Lamiaceae. *Identification and Control of Common Weeds: Volume 3*, 181-265.

Yorgancılar, M., Yakışır, E., & Erkoyuncu, M. T. (2015). The Use of Molecular Markers in Plant Breeding. Bahri Dağdaş Journal of Crop Research, *4*(2), 1-12.

Zagorcheva, T., Stanev, S., Rusanov, K., & Atanassov, I. (2020). SRAP markers for genetic diversity assessment of lavender (*Lavandula angustifolia* mill.) varieties and breeding lines. *Biotechnology & Biotechnological Equipment*, *34*(1), 303-308.

Zietkiewicz, E., Rafalski, A., & Labuda, D. (1994). Genome fingerprinting by simple sequence repeat (SSR)-anchored polymerase chain reaction amplification. *Genomics*, *20*(2), 176-183.

CHAPTER 10

FEASIBILITY ANALYSIS FOR ZERO ENERGY CONSUMPTION EDUCATIONAL BUILDINGS WITH HOMER SOFTWARE

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I. INTRODUCTION

Global warming occurs because of the accumulation of greenhouse gases in the atmosphere that are emission of fossil fuels powered plants and automotives, is seen as one of the most fundamental reasons for changing climate conditions today. Reducing the use of fossil fuels is among the primary requirements to reduce the effects of global warming. Due to the increase in energy demand, consumption of fossil fuels should be reduced and power supply systems should turn to renewable energy sources. Electricity production with renewable energy systems prevents greenhouse gas emissions and slows down global warming. However, many renewable energy sources are not continuous (solar radiation, wind speed, etc.). For this reason, the best option is to use different types of renewable energy systems together for continuous and reliable electricity production. In the literature, in recent years, there have been studies conducted on modeling renewable energy systems to meet the energy demand of buildings and building communities, especially campus areas using different software tools.

Hadi Taghavifar and Zahra Sadat Zomorodian (Hadi Taghavifar, 2021) analyzed grid-connected PV/wind and PV/wind/generator systems of an educational building located in Malayer City, Iran, in order to sell back the excess electricity and thus make the building economical as a source of income, from a techno-economic perspective using Homer pro and DesignBuilder software. In the first scenario, the net present cost (NPC) was $49,022, the renewable energy ratio (RF) was 85.5% and the cost of energy (COE) was $0.0024 at a 10% inflation rate. In the second scenario, for the most suitable design, NPC was $224,430, COE was $0.0272, RF was 63.6%. as a results of the study, PV/wind combination was decided as the most economical and ecological design in the first scenario with a payback period of 4.5 years.

Saba Arif and friends (Saba Arif, 2021), designed a hybrid zero energy building (ZEB) using Homer software and measuring climate data for one year to obtain an optimized grid-connected hybrid net zero energy shopping mall for Thailand and Pakistan. The proposed hybrid microgrid is composed of photovoltaic (PV) modules and converters. As a result, by adapting the ZEB system, the electricity unit price was reduced, and the system was 9.5% more profitable for Thailand and 7.1% more profitable for Pakistan. It was observed that the study was economical and had a payback period of 1.84 years in Thailand and 2.66 years in Pakistan.

Vasileios Sougkakis and friends (Vasileios Sougkakis, 2020) carried out the feasibility study of developing a newly built positive energy consumption community (PECC) area in Alexandroupolis, Greece and adapting an existing area to the performance levels of nearly zero energy consumption communities (nZECC). The main objective of the study was to adapt Greece to these building communities by developing PECC and nZECC. The newly built PECC settlement consists of 100 two-storey detached houses. The nZECC includes 95 terraced and intermediate terraced houses. In both cases, grid-connected renewable energy sources such as PV, geothermal heat pumps were used, and analyses were performed in RETScreen Expert and EnergyPLAN programs. The results showed that zero and nearly zero emission targets were met with various combinations applying insulation levels according to building regulations or slightly higher, and considering renewable energy production more widely. Finally, the feasibility study concluded that the payback period for a newly constructed PECC varies between 12.5 and 12.9 years, while the payback period for a nZECC varies between 9.7 and 12.2 years.

Laetitia Uwineza and friends (Laetitia Uwineza, 2021) conducted feasibility analysis of integrating HRES supported with a diesel generator on the Popova Island near Vladivostok using HOMER and Monte Carlo analytical model. The model consists of off-grid PV, diesel generator, wind turbine and batteries. Physical properties and meteorological year data were

utilized for calculations. The results show that the LCOE (levelized cost of electricity, $/kWh) calculations in HOMER are too optimistic. The results of the research concluded that Popova Island should be encouraged to use a hybrid system with different renewable energy technologies. This will reduce the heavy dependence on diesel generators alone, reduce electricity costs and minimize greenhouse gas emissions.

Charafeddine Mokhtara and friends (Charafeddine Mokhtara, 2021) analyzed and simulated an educational building using Ecotect, ArcGIS, HOMER programs in order to contribute to reducing grid dependency, CO_2 emissions and the being effected by grid outages in the building. Three buildings were located on a university campus in the Ouargla province of Algeria. As a result of the study, installing PV panels on only 60% of the total roof area was found to result in an annual electricity production of 2,333 MWh/year. It was observed that in rooftop installations, shading effects can significantly reduce the potential of PV systems. Finally, it was concluded that battery-free systems are a technically and economically viable solution for educational buildings.

Bharosh Kumar Yadav and friends (Bharosh Kumar Yadav, 2021) conducted an analysis for the installation of a grid-connected PV power plant to meet 100% energy demand of the campus using potential areas within the Purwanchal Campus of the Institute of Engineering, Tribhuvan University. The capacity and system performance of the PV power plant were estimated using PVSYST V7.0 software. For the study, daily, monthly and annual electricity consumption and solar radiation data of the campus for the past years were obtained. The simulation results show that there is a PV power potential of 110 kWp. The designed PV system has a total capacity of producing 181.5 MWh/year annual electricity and the campus's energy consumption was 161 MWh/year. Daytime energy demand met by PV was 66.4 MWh/year. The result also shows that the 115.1 MWh/year excess energy generated from the PV power plant can be injected into the grid to provide significant savings in grid costs. Finally, it was concluded that the lifetime of the project will be 20 years starting from 2021.

Moriarty P. and Honnery D. (Moriarty & Honnery, 2020) aimed to examine whether the world is fully supplied with renewable energy (RE) at the current state or at higher global energy levels and then to examine whether this scenario is feasible. In the current study, wind, solar energy, hydro, geothermal and biomass were investigated for RE future. However, as a result of the research, it was concluded that hydro, geothermal and biomass energies are more limited than solar and wind energy and that the use of wind and solar energies would be suitable for RE future. Considering the severity of climate change and other global environmental challenges, it was concluded that the world should rely heavily on renewable energy sources (RES) in 2050.

Ahmad F. Tazay and friends (Tazay, 2021) aimed to meet the energy demand of an educational building located in Baha University in the Kingdom of Saudi Arabia by using RES such as PV, wind and hydrogen fuel energy. In this study, real time monthly load data, climate data and available area for RES installation data are utilized for system analysis. In this study, three optimization techniques were applied to obtain the optimal dimensioning of the HRES which were cultural algorithm (CA), JAYA algorithm and particle swarm optimization (PSO) algorithm. Simulation results were obtained using MATLAB R2019 software tool. Autonomous HRES composed of three different technologies (PV, Wind and Hydrogen fuel) was analyzed to transmit electrical energy to a remote area of Baha University. It was found that 84%, 11% and 5% of the energy produced by HRES was provided by PV, wind turbines and hydrogen fuel system, respectively. Sensitivity analysis and simulation results showed that hydrogen energy system is less economic and ecological for HRES compared to other sources.

M. M. Fouad and friends (M.M. Fouad, 2020) simulated a net zero energy consumption community (NZECC) with 52 buildings and 8 different designs and compared it with a conventional community in Egypt. In this comparison, PV and wind turbine were analyzed using DesignBuilder and EnergyPlus software to simulate the two communities. The results showed that all buildings in NZECC achieved the zero energy target and the load was met entirely by RES. The net site energy of NZECC was 57.6% lower than the conventional community, equivalent to 51 million kWh/a. NZECC decreased CO_2 emissions 390 tons per year compared to the conventional community. It was observed that the payback period of different scenarios varied between 1-11 years, proving the feasibility of the proposed NZECC.

Loiy Al-Ghussain and friends (Loiy Al-Ghussain, 2021) evaluated the optimal grid-connected HRES (PV/wind/biomass) with and without energy storage, for the Middle East Technical University Northern Cyprus Campus located in Güzelyurt, Northern Cyprus. The Generalized Reduced Gradient algorithm was used in this study to evaluate the capacities of the optimal components of the proposed system. The optimal system was composed of 1.79 MW PV, 2 MW wind and 0.92 MW biomass systems with 24.39 MWh pumped hydro storage system and 148.64 kWh batteries providing 99.59% efficiency and the electricity cost was calculated as 0.1626 $/kWh. Simulation results showed that the integration of a hybrid energy storage system with a PV/wind/biomass system provides high autonomy. It was proven that the use of the system with energy storage is more optimal.

In these studies, HRES designed using one or two RES in buildings on campus areas, with the help of software tools such as Ecotect, ArcGIS, HOMER, PVSYST, Design Builder, EnergyPlus, RETScreen Expert and Energy PLAN. In this study, hourly electricity load of a building on campus was measured. Then, optimal grid-connected HRES (PV panels, wind turbines and biomass) was designed using HOMER software tool.

2. MATERIAL AND METHODS

In this study, firstly hourly electricity consumption data of educational building is gathered. Then economic data such as electricity purchase and sell price are collected. Then renewable energy systems are selected. Finally, optimum HRES has been for the selected building via HOMER software.

Data on Buildings

Within the scope of the “Selçuk University Smart and Green Campus Application” project, energy analyzers were installed in buildings with internet lines on the campus. Hourly electricity consumption data of the buildings were obtained from these analyzers. Data about the geometry and the physical characteristics of the buildings were obtained from the Department of Construction Works of the Selcuk University.

Hourly wind speed, solar radiation, air pressure and air temperature data for Konya province were obtained from the internet. The hourly Typical Meteorological Years (TMY) weather data set of Konya is obtained which was a mixture of last 15 years (2006-2021) (Crawley & Lawrie, 2022).

Data on Renewable Energy Systems

The following RES were used as energy sources in the study.

1- Solar energy

2- Wind energy

3- Biomass

In this study, the selected HYES components were decided according to the components in the HOMER software database. In the decision process, the usability and efficiency of the devices were taken into consideration. The selected PV, RT and biomass features are given in Table 1, Table 2 and Table 3.

A 345 W power panel available in the HOMER database was selected as the PV panel in this study. The technical features of the selected panel are given in Table 1.

Table 1. Technical specifications of PV used in the study

HYES elements	**Features**	**Values**
PV	Nominal power (Ppv)	257 W
	Efficiency (ηpv)	17.4 %
	Maximum Power-PMAX	345 Wp
	Maximum Power Voltage-VMPP	38.2 Volt
	Maximum Power Current-IMPP	9.04 Ampere
	PV area	1.984 m2
	Operating temperature	-40~+85°C
	Nominal Operating Cell Temperature	44°C (±2°C)
	Ambient temperature under standard test conditions	25 °C
	Temperature Coefficient (Pmax)	- 0.39 %/°C
	Life	25 years

In this study, a Generic model wind turbine was used in the simulations to be made for Konya with the HOMER program. This is a high-performance turbine that is available in the HOMER database and is also used in some wind power plants in Turkey. The characteristics of the RT are given in Table 2.

Table 2. Technical specifications of the RT used in the study.

HYES element	**Features**	**Values**
Wind turbine	Model	Generic
	Rotor diameter	3.9 m
	Max. Central peak	9 m
	Rated power	3 kW
	Circulating wind speed	2.5, m/s
	Life	25 years

In this study, the Generic model, biogas fuel type biomass system was used in the simulations to be made for Konya with the HOMER program. The technical specifications of the system used are given in Table 3.

Table 3. Technical specifications of the biomass system used in the study

HYES element	Features	Values
Biomass	Model	Generic
	Fuel type	Biogas
	Low heating value	5.5 MJ/kg
	Density	0.720 kg/m^3
	Carbon content	5 %
	Life	15 years

Environmental Data

To calculate the reduction in CO_2 emissions due to electricity savings achieved with design models, the distribution of Türkiye's electricity production in 2022 by primary energy type and the specific emission factors were used. The CO_2 emission factor from Türkiye's electricity production in 2022 was calculated as 0.325 kg CO_2/kWh (Chamber of Electrical Engineers of Turkey, 2021)**.**

HOMER Software

The HOMER software tool was used to create the campus's energy consumption model in the study. HOMER is a tool that compares RES powered electricity generation technologies and applications, evaluating the LCOE of design taking into account the physical behaviors and life cycle cost of power systems. HOMER was developed by the National Renewable Energy Laboratory (NREL) in the United States and then became a commercial product under Homer Energy and was offered to the sector. HOMER can combine many different RES in the same system and determine the system where these resources can be used together optimally thanks to certain inputs. The program can model grid-connected or stand-alone systems using any combination of biomass, PV, wind turbine, small sized hydroelectric plants, generators, accumulator, and hydrogen storage options.

HOMER basically performs three tasks: simulation, optimization, and sensitivity analysis. In the simulation method, Homer simulates the operation of a system by performing energy balance calculations at every time interval of the year and compares the electrical and thermal demand at that time step with the energy that the system can generate at that time step for each time step. In the optimization phase, HOMER simulates various HRES systems to find and model the design that will provide the lowest life cycle cost. In the sensitivity analysis process, HOMER performs multiple optimization processes to determine the effects of changes or uncertainties in various input data. In the optimization phase, the user determines the optimum values of variable components. In the sensitivity analysis, the effects of unknown variables such as regional wind speed and future fuel prices are determined.

3. RESULTS AND DISCUSSION

Within the scope of the “Selcuk University Smart and Green Campus Application” carried out on the Selcuk University campus, energy analyzers have been installed in 52 locations with internet lines on the campus. With these analyzers, the hourly electricity consumption of the buildings is measured, and the measured data is stored. The analyzers installed on the buildings are shown in Figure 1.

Figure 1. Modem and energy analyzer

In this study, electricity consumption data of the one Faculty building was used. The average electricity consumption of the faculty for each hour of the day is given separately for weekdays and weekends in Figure 2.

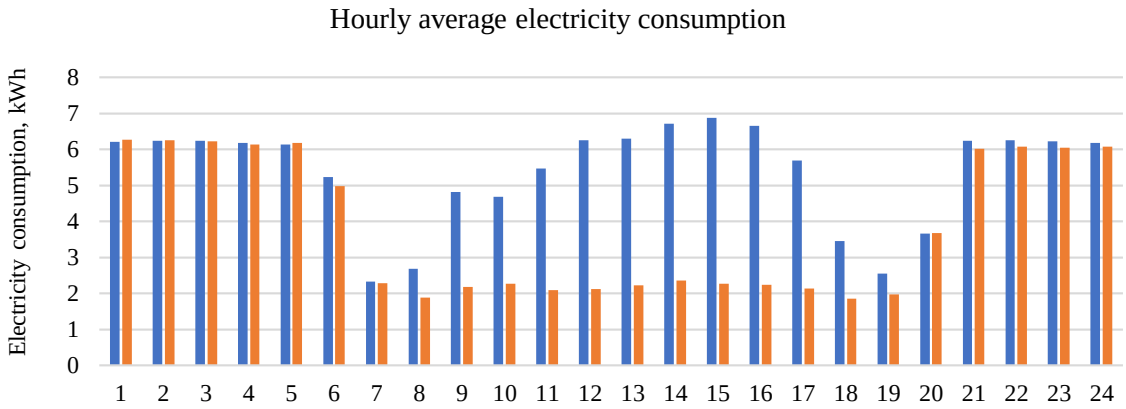


Figure 2. Average hourly electricity consumption of the Faculty of Technology (Blue lines: Weekday, Orange lines: Weekend)

As seen in Figure 2, electricity consumption varies significantly during weekdays and weekends. This detail has a significant impact on the designed system. For this reason, in many studies, hourly data was not used and the models developed were not economical enough. At the same time, the change in hourly electricity consumption also has significant effect on the

HRES design. Hourly energy consumption during the day influences the optimization of the designed system due to the hourly change of solar radiation and wind speed.

The optimum design developed was modeled as grid-connected PV/wind/biomass, as seen in Figure 3. According to 2022 data for the designed system, the cost of electricity purchased from the grid was uploaded to the HOMER Pro program was 1.76 TL/kW; the cost of electricity sold to the grid was 1.37 TL/kW.

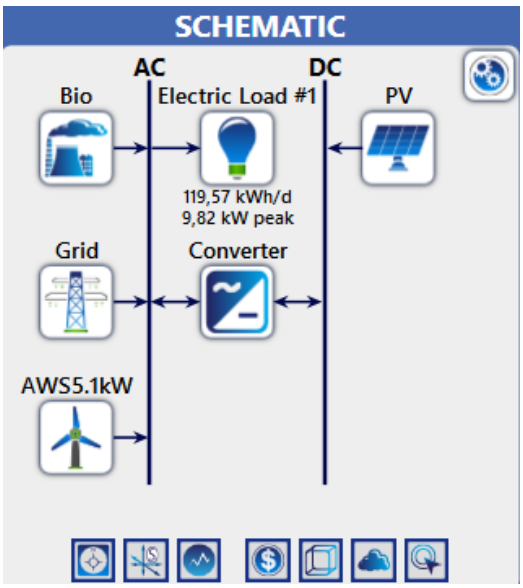
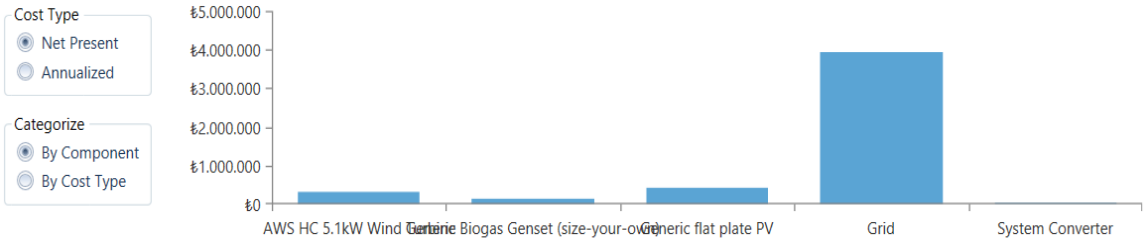


Figure 3. Energy system model designed for the Faculty of Technology

The simulation results of the system designed to be connected to the grid in the HOMER Pro program are given in Figure 4-6.



Component	Capital (₺)	Replacement (₺)	O&M (₺)	Fuel (₺)	Salvage (₺)	Total (₺)
AWS HC 5.1kW Wind Turbine	₺308.846,85	₺0,00	₺27.147,78	₺0,00	₺0,00	₺335.994,63
Generic Biogas Genset (size-your-own)	₺180.000,00	₺0,00	₺20,68	₺10.563,63	-₺34.323,85	₺156.260,46
Generic flat plate PV	₺421.123,50	₺0,00	₺11.634,76	₺0,00	₺0,00	₺432.758,26
Grid	₺0,00	₺0,00	₺3.923.676,82	₺0,00	₺0,00	₺3.923.676,82
System Converter	₺23.533,01	₺2.667,26	₺0,00	₺0,00	-₺502,01	₺25.698,26
System	₺933.503,36	₺2.667,26	₺3.962.480,05	₺10.563,63	-₺34.825,85	₺4.874.388,44

Figure 4. Cost values of the grid-connected hybrid energy system

While the cost values of the grid-connected system were examined, the net present cost of the system was calculated as 4,874,388 TL (Figure 4).

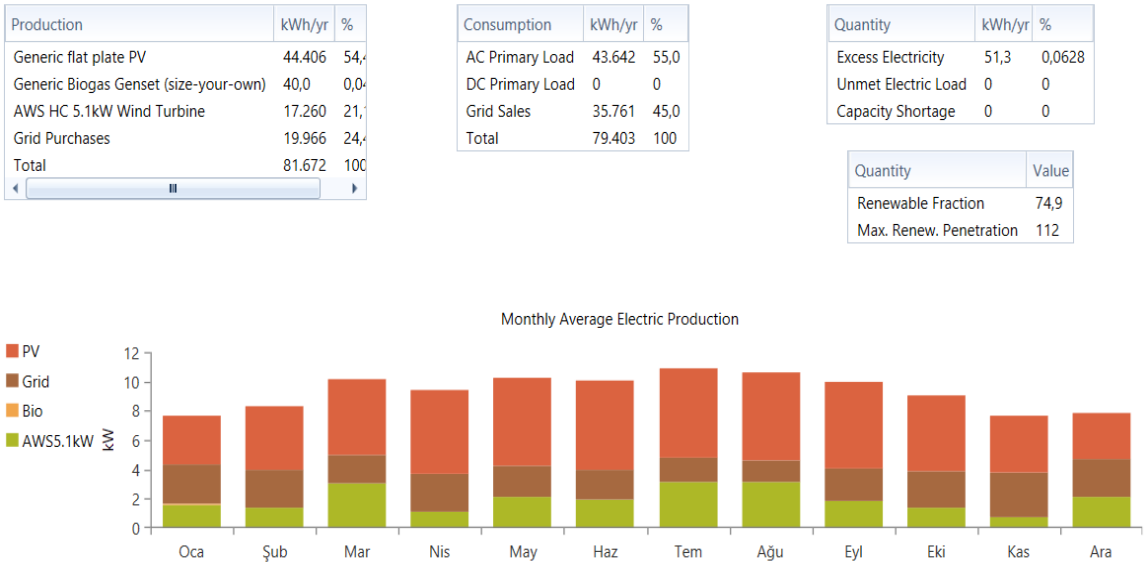


Figure 5. Electricity production in the grid-connected system

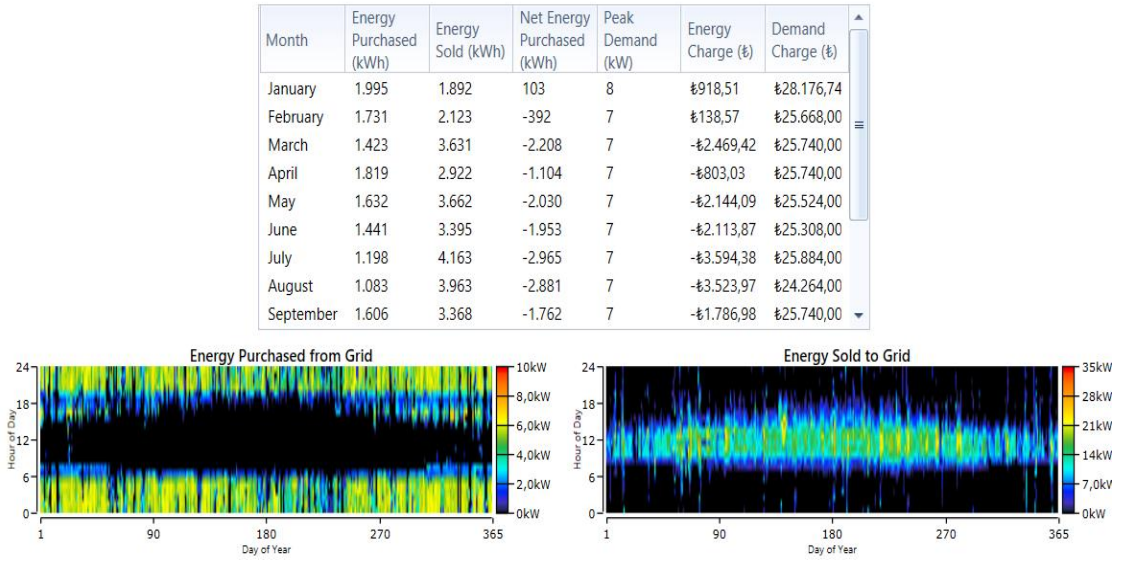


Figure 6. Energy received from and given to the grid

In the study, the optimum system capacity required for the building to produce as much energy as it consumes annually, the LCOE values of the optimum system required, and the renewable share (RS) are given in Table 4.

Table 4. System capacity, LCOE and RF

	System capacity, LCOE and RF	Values
PV+WT+BIO	PV	11,7 kW
	WT	24 kW
	BIO	0,8 kW
	LCOE	0,08 $/kW
	RF	64 %

As seen in Table 1, because of the combined use of renewable energy sources such as photovoltaic panel (PV), wind turbine (WT) and biomass (BIO), the electricity cost (LCOE) was 0.08 and the renewable ratio (RR) value was 64%.

4. CONCLUSION

In this study, a HRES design to achieve net zero-energy consumption building target was carried out using renewable energy systems such as PV, wind turbine and biomass for an educational building located in a campus. In the implemented design, the levelized cost of electricity (LCOE) was found to as 0.08 $/kW and the renewable share (RS) was found to as 64 %. As the RS decreases, the purchased electricity increases, and consequently LCOE increases. This study proves the importance of using hourly electricity consumption data in HRES design due to the hourly change of renewable sources such as solar radiation and wind velocity.

REFERENCES

Bharosh Kumar Yadav, P. K. (2021). Sustainable green campus in NEPAL: 3E analysis. *International Journal of Low-Carbon Technologies, 16*(2), 531–542. doi:https://doi.org/10.1093/ijlct/ctaa088

Chamber of Electrical Engineers of Turkey. (2021, 12 19). *Turkey Electricity Statistics FEBRUARY 2021*. Retrieved from https://www.emo.org.tr/ekler/095e69ae7d0338f_ek.pdf?tipi=41&turu=X&sube=0

Charafeddine Mokhtara, B. N. (2021). Optimal design of grid-connected rooftop PV systems: An overview and a new approach with application to educational buildings in arid climates. *Sustainable Energy Technologies and Assessments, 47*(ISSN 2213-1388), 101468. doi:https://doi.org/10.1016/j.seta.2021.101468

Crawley, D., & Lawrie, L. (2022, 8 14). *Climate.OneBuilding.Org.* Retrieved from http://climate.onebuilding.org/default.html

Hadi Taghavifar, Z. S. (2021). Techno-economic viability of on grid micro-hybrid PV/wind/Gen system for an educational building in Iran,. *Renewable and Sustainable Energy Reviews, 143*(ISSN 1364-0321), 110877. doi:https://doi.org/10.1016/j.rser.2021.110877.

Laetitia Uwineza, H.-G. K. (2021). Feasibility study of integrating the renewable energy system in Popova Island using the Monte Carlo model and HOMER. *Energy Strategy Reviews, 33*(ISSN 2211-467X), 100607. doi:https://doi.org/10.1016/j.esr.2020.100607

Loiy Al-Ghussain, A. D. (2021). An integrated photovoltaic/wind/biomass and hybrid energy storage systems towards 100% renewable energy microgrids in university campuses. *Sustainable Energy Technologies and Assessments, Volume 46*(ISSN 2213-1388), 101273. Retrieved from https://www.sciencedirect.com/science/article/pii/S2213138821002836?casa_token=Oo-s5TBmUbwAAAAA:k04-drw1b5B0uvNQPHanbqwEfwnAhsbCJDg9xYxe29_QvW9GYlZNFZ4ErzN3uIbXNIcZ9NLbQ6I

M.M. Fouad, J. I. (2020). Energy, carbon and cost analysis for an innovative zero energy community design. *Solar Energy, Volume 206*,(ISSN 0038-092X,), 245-255. doi:https://doi.org/10.1016/j.solener.2020.05.048.

Moriarty, P., & Honnery, D. (2020). Feasibility of a 100% Global Renewable. *Energies, 13*(Issue 21), 5543. doi:10.3390/en13215543

Saba Arif, J. T. (2021). Feasibility study and economic analysis of grid connected solar powered net zero energy building (NZEB) of shopping mall for two different climates of Pakistan and Thailand,. *Case Studies in Thermal Engineering,, 26*(ISSN 2214-157X), 101049. doi:https://doi.org/10.1016/j.csite.2021.101049.

Tazay, A. (2021). Techno-Economic Feasibility Analysis of a Hybrid Renewable Energy Supply Options for University Buildings in Saudi Arabia. *Open Engineering, 11*(1), 39-55. doi:https://doi.org/10.1515/eng-2021-0005

Vasileios Sougkakis, K. L. (2020). An Investigation on the Feasibility of Near-Zero and Positive Energy Communities in the Greek Context. *Smart Cities, 3*(Issue 2), 362-384. doi:10.3390/smartcities3020019

CHAPTER 11

SOLAR COLLECTOR USAGE AND CALCULATION OF YIELD ANALYSIS IN KONYA PROVINCE

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1. INTRODUCTION

Energy is an indispensable need of human beings as an indicator of economic and social development. The concept of energy and the sustainability of energy resources have been one of the most important issues and problems of the world from past to present. Energy is vital for technological production and development, as well as being a factor in increasing the quality of life (Beji, 2020). Factors such as the rapid consumption of energy resources, the unconscious use of non-renewable resources such as oil, coal, nuclear energy, and the pollution caused by these resources to the environment and the atmosphere have led people to use renewable energy sources(Ağı and Günerhan, 2003).

Use of renewable energy; It is an option that increases diversity in energy sources, can replace declining fossil resources, reduces foreign dependency on fossil fuels because it is domestic, is important in providing electricity in rural areas, and will provide solutions to air pollution-greenhouse gas problems by using fossil fuels instead (Shafieian and Khiadani, 2020). Energy consumption, which is one of the most important needs of highly developed countries, is constantly increasing and this increase will continue in the future (Nurula et.al., (2020). We have to consume energy directly and indirectly in order for the technological developments we have today to continue and the opportunities they offer to continue in our lives (Yiğit, 2010). Today, most of the energy we have to consume is met from fossil fuels, and the rest is met from nuclear and renewable energy sources (Şahin, 2010). The damage caused by the use of fossil fuels on the environment and human health all over the world, and if precautions are not taken, it will be inevitable that the price to be paid by people who will live in the future to compensate for these damages will reach very large dimensions (Bakanlık, 2012).

As seen in Figure 1.1, Türkiye is in a very fortunate position compared to many countries in terms of solar energy potential (Taşova, 2018). Our country is far ahead of other countries in terms of its geographical location and has an advantage in terms of energy The sun sends about 170 million MW of energy per second to the earth. According to many academic and scientific researches; It is said that the solar energy coming to our world per second is 1700 times the annual energy production of our country (Varınca ande Gönüllü, 2006), (Kılıç, 2018).

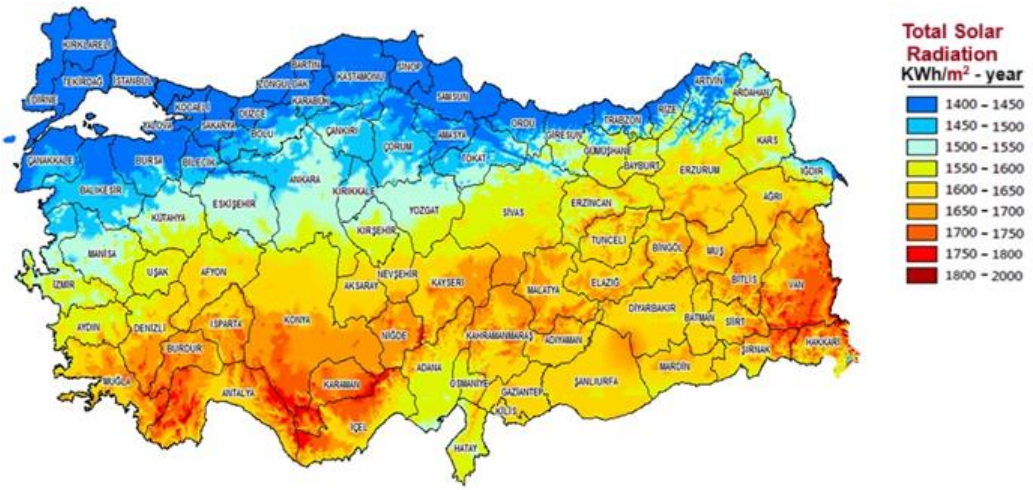

Figure 1.1. Solar energy atlas of Turkey (Taşova, 2018)

The energy need in the world is increasing by approximately 4-5% every year. On the other hand, the fossil fuel reserves that meet this need are decreasing much faster. Even the most optimistic forecasts show that in the next 50 years, oil reserves will be largely depleted and will not be able to meet the need (Binark and Deliçay, 1993). A similar situation exists for coal and natural gas in the long run. In addition, the use of fossil fuels has increased the world's

average temperature, causing a noticeable increase in natural disasters such as floods and storms, which cause billions of dollars in damage, as well as intense air pollution. For this reason, human beings have to turn to renewable energy sources without waiting for fossil fuel reserves to run out (Nwaji et al., 2020).

Although our country has a very high energy potential of 110 days on average, the necessary solar energy will be provided if the necessary and appropriate investments are made and implemented. Thus, we will make solar energy, which our country is lucky to be lucky due to its geographical location, more efficient. In this context, Konya province has many advantages in energy production with solar collectors, especially in terms of the angle of the sun coming to the region and geographical conditions. The developing industry and the energy needs of the people of the region with solar collectors provide both economic and environmental benefits for the people of the region, especially for natüre (Altıntop et al, 1997).

In this study, the gain from energy by using alternative energy source (solar energy) in Konya climatic conditions was examined. The earnings that can be obtained by making solar collector calculations have been determined.

2. SOLAR COLLECTOR

Solar collectors are devices of various types and forms that collect solar energy and transfer it as heat to a fluid. Solar energy collectors are used in air conditioning from solar energy and hot water production applications. Solar collectors are placed at a fixed angle so that they receive the sun to the maximum depending on the latitude of the region. Temperatures up to 100°C can be reached. The heat generated is transferred to heating devices such as underfloor heating, wall heating, radiators, fan coils through other devices (Özsoy and Galip, 2019), (Valladares and Yudonago, 2020).

Today, solar collectors are used in homes both to meet the need for hot water and to be used for heating purposes. These systems are:

a) Natural Circulation Systems,

b) Pumped Systems,

c) Open Systems,

d) Closed Systems

It can be grouped into four groups.

a) Natural Circulation Systems: Natural circulation systems are systems in which the heat transfer fluid circulates spontaneously. It is based on the property that the density of the heated water in the collectors decreases and rises. In such systems, the tank is higher than the upper level of the collector.

b) Pumped Systems: These are the systems in which the heat transfer fluid is circulated by a pump in the system. The warehouse does not have to be above.

c) Open Systems: These are the systems in which the domestic water and the water circulating in the collectors are the same. Compared to closed systems, their efficiency is high and the cost is cheaper. They are used in areas where the water is lime-free and there are no freezing problems.

d) Closed Systems: These are systems in which domestic water and heating water are different. The water heated in the collectors transfers its heat to the domestic water by means

of a heat exchanger. They are used as a solution against freezing, scaling and corrosion. Their cost is higher than open systems and their efficiency is lower due to the heat exchanger (TSE, 2008), (Özsoy and Galip, 2019).

2.1. Planar Solar Collectors

This type of planar absorbs some of the solar energy and transmits this energy to the liquid in the collector as heat. They consist of transparent cover, absorber surface, fluid pipes, thermal insulation and collector casing. Some of the sun's rays are reflected from the transparent cover, and some of them are absorbed in the transparent cover. When the incoming rays reach the absorber surface, they are absorbed at different rates according to the characteristics of the absorber surface, and the absorbed energy is sent to the tank with the help of fluid pipes.

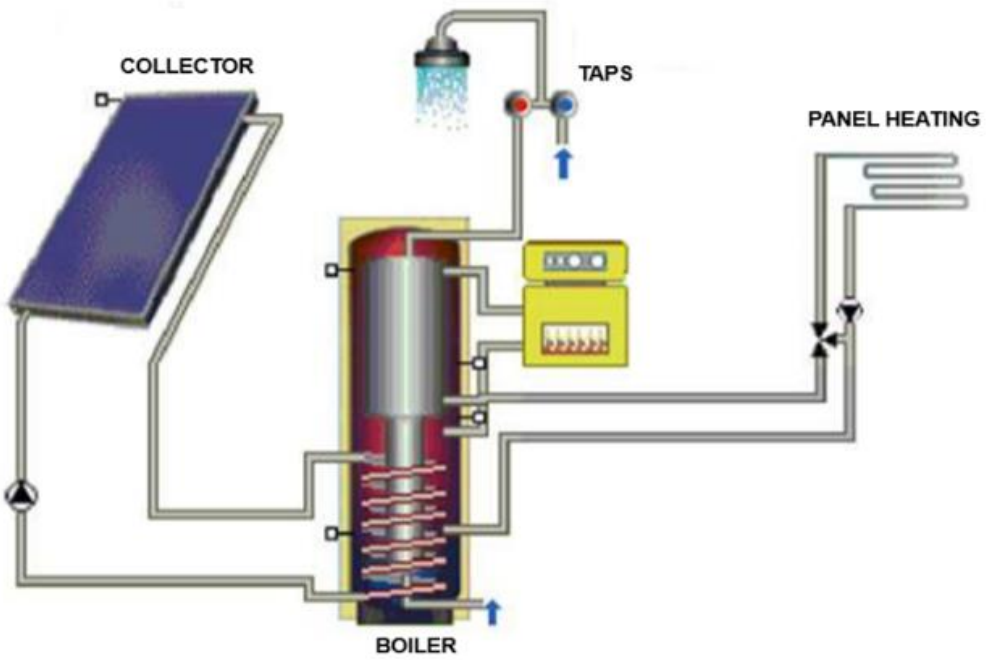

Figure 2.1. Equipment of Planar Solar Collector System (Özdoğan, 2018)

As seen in Figure 2.1, The purpose of the transparent cover is to protect the absorber surface and prevent heat loss. At the same time, it should be permeable to the sun's rays. Glass or plastic wrap is used as a material. The main purpose of the absorber surface is to absorb the sun's rays and transmit this energy to the fluid pipes. The main purpose of thermal insulation is to prevent heat loss, there will be a difference between the heating of the collector and the ambient temperature, and this causes heat loss (Özdoğan, 2018). Fluid pipes transfer the energy absorbed by the absorbing surface to the liquid in them, allowing the heated liquid to be sent to the tank. Various materials such as aluminum, stainless steel, galvanized steel and plastic are used as collector casings. (Değirmencioğlu and İlken, 2003).

2.2. Solar Collector Working Principle

While some of the solar energy coming on the transparent cover is reflected and goes to the environment, the other part comes on the absorbing surface. Most of the radiation incident on the absorber surface is absorbed by the absorber surface, and some of it is reflected towards the transparent cover as long wavelength radiation. Some of this radiation, which is reflected on the transparent cover, is reflected back on the absorber surface, and some of it passes through the transparent cover and goes to the environment. The heated absorber transmits most of the surface energy to the heat carrier fluid. Some of it is also spread from the case to the

environment by conduction and convection. When water is used as a heat carrier fluid, the cost of absorber plates is higher. There are many different types of collectors that work using water. Corrosion and freezing are two important issues to consider in collectors that use water. Since normal tap water is highly corrosive, some precautions should be taken against corrosion. Any metal must be used under certain conditions.

While the water used in the system with antifreeze prevents saturation and thus the damages that may occur from freezing, antifreeze also brings water-specific problems, and antifreeze water brings some additional costs to the system. When water with antifreeze is used, there is a necessity to use a heat exchanger in the system. Because we cannot use water with antifreeze directly. Thus, the circuit of antifreeze water and potable water is separated from each other. Using a heat exchanger slightly reduces the efficiency of the system. Glycol, which is used as an antifreeze agent, has a corrosion effect by forming glycolic acid at high temperature. Therefore, high temperatures should not be reached (Aytaç et al.,2023).

In liquid collectors, some fluids other than water can be used as heat carrier fluid. Some properties to look for in fluids other than water are high ignition and boiling point temperature, low freezing temperature and no corrosion effect. In liquid collectors, the flow channels cannot cover the entire surface of the absorber plate. Therefore, heat reaches the fluid through conduction through the absorbing plate. Heat carrier pipes are placed at intervals on the absorber plate. The absorber plate surfaces between the pipes serve as wings attached to the pipes. Heat is transferred from these channels to the pipes, and the pipes transfer the liquid (usually water) in them. Copper and aluminum, which have high thermal conductivity and are not affected by corrosion, are a good absorber plate material (Saxena and Gaur, 2020).

Pipe spacing on the absorber plate varies depending on the fin efficiency and pipe cost. The absorber surface is generally about 0.5 mm thick when copper is used and the distance between the copper pipes is 10-15 cm. Blade efficiency can be up to 97%. Figure 2.2 shows the structure of the Planar Solar Collector (Chong and Wong, 2009).

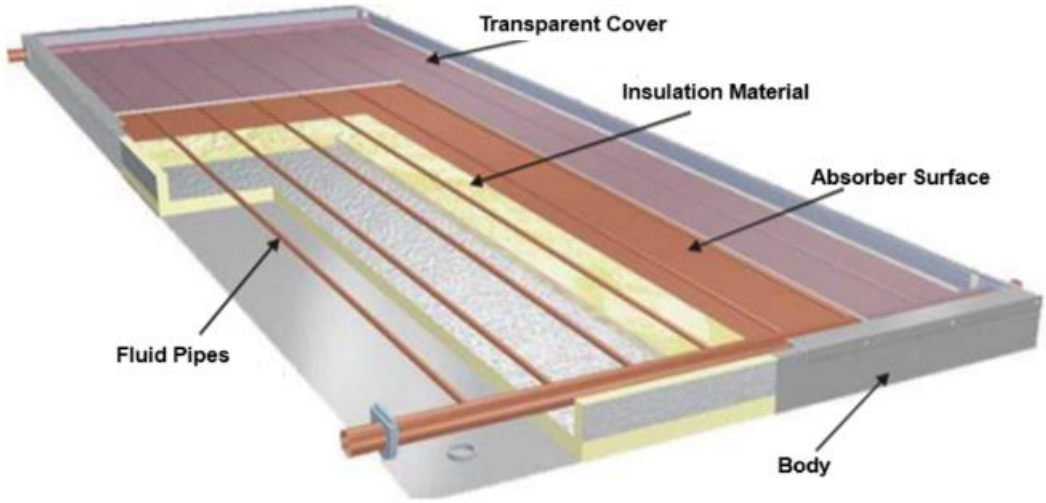

Figure 2.2. Structure of Planar Solar Collector (Chong and Wong, 2009)

2.2.1. Transparent Cover

The main task of the transparent cover is to reduce the heat loss from the collector to the environment and to protect the absorbing surface from external factors such as rain, hail and

dust. The radiation from the sun is of short wavelength, while the radiation reflected and emitted from the absorbing surface is of long wavelength. From this surface, the transparent cover; It is desirable that the rate of transmitting short-wavelength radiation is large, and the rate of transmitting long-wavelength radiation emitted from the absorber plate is small. In addition, the cover material used should have a high permeability rate, and the absorption and reflection rates should be minimal (Ağrı ve Günerhan, 2003)

Features required from transparent cover;

1) It must transmit most of the sun's radiation

2) It should not transmit heat radiation with long wavelength

3) It should not change shape due to temperature

4) Must withstand temperature of at least 100oC

5) It should not be easily broken, corroded and scratched.

6) It should not decompose from ultraviolet radiation over time

7) It should be light and inexpensive

2.2.1.1. Glasses

Glasses transmit most of the short-wavelength solar radiation between 0.3 μm and 3 μm. The permeability rates of long-wavelength (3 μm to 50 μm) radiation emitted from the absorber surface are low. It is resistant to abrasion and scratching. Due to these properties, glasses are widely used as transparent covers. The drawback of glasses is that they are fragile and heavy compared to plastic-based covers.

Glass transmits 85-90% of the visible part of sunlight that falls on it. The remaining part is swallowed by the glass during the passage of light through the glass. The amount of light absorbed depends on the iron oxide (Fe2O3) content of the glass. With the increase in iron content, the amount of light absorbed also increases. This reduces the total radiation transmission rate of the glasses. For this reason, those with a Fe2O3 ratio less than 0.0005 should be preferred. Window panes are above this rate. Therefore, the glasses to be used as transparent covers in solar collectors must be specially manufactured. The cut parts of the window panes appear green, this is because the glass contains too much iron oxide. In addition, it affects the radiation transmission rate of the glasses in the reflection at the interface. To reduce this reflectivity, the upper surface should be coated very thinly with materials such as Teflon with a small refractive index. In order to reduce the long-wavelength radiation losses from the absorber surface to the environment, it is necessary to cover the inner surface of the glass with infrared radiation reflectors. These are materials such as metal oxide and tin oxide films (Saxena and Gaur, 2020).

The application is mostly used in low iron oxide tempreli and pyrismatic glasses. The reason why it is tempered is so that when it breaks, it does not break into pieces like a sword and cause injuries. The reason why the glasses are prismatic is to reduce the reflection rate of the rays coming on them.

Apart from the optical properties of transparent cover materials, their mechanical properties should also be tested. Its resistance to hail damage and snow load must be determined. In areas with high amounts of snowfall, there should be a minimum slope angle of 30^{o}. Transparent covers are used to reduce convection losses from the absorber surface to the environment. Therefore, in cold climatic regions, it is necessary to use two transparent covers

instead of one. When two transparent covers are used, the transport losses to the environment are reduced, but the absorption multiplier is reduced. Therefore, a good analysis should be made and two transparent covers should be used (Devan et al., 2020).

2.2.1.2. Plastic Covers

Plastic covers are made of actual, teflon, poly-carbonate, glass-reinforced plastic-based materials. The most widely known is plexsig. Plastic covers have a low rate of permeability to solar radiation, they are high like iron oxide glasses, they are unbreakable and tipped. However, it is not preferred because of its high rate of thermal radiation reflected from the absorber, its large thermal expansion coefficient, its lack of resistance to high temperatures, its deterioration of the radiation pass rate by deteriorating over time from ultraviolet radiation and its lack of resistance to abrasion (Fudholi et al., 2010).

2.3. Absorbing Surface

It is the part that absorbs solar radiation and transmits heat to the fluid in the pipes. Copper, aluminum and steel are generally used as absorbing surface materials. Although copper and aluminum have a high thermal conductivity coefficient, they are expensive compared to steel. Steel is cheaper, but not resistant to corrosion. The manufacturing properties of the material selected as absorbers, such as soldering and welding, are also important.

Required properties of absorber materials

1) The rate of absorption of solar radiation should be high.

2) The emission rate of long-wavelength thermal radiation should be small.

3) The heat conduction coefficient should be large.

4) It must be corrosion resistant.

5) The sheet should be made thin.

6) It should be able to be processed well.

The most desired feature from the absorber surface is that the absorption rate of short-wavelength radiations is large, and the long-wavelength thermal radiation emission rates are low, as stated in the figure below. Ideal black surfaces have the highest radiation absorption rate and the highest thermal radiation emission rate (ε=1 (epsilon)). Black painted surfaces are close to the ideal black surface. Therefore, black painted surfaces are not ideal surfaces for absorber surfaces. At the end of the researches, surfaces with a high radiation absorption rate and a low thermal radiation emission rate are obtained. These surfaces are called selective surfaces. Two types of absorbing surfaces are used in their collectors.

2.3.1. Black Surfaces

Black surfaces are obtained by painting the absorber surface with sun-resistant matte black paint. It is inexpensive and easy to manufacture. As mentioned above, these surfaces have a high absorption rate of short-wavelength radiation, as well as high thermal radiation patch rates (ε=0.90~0.95). Ideal black surfaces absorb all radiation from all angles at all wavelengths. Black surfaces, called non-ideal gray surfaces, reflect some of the radiation depending on the angle of incidence. As can be seen in the chart below, due to the fact that the radiation absorption coefficient of the white paint is very small and the emission coefficient is high, painting the outer surfaces of the houses white in places where the summer heat is very high reduces the heating of the houses.

2.3.2. Selective surfaces

Surfaces that absorb almost all of the short-wavelength radiation and emit very little long-wavelength radiation are called selective surfaces. A good selective surface is an ideal absorber. In recent years, selective surface has been used in most of the solar collectors. Selective surfaces are obtained by coating materials such as aluminum, steel and copper such as black nickel, black copper, black chrome. Soot is also a good selective surface, but it is difficult to coat on the surface. Coatings are made in the form of chemical baths, spraying methods or electroplating.

When the coated surfaces are examined with a microscope, it is seen that the surface is covered with pits in the order of microns. The outflow of the ray entering these pits is greatly reduced and the situation increases the absorption coefficient. Although the selective surface appears dark in color, the radiation emission rate is small because it is not actually a black surface. Generally, on selective surfaces, the ratio of the absorption coefficient to the smear coefficient (α/ε) is required to be greater than 4. In practice, when the spread rate becomes too small, the swallowing rate also decreases. Therefore, the fact that the α/ε ratio is too large does not indicate that the selective surface is very good. Today, surfaces made on copper and aluminum are used more.

The most important part of the solar collectors is the absorber surface. The yield absorber of the collector varies depending on the surface coating, geometry and the property of the material selected for the surface. Fluid channels can be formed directly in, above and below the plate by one of the processes of roll-bond, extrusion, pressing or similar processes. When using selective surfaces that are not resistant to moisture, a good seal should be provided so that rainwater does not get on the absorber surface at all. The most preferred chrome plating is selective surfaces. The angle of incidence of solar radiation affects the absorption coefficient (α). The absorption coefficient does not change greatly for values up to 60oC of the sun's angle of incidence, but at higher angles of incidence, the absorption decreases rapidly. That is, in the morning and in the evening, the swallowing coefficient is small, and in the noon hours it is high.

2.4. Heat Insulation

Glass wool, rock wool, polyurethane foam and similar insulation materials are used as insulation materials in collectors. In the case of using glass wool or rock wool, the gas output should be examined. If the necessary precautions are not taken, the gases coming out of the binding materials of mineral wool can accumulate in the transparent cover and reduce the radiation transmission rate. The insulation between the side and bottom surfaces of the case and the absorber should be taken at least 30-50 mm and 50-100 mm, respectively glass wool, 30-85 mm for polyurethane board, and at least 95 mm for polyurethane foam. In addition, a gap of 1-2 cm should be left between the absorber plate and the bottom insulation. The part facing the insulation absorber plate should be covered with aluminum foil to ensure the return of long-wavelength rays to the absorber (Wang et.al. 2019). The insulation should be covered in such a way that it is not affected by atmospheric conditions such as rain wind. The covering material of the side and bottom surfaces of the insulation should be temperature-resistant, resistant to moisture and rain, should not change shape over time, be resistant to combustion, and the coefficient of thermal conductivity should be small (Saini et al., 2020).

2.5. Collector Chassis

Various materials such as aluminum, stainless steel, galvanized steel and plastic are used as collector casings. Depending on the material used, the task design varies. Many module

collectors are made in extruded aluminum profile. Extruded aluminum profile is light weight. It has the highest possible flexibility in module dimensions. Their cost is also very low. Cases made of galvanized sheet metal or stainless steel are quite heavy. The manufacture of the casing must be sealing that will prevent the insulator from getting wet. Full sealing of the case should be ensured, especially at the collector entrances and exits. The thermal expansion of the materials used in its construction should also be taken into account.

2.6. Fluid Pipes

While most of the energy coming to the absorber surface passes to the thermal fluid pipes (useful heat), some of it is stored in the collector, and the rest goes to the environment by radiation, convection and conduction. Pipes should be attached by soldering or various welding methods so that the thermal resistance of contact with the absorber surface is very small. Pipes should be made of materials with a high coefficient of heat conduction. Copper, stainless steel and aluminum pipes are commonly used. The pipe diameter should be selected larger than 12 mm. Especially in natural circulation systems, larger diameter pipes should be used in order to have good water circulation (Veeramanikandan et al., 2021).

3. SOLAR ENERGY COLLECTOR ACCOUNT

The useful heat energy to be obtained from the solar energy system is a function of the size and quantity of the system elements. At the same time, the function varies throughout the year. In Konya, the amount of solar radiation falling on the earth during the day in January is 1.98 kcal/m² day, while this value is 5.20 kcal/m² day in April and 6.05 kcal/m² day in August. The rate of conversion of these radiations into useful energy; The type of collector is closely related to the angle and direction of inclination of the mount. In this case, the quantities of collectors required to meet monthly needs will also be different. In solar energy systems, the amount of hot water needed is expressed as the daily amount per person. Often the reference value for water temperature is 45 C. According to this value, the daily amount of hot water needed per person in residences is between 35 and 50 liters (Tezcan, 2002).

$Q= m\times Vb \times (Twater-Tcity) \times e$

$Qk=R\times F\times S\times nk$

K=Qi/QkQi: Total energy requirement per day (kcal/day)

m : Number of users (person)

Vb: Daily hot water requirement per user (liters/person.day)

City: Average temperature value of mains water (C)

Tsu: Reference value of domestic hot water consumed (C)

Qk: Useful energy consumed by the collector (kcal/day.collector)

R: Sunlight incident on the horizontal surface (kcal/m².day)

F: Correction factor according to the collector mounting tilt angle (dimensionless number)

S: Collector beam absorber net surface (m²/collector)

nk: Collector average yield value (dimensionless number)

e: Safety factor against energy losses (dimensionless number)

K: Amount of collectors needed (pcs)

Güneş kolektörlerinde emici yüzeye gelen enerji, iletim ve taşınım yoluyla çalışma akışkanına iletilmektedir. Dolayısıyla sistemlerin verim hesaplamaları yapılırken depo suyu sıcaklıkları ile verim hesaplamasına gidilmiştir.

Usable heat energy (Qu) in warehouses;
The total mass of water in the systems (ms),
The initial temperature of the water (Ti) is ,
Final temperature of water (Ts)

$$Q_u = \frac{m_s \times C_{ps} \times (T_s - T_i)}{7 \times 3600}$$

Taking into account the daily experiment time of 7 hours;
It is calculated by equality.
The solar energy (Qc) coming to the collector; collector surface area (Ac), taking into account the average solar radiation intensity $\bar{I}$ per unit surface area;

$$Q_c = \bar{I} \times A_c$$

It is calculated by equality. Efficiency is obtained by proportioning both values found to each other.

$$\eta = \frac{Q_u}{Q_c} = \frac{\frac{m_s \times c_{ps}}{7 \times 3600} \times (T_s - T_i)}{\bar{I} \times A_c}$$

In equality;
η: Performance
I: Average solar radiation intensity (kW/m^2)
Ti: Water initial temperature of the experiment (°C)
Ts: Water temperature reached at the end of the test period (°C)
Ac: Collector surface (m^2)
cps: Specific heat of heating of water (kJ/kg °C)
ms: It is given as the total mass of water (kg).
In the calculations, the number of people was 4, the unit water consumption was 500, the mains water temperature was 45 ° C, and 100% efficiency was selected as August. The panel orientation is designed as South and the horizontal tilt angle is 30° (İnce, 2016), (Özsoy and Galip, 2018).

4. DETERMINATION OF KONYA SOLAR ENERGY POTENTIAL

TR52 Level 2 Region is one of the regions with the most important potential for solar energy investments in Turkey. The total annual sunshine duration for Konya is 2902.5 hours, which is higher than the average in Turkey. With the decision announced by the Ministry of Energy and Natural Resources and published in the Official Gazette dated 08.01.2011, the regions where licenses can be granted for electricity investments from solar energy, which are

limited to a total capacity of 600 MW until the end of 2013, are specified (İnce, 2012). Investment permits were granted to a total of 27 regions, and Konya was determined as the region with the highest number of investment permits among these regions. A total of 13 substations have been determined for Konya, and 92 MW of the total investment of 600 MW has been allocated to Konya. By the end of 2013, it had a share of 22% of the licenses to be issued for solar energy investments in Turkey. Konya is an important center of attraction for investments in electricity generation from solar energy with its high amount of flat, uneven and unsuitable for agriculture (Çetin et al., 2019).

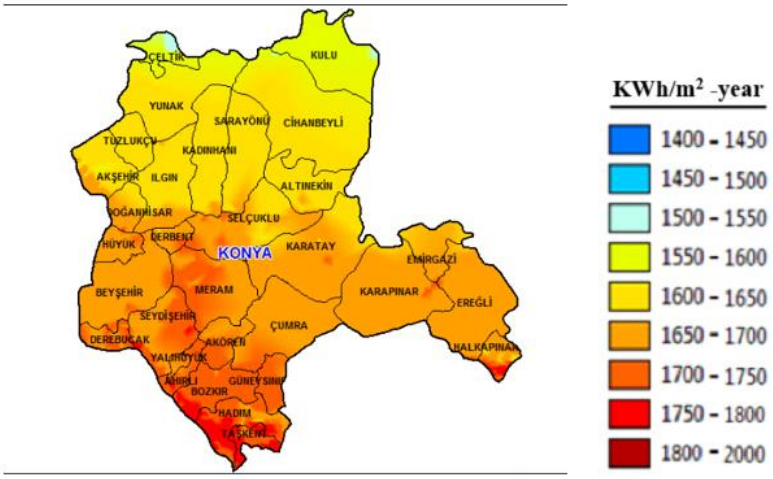

Figure 4.1. Radiation map of Konya province

As seen in Figure 4.1, we can see a significant increase in the amount of radiation coming from the sun from north to south in the radiation map of Konya province. According to the data of the General Directorate of Energy Affairs, the graphs of radiation, sunshine durations and the amount of energy that can be produced in Konya are as follows.

When Figures 4.2 and 4.3 are examined, it is seen that the amount of radiation and sunshine duration in Konya province reached its maximum values in July. These data are higher than in other provinces. If we take the surface areas of other provinces in Turkey as a basis, Konya province has a very high efficiency in terms of solar energy among renewable resources.

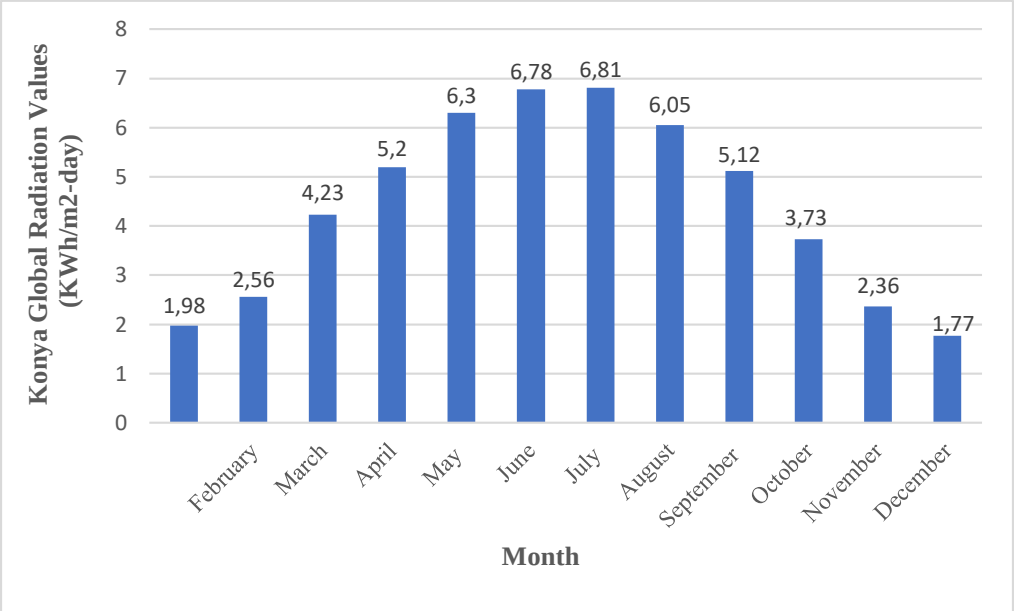

Figure 4.2. Konya Global Radiation Values (KWh/m^2-day)

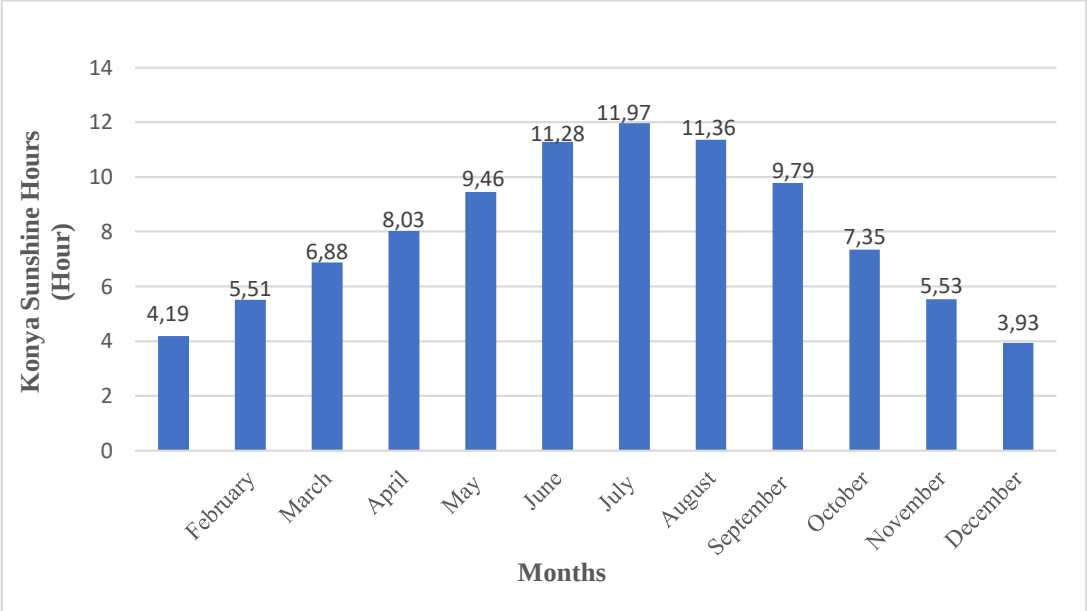

Figure 4.3. Konya Sunbathing Times (Hours)

The amount of energy that can be produced according to the PV type in Konya is shown in Figure 4.4. When the figure is examined, it is seen that monocrystalline silicon type Pv produces the most energy in the same area.

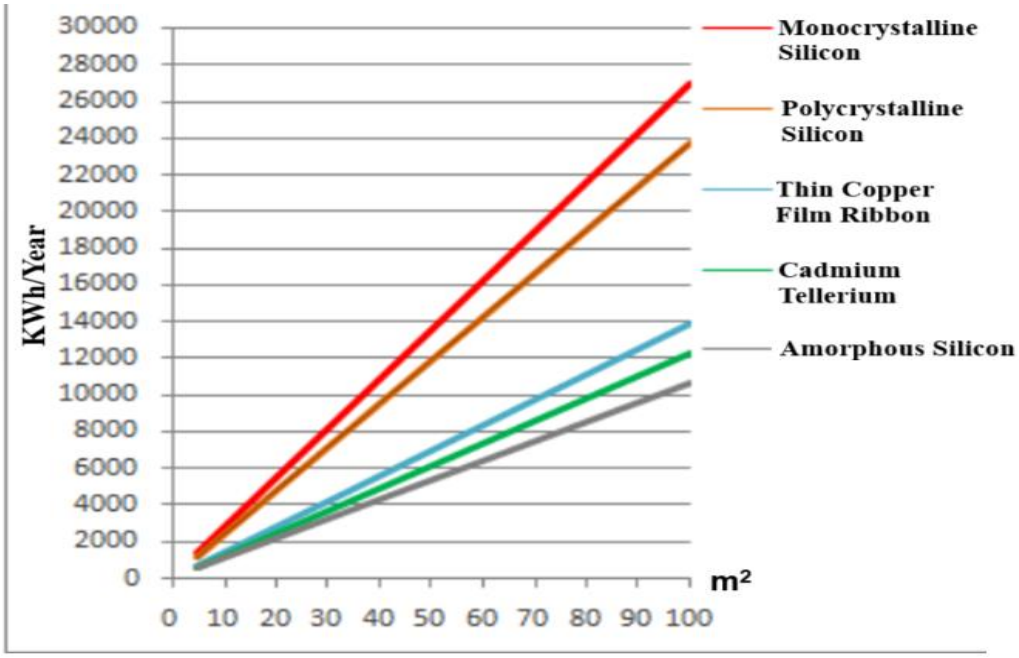

Figure 4.4. Konya PV Type-Area-Energy That Can Be Produced (KWh-Year)

4.1. Solar Collector Efficiency for Konya Province

The monthly water temperatures for the collector were calculated as shown in Figure 4.5. The lowest water temperature is observed in February, while the highest water temperature is determined in August. The difference between the highest and lowest temperature was determined as 15.5 oC. The reason for this difference is that Konya has a continental climate.

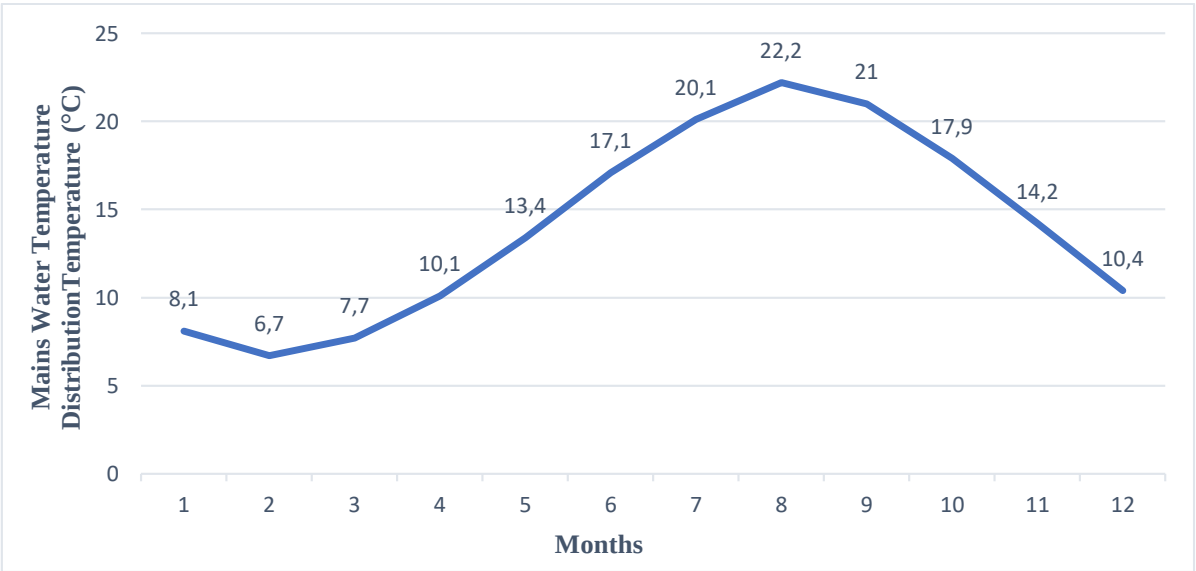

Figure 4.5. Mains water temperature distribution by months in Konya

The energy required for the collector is inversely proportional to the change in mains water temperature. Between February and August, the energy required is approximately 32,000

kcal/day, as shown in Figure 4.6. Since the energy obtained from the collector has the highest value in August, the energy required is less in this month compared to other months.

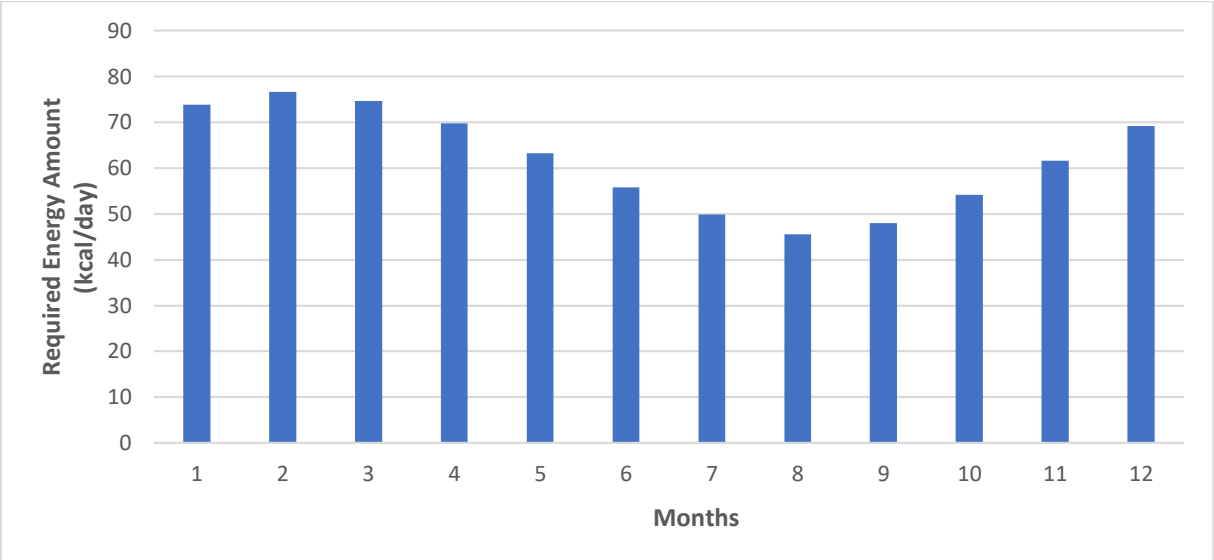

Figure 4.6. The amount of energy required per day for the collector in Konya province

When Figure 4.7 is examined, the radiation value provided by the collector differs according to the angle of incidence of the sun's rays according to the months. Since the angle of arrival is the highest for Konya in July, the amount of radiation provided is high. When the radiation value is considered as a single, it is not a factor affecting the efficiency. We cannot conclude that the efficiency is high because of the high radiation value.

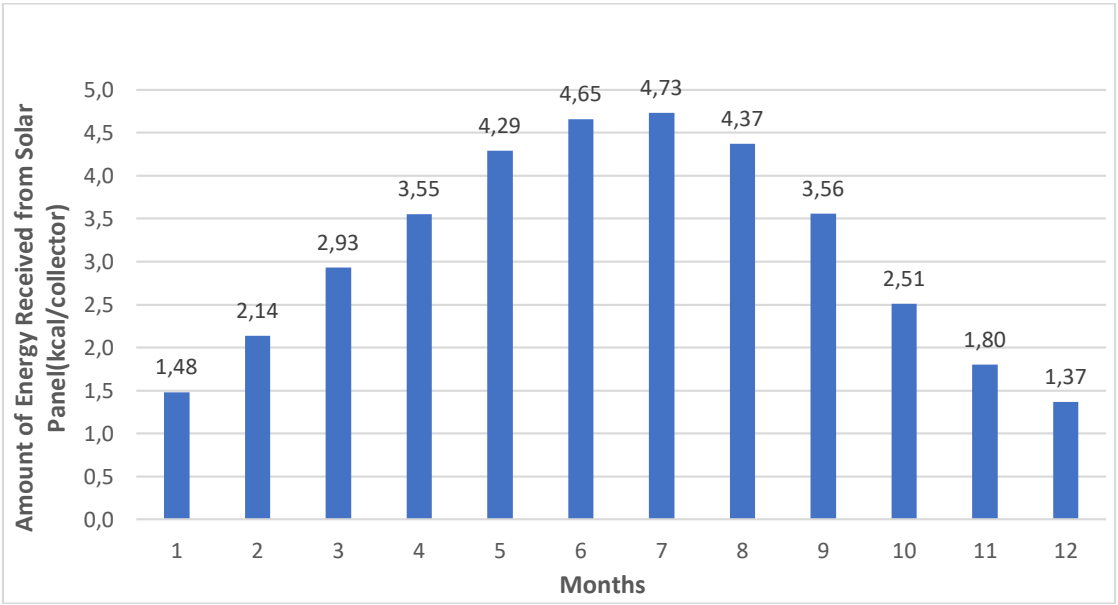

Figure 4.7. Solar irradiance value in Konya province

According to the months, the energy received from the solar panels is directly proportional to the radiation. As can be seen in Figure 4.8, depending on the angle of incidence, the energy received in June and July is close to each other. It is seen that the reason why there

are big differences in the amount of energy in Konya according to the months is especially due to climatic conditions.

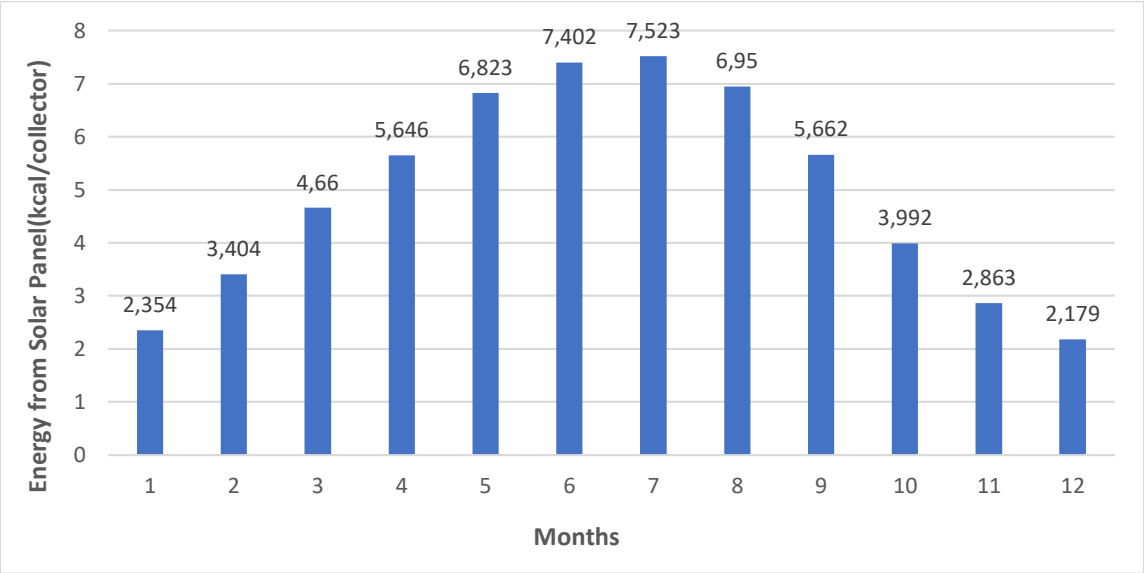

Figure 4.8. Konya Province Panel Energy Amount

In Figure 4.9, collector water volume capacities are calculated by months. When the figure is examined, the water volume capacity efficiency is highest in August compared to other months. We can show this as the duration of sunlight and sunlight angles as the reason.

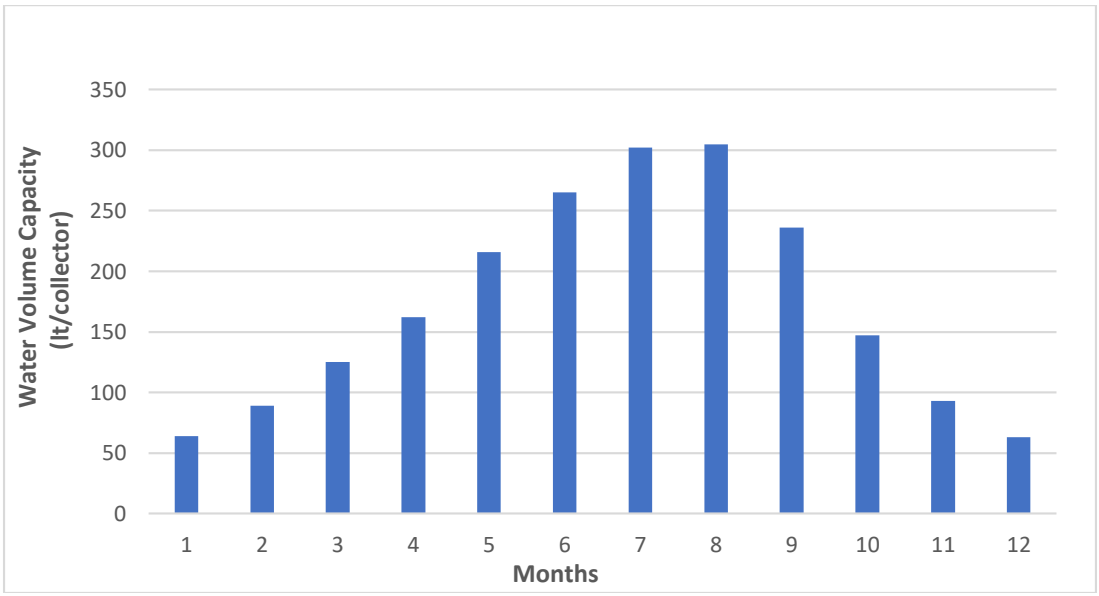

Figure 4.9. Collector Water Volume Capacity

When Figure 4.10 is examined, it is seen that more collectors are needed in the months when the sun's rays come at an acute angle in order to provide energy. In order to reach the energy we want to obtain, collectors are used according to the angle of incidence of the sun's rays. In summary, as the angle of incidence of the sun's rays decreases, more collectors are needed.

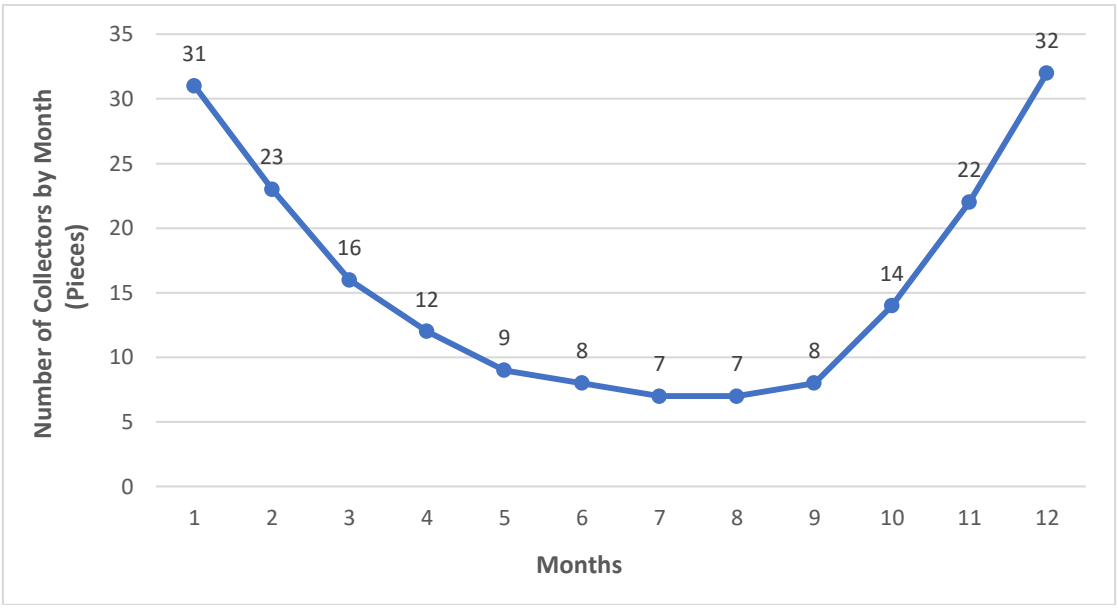

Figure 4.10. Number of Collectors

The greater the number of collectors, the greater the amount of hot water production. In Figure 4.11, when we look at the months, we see that the number of collectors and the amount of water production are directly proportional to each other.

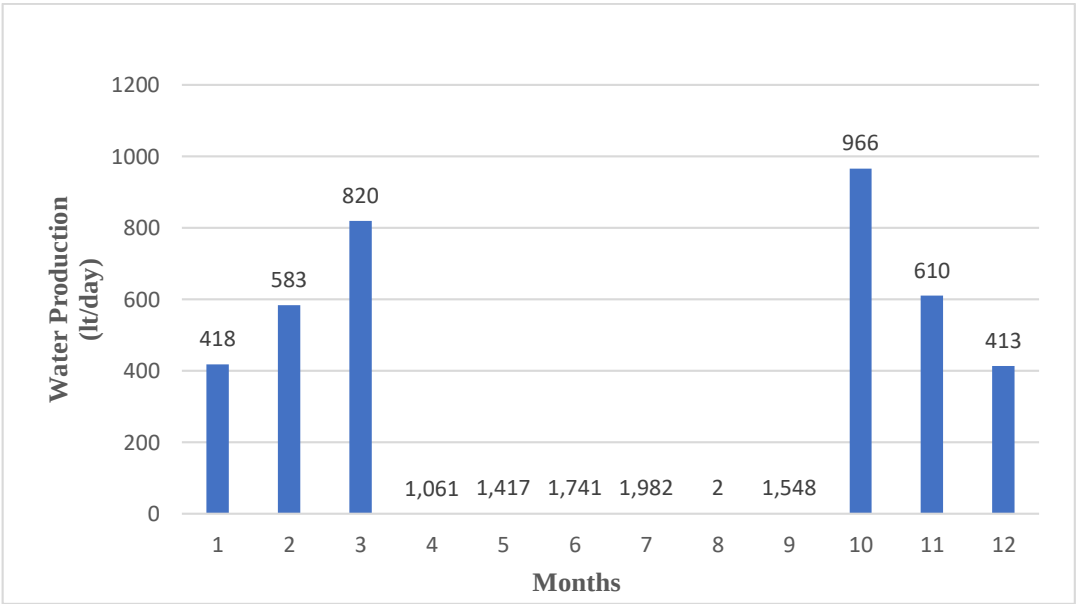

Figure 4.11. Water Production

It is seen in Figure 4.12 that the energy supplied is higher in July and June than in other months. We can say that the reason for this is the excess of solar radiation. Solar radiation is directly proportional to the angle of incidence. The higher the solar radiation, the higher the energy supplied from the collector.

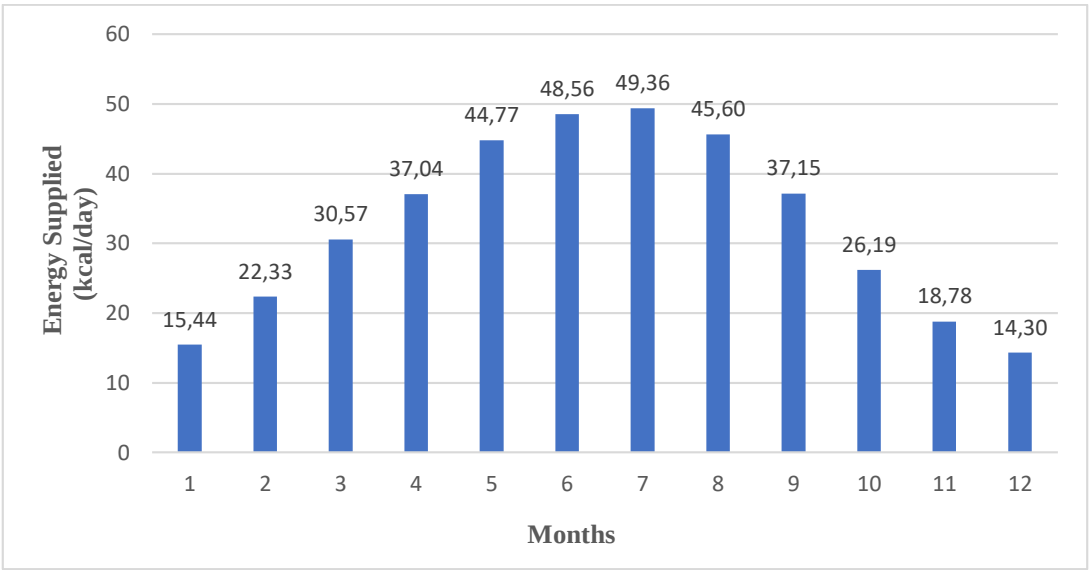

Figure 4.12. Energy Supplied

When we look at the energy coverage percentage of the collector in Figure 4.13, it was the highest reception in August compared to other figures. When we look at the energy schedule made, we see that the highest is in July, it is expected to be more in August. This is due to the calculation of yields. Efficiency is not the energy provided by the collector. It is the ratio of inputs and outputs of the collector during operation.

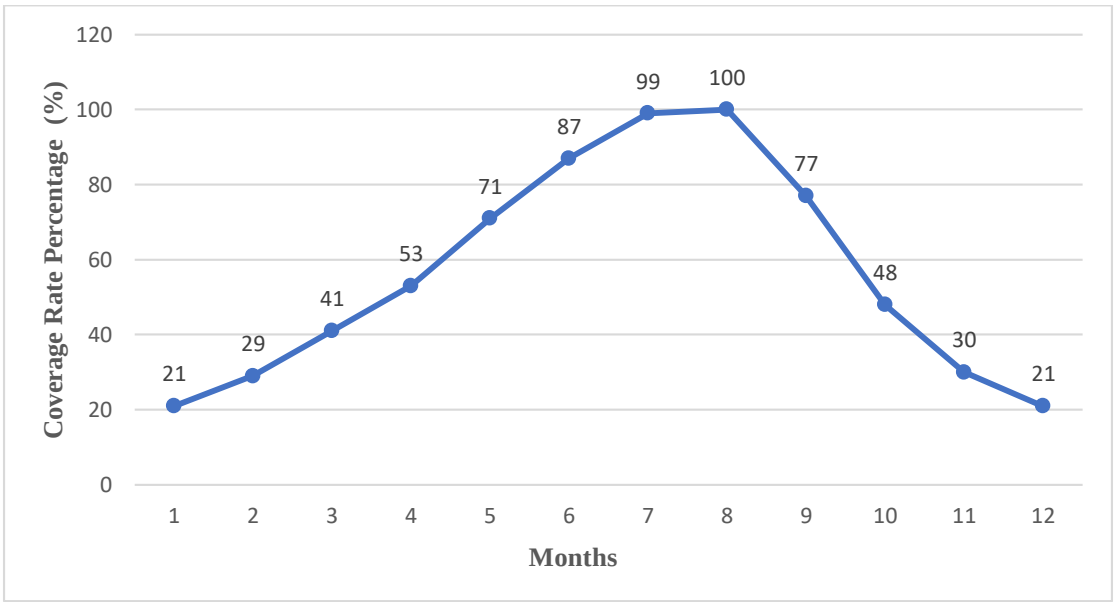

Figure 4.13. Coverage Rate Percentage

5. CONCLUSION

In this study, the yield analysis of the solar collector according to the months in Konya climatic conditions was carried out. In the researches, the required energy, solar radiation value, solar panel received energy, collector water volume capacity, number of collectors, daily hot

water production, energy provided and coverage ratios were compared and graphed according to the months. The prepared graphs helped to present the data in a more understandable way.

In the calculations, it is seen that the mains water temperature in collectors is the lowest in February. The highest water temperature occurred in August. The amount of energy required for the collector is less in August than in other months. The reason for this is that the energy supplied from the sun is too much for the month of August.

The radiation value provided by the collector differs according to the angle of incidence of the sun's rays according to the months. Since the angle of arrival is the highest for Konya in July, the amount of radiation provided is the highest. Depending on the angle of incidence of the energy supplied from the panel, the energy received from the sun in June and July is higher than in other months. In order to reach the energy we want to obtain, the use of collectors should be regulated according to the angle of incidence of the sun's rays. As the angle of incidence of the sun's rays becomes smaller, more collectors are needed. The greater the number of collectors, the greater the amount of hot water production. Solar radiation is directly proportional to the angle of incidence. Excess radiation is a parameter that ensures that the energy obtained is high. It was determined by calculations that the coverage ratio (collector efficiency) reached the highest value in August. The parameters that affect this situation are shown in detail in the graphs.

In our country, which is very lucky in terms of renewable energy sources, ways to make more use of solar energy should be sought to reduce fossil fuel consumption and thus environmental pollution. Environmentally friendly collectors are a type of renewable energy source that has a high availability due to the availability of urbanization and large industrial areas in Konya in obtaining energy.

RESOURCES

Ağı, S., & Günerhan, H. (2003). Possibilities of Increasing Efficiency in Liquid Planar Solar Collectors. TMMOB Chamber of Mechanical Engineers, *6th National Plumbing Engineering Congress and Exhibition Proceedings Book*, (Supplementary Proceedings), Publication No: E/2003/328-1, 675-692.

Altuntop, N., Demiral, D., & Çınar, G. (1997). Analytical and Experimental Investigation of Matrix Type Planar Air Solar Collectors. *Ulıbtk,* 97(11), 992-1001.

Aytaç, İ., Tuncer, A. D., Khanlari, A., Variyenli, H. İ., Mantıcı, S., Güngör, L., & Ünvar, S. (2023). Investigating the effects of using MgO-CuO/water hybrid nanofluid in an evacuated solar water collector: A comprehensive survey. *Thermal Science and Engineering Progr*ess, 39, 101688.

Bakanlığı, M. E. (2012). Renewable Energy Technologies. *Renewable Energy Sources and Their Importance*. Ankara: Republic of Turkey Ministry of Education, 4.

Beji, C., Merabtine, A., Mokraoui, S., Kheiri, A., Kauffmann, J., & Bouaziz, N. (2020). Experimental study on the effects of direct sun radiation on the dynamic thermal behavior of a floor-heating system. *Solar Energy, 204*, 1-12.

Binark, K., & Deliçay, Ş. (1993). Design of Air Heating Solar Collectors. *Thermal Science Technique*, 9, 204-212.

Chong, K. K., & Wong, C. W. (2009). General formula for on-axis sun-tracking system and its application in improving tracking accuracy of solar collector. Solar Energy, 83(3), 298-305.

Çetin, S., Turan, E., & Bayrakdar, E. (2019). Turkey's solar energy policies. *Third Sector Social Economic Review*, *54*(2), 949-968.

Değirmencioğlu, C., & İlken, Z. (2003). A Literature Survey and Basic Principles on Air Solar Collectors. *Turkish Plumbing Engineers Association Journal*, *27*.

Devan, P. K., Bibin, C., Gowtham, S., Hariharan, G., & Hariharan, R. (2020). A comprehensive review on solar cooker with sun tracking system. *Materials Today: Proceedings*, 33, 771-777.

Fudholi, A., Ruslan, M. H., Othman, M. Y., Yahya, M., Supranto, S., Zaharim, A., & Sopian, K. (2010, October). Collector efficiency of the double-pass solar air collectors with fins. *In Proceedings of the 9th WSEAS international conference on System science and simulation in engineering* (pp. 428-434).

García-Valladares, O., & Ituna-Yudonago, J. F. (2020). Energy, economic and emissions avoided contribution of domestic solar water heating systems for Mexico, Costa Rica and the Democratic Republic of the Congo. *Sustainable Energy Technologies and Assessments*, *39*, 100721.

İnce, M. E. (2016). A New Opportunity for Konya: Solar Fields Project and Renewable Energy. *Konya Chamber of Commerce*. Konya

Kılıç, A. (2018). Development of a new air solar collector, performance analysis and application in drying of agricultural products. *Selcuk University, Institute of Science, Department of Thermodynamics,* Konya

Narula, K., De Oliveira Filho, F., Chambers, J., Romano, E., Hollmuller, P., & Patel, M. K. (2020). Assessment of techno-economic feasibility of centralised seasonal thermal energy storage for decarbonising the Swiss residential heating sector. *Renewable Energy*, 161, 1209-1225.

Nwaji, G. N., Okoronkwo, C. A., Ogueke, N. V., & Anyanwu, E. E. (2020). Investigation of a hybrid solar collector/nocturnal radiator for water heating/cooling in selected Nigerian cities. *Renewable Energy*, *145*, 2561-2574.

Özdoğan, M. (2018), Solar Water Heating Systems, *Ondokuz Mayıs University Mechanical Engineering Department Solar Energy Lecture Notes*. Samsun

Özsoy, A., & Galip, M. (2018). Design and Manufacturing of Solar Simulator for Solar Collector Testing. *Academic Platform-Journal of Engineering and Science*, 6(2), 55-62.

Saini, P., Singh, J., & Sarkar, J. (2020). Thermodynamic, economic and environmental analyses of a novel solar energy driven small-scale combined cooling, heating and power system. *Energy Conversion and Management*, *226*, 113542.

Saxena, G., & Gaur, M. K. (2020). Energy, exergy and economic analysis of evacuated tube solar water heating system integrated with heat exchanger. *Materials today: Proceedings*, *28*, 2452-2462.Esen, M. and Esen, H., 2005, *Experimental Investigation of a Two-Phase Closed Thermosyphon Solar Water Heater, Solar Energy* 79:459-468

Shafieian, A., & Khiadani, M. (2020). Integration of heat pipe solar water heating systems with different residential households: An energy, environmental, and economic evaluation. *Case Studies in Thermal Engineering*, *21*, 100662.

Şahin, T. (2010). Experimental investigation of planar and bent collectors (Doctoral dissertation, *Süleyman Demirel University, Institute of Science*. Isparta

Taşova, M. (2018). Turkey's solar energy parameter values and solar energy utilization opportunities. *Advanced Technology Sciences Journal*, 7(3), 10-17.

Tezcan, M. (2002). Planar solar collectors and efficiency calculations (Doctoral dissertation, *Istanbul Technical University*, *Institute of Science*, *Department of Chemical Engineering*, İstanbul

TS EN 12975. (2008). Thermal Solar Energy Systems and Components-Solar Energy Collectors-Part 2: Test Methods, *Turkish Standards Institution -TSE*, Ankara, 109s

Varınca, K. B., & Gönüllü, M. T. (2006). A study on the solar energy potential in Turkey and the degree, method and prevalence of its use. *National Solar and Hydrogen Energy Congress*, *21*, 23.

Veeramanikandan, M., Sathish, D., Jeryrajkumar, L., & Boovendravarman, S. (2021). Effective study on developments in photovoltaic thermal (PV/T) water heating system. *Materials Today: Proceedings*, *42*, 584-589.

Wang, J., Ma, C., & Wu, J. (2019). Thermodynamic analysis of a combined cooling, heating and power system based on solar thermal biomass gasification☆. *Applied Energy*, *247*, 102-115.

Yiğit A ve İ, A. *(*2010), Solar Energy, *Alfa Current Distribution*, Bursa.

CHAPTER 12

ANTIOXIDANT AND ANTIMICROBIAL EFFECTS OF TOTAL PHENOLIC AND FLAVONOID SUBSTANCE CONTENTS OF 3 DİFFERENT ALGAE DISTRIBUTED IN THE MEDITERRANEAN

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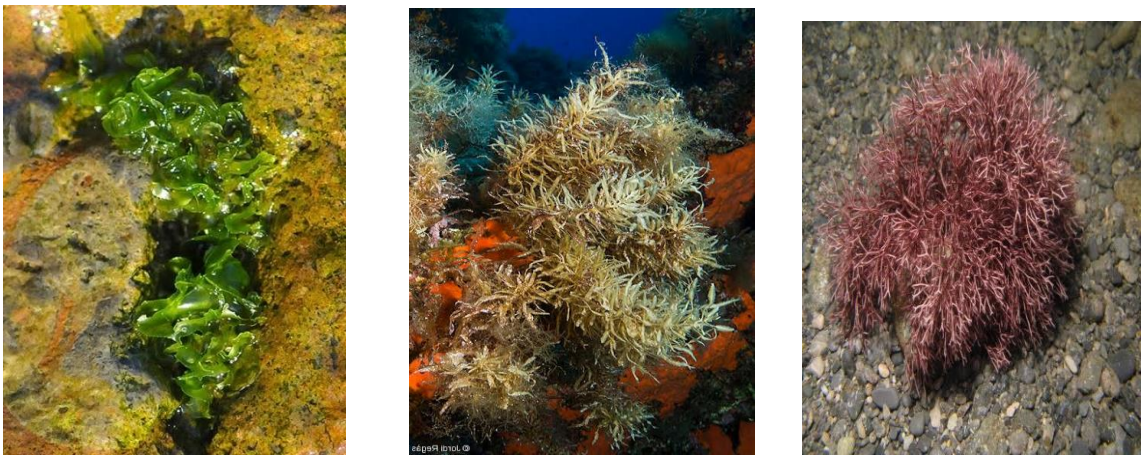
I. INTRODUCTION

Algae are photosynthetic organisms that grow in a variety of aquatic habitats, including lakes, rivers, oceans, and even wastewater. (AKTAR & CEBE, 2010). Algae contain many bioactive molecules with wide biological activities such as antioxidant, antibacterial, antifungal, antiviral (Sasa et al., 2020). Algae are used in many industrial areas such as food, agriculture, pharmacy, medicine and energy due to the important substances they contain.Seaweed is an important food source especially in East Asian countries. It is rich in vitamins A, B1, B2, B6 and C, potassium, iron, magnesium and calcium. The marine ecosystem has become a focus of attention in many areas from past to present due to its chemical and biological differences. However, new discoveries and natural use of marine fauna and flora have played a key role in the fight against various diseases and in nutrition. (Chapman, 1970).

As photosynthetic organisms, algae are the primary producers of aquatic environments, especially marine environments, with rich biological diversity. At the same time, they are very important both ecologically and biologically, as they are widely distributed in all marine resources and lakes in the world and carry out vital activities in the feeding, reproduction and protection of other living things in the environment. In this study, the antioxidant activity (determination of total phenolic substance (TPC), determination of total flavonoid substance (TFC) and antimicrobial activity (MIC) method of extracts prepared with 4 different solvents of 3 different macroalgae species consisting of *Sargassum vulgare* from the Phaeophyta section, *Liagora viscida* from the Rhodophyta section and *Ulva rigida* from the Chlorophyta section, which are macro algae spreading in our seas, were determined. In the studies performed phenolic substance concentrations; S. vulgare the most effective acetone extract was found as 78.15±0.46µg/ml, *U. rigida*; methanol extract was found as 25.78±0.001µg/ml, *L. viscida*; acetone extract was found as 61.73±0.29µg/ml, and extracts made with water did not give results. Flavonoid substance concentrations; *S. vulgare* the most effective methanol extract was found as 19.68±0.02µg/ml, *U. rigida*; the most effective methanol extract was found as 11.02±0.004µg/ml, and similar results were found in other solvents. *L. viscida*; the most effective ethanol extract was found as 10.14±0.01µg/ml, and similar amounts were found in other solvents, but water extract was negative. According to the results obtained, S. vulgare, which was effective against antimicrobial tests, was found in *P. aeruginosa*, *B. cereus*, methanol, ethanol and acetone extracts (MIC: 1.56 mg/ml), *S. Aureus* was found in methanol, ethanol, acetone (MIC: 3.12 mg/ml), *S. lutea* was found in methanol extract (MIC: 1.56 mg/ml). In *C.albicans* (methanol, ethanol, acetone) extracts (MIC: 0.78, 1.56, 0.78 mg/ml), *U.rigida*, *P. aeruginosa* methanol, *S. lutea* methanol, ethanol extracts (MIC: 1.56 mg/ml), *S. aureus* ethanol, acetone extracts (MIC: 3.12 mg/ml), B.cereus (methanol, ethanol, acetone) extracts (MIC: 0.19, 1.56, 0.39 mg/ml), *C.albicans* (methanol, acetone) extracts (MIC: 1.56, 0.78mg/ml). *L.viscida* was found in *P. aeruginosa* acetone extract (MIC: 1.56 mg/ml), *S. aureus* in methanol, ethanol and acetone extracts (MIC: 3.12 mg/ml), *B. cereus* in methanol extract (MIC: 0.19 mg/ml),

C. albicans in methanol extract (MIC: 0.78 mg/ml). It was observed that the water extract did not show antimicrobial activity against any of the test microorganisms. As a result; according to the results we obtained, the highest rates were found in the extracts obtained with acetone and methanol solvents.



Ulva rigida *Sargassum vulgare.* *Liagora viscida*

Photo 1. Photos of sample Algae

2. MATERIAL and METHOD: photos of sample algae

Collection and preparation of algae: Samples were collected from some macroalgae species belonging to the divisions *Chlorophyta, Rhodophyta and Phaeophyta* spreading along the coasts of the Aegean Sea. First, these algae were washed with the ambient water they were in to remove foreign substances and brought to the laboratory environment in sterile polyethylene bags. The samples were washed again with sterile water to remove epiphytic organisms and necrotic parts on them. The drained macroalgae were left to dry in the dark. After the macroalgae samples were dried under appropriate conditions, they were powdered with the help of a homogenizer (ISOLAB).

Methanol, ethanol, acetone and water were used as solvents in the extraction to determine the antioxidant and antimicrobial effects of algae.

Photo 2. Extracts of algae

Preparation of algae extracts: Each sample to be used in the study was weighed in 30 grams on precision scales and transferred into 500 ml Erlenmeyers and then 200 ml of the solvent used in the study was added to prepare a total of 12 algal extracts. After the mouths were covered with aluminum foil, they were subjected to a mixing process at 93 Rpm in a mixer for 24 hours. At the end of the period, the extracts were passed through filter paper. The extracts were transferred into volumetric flasks and evaporated in a Rotary Evaporator at 40°C for 30-60 minutes until the solvent remained 1-2 ml. The obtained extracts were dissolved in volumetric flasks with the help of their own solvent. The vial was tared. After the obtained extracts were transferred to the vials, they were kept on a bain-marie until they dried. The dried extracts were closed with parafilm and stored at +4 C until the time of analysis. (Albayati, 2020)

Photo 3. Soxhlet appliance

Antioxidant Activity Analyses:

1. Total phenolic amounts of the extracts were determined as gallic acid equivalents using FCR (Folin Ciocalteu phenol reagent) (Slinkard and Singleton, 1977). Solutions containing 1 mg of sample were made up to 1ml (Et-OH) and 500μL of FCR and 3 min later 300μL of 7.5% Na2CO3 solution were added to this mixture. The mixture was kept at room temperature for 2 hours with shaking and then the absorbance of the samples was read at 765 nm.

2. Total flavonoid quantification (TFC) Total flavonoid amounts of the extracts were determined as quercetin equivalents by the aluminum nitrate method (Moreno et al., 2000). For this purpose, Solutions containing 1 mg of sample were completed to 4.8 ml with ethanol and 75μL of 1 M potassium acetate and 5μL of 10% aluminum nitrate solution were added to this mixture. After the samples were kept at room temperature for 40 min, their absorbances were read at 415 nm.

Bacterial strains: In the scope of the study, standard bacterial and fungal strains including Gram positive and Gram negative bacteria and fungi were used from stock cultures obtained from the Microbiology Laboratory Culture Collection of the Biology Department of the Faculty of Science of Selcuk University (Escherichia coli ATCC 25922, Pseudomonas aeruginosa ATCC 27853, Klebsiella pneumoniae ATCC 70603, Staphylococcus aureus ATCC 43300, Salmonella enteretidis ATCC 13076, Sarcina lutea ATCC 9341, Bacillus cereus ATCC 11778) and Candida albicans.

Preparation of bacterial cultures: A single colony was taken from the bacterial strains incubated at 37 °C for 1 night in Brain Hearth Infusion Agar medium and inoculated into 5 ml of Brain Hearth Infusion Broth. The cultures incubated at 37 °C for 18-24 hours were used to determine the antimicrobial effect.

Broth Microdilution Method: In this study, Gentamicin was used as a negative control (DMSO) and a positive control in different plates. 100 µl of its 0.1 mg/ml solution was added to the first wells as in the addition of extract.0.025 mg/ml-0.02 µg/ml concentrations were obtained between wells 1-12 with dilutions.After these procedures, the plates were closed and left to incubate at 37 °C for 18 hours. At the end of the incubation period, to indicate the wells with coloration, 20 µl of aqueous 2,3,5-triphenyltetrazolium chloride (TTC) (0.5%) was added to the wells and incubated for another 30 minutes at 37 ° C. At the end of the incubation period, the growth in the plates was checked and the lowest extract concentration at which there was no visible growth (non-coloring areas), thus inhibiting growth, was evaluated as the MIC.

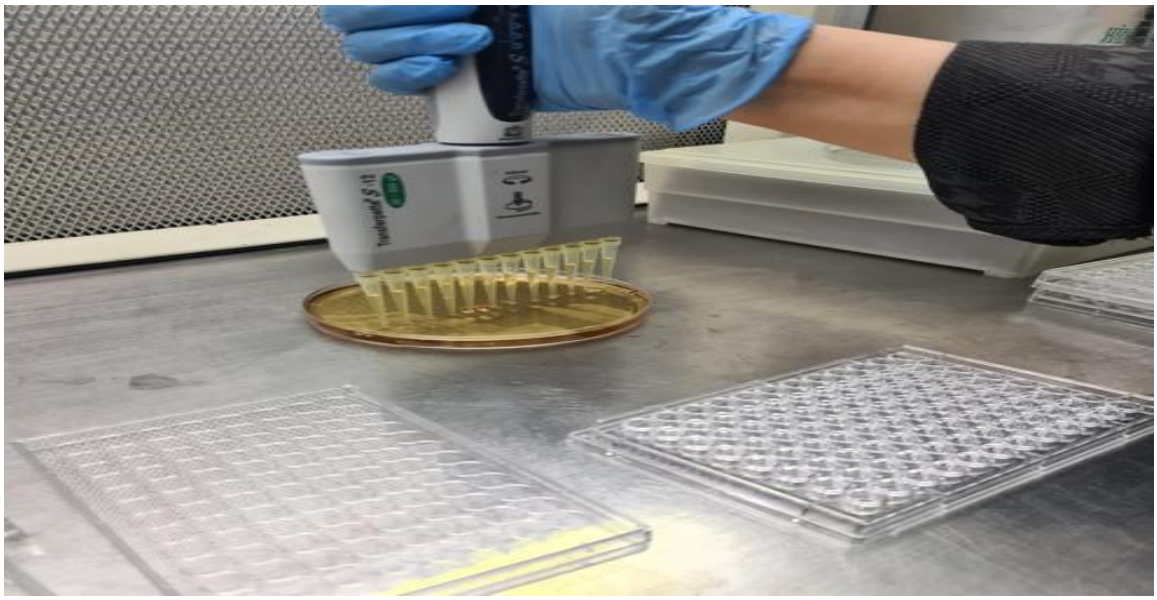


Photo 4. Antimicrobial analyses

Table. 1. Results of Antioxidant Activity Assays

TYPE	EXTRACT	TOTAL PHENOLIC AMOUNT (µg GAEs /mg EXTRACT)a	TOTAL FLAVONOID AMOUNT (µg QEs /mg EXTRACT)b
Sargassum *vulgare*	Methanol	21,593±0,004	19,681±0,017
	Ethanol	34,617±0,054	16,814±0,029
	Acetone	78,149±0,464	9,356±0,012
	Water	27,928±0,155	2,699±0,032
Ulva rigida	Methanol	25,784±0,001	11,020±0,004
	Ethanol	18,208±0,008	4,173±0,010
	Acetone	23,958±0,057	4,588±0,049
	Water	21,114±0,006	2,539±0,004
Liagora viscida	Methanol	21,779±0,001	6,337±0,008
	Ethanol	44,515±0,143	10,140±0,019
	Acetone	61,731±0,294	4,333±0,011
	Water	----------	----------

Determination of Total Phenolic: S. vulgare the most effective acetone extract was 78.15±0.46 µgGAEs/mg, different amounts were also observed in other solvents. *S. vulgare* the most effective acetone extract was 78.15±0.46 µgGAEs/mg, different amounts were also observed in other solvents.*U. rigida*; methanol extract was 25.78±0.001µg GAEs/mg, different amounts were also found in other solvents. *L. viscida*; acetone extract was 61.73±0.29µg GAEs/mg, different amounts were also found in other solvents, but the water extract result was negative.

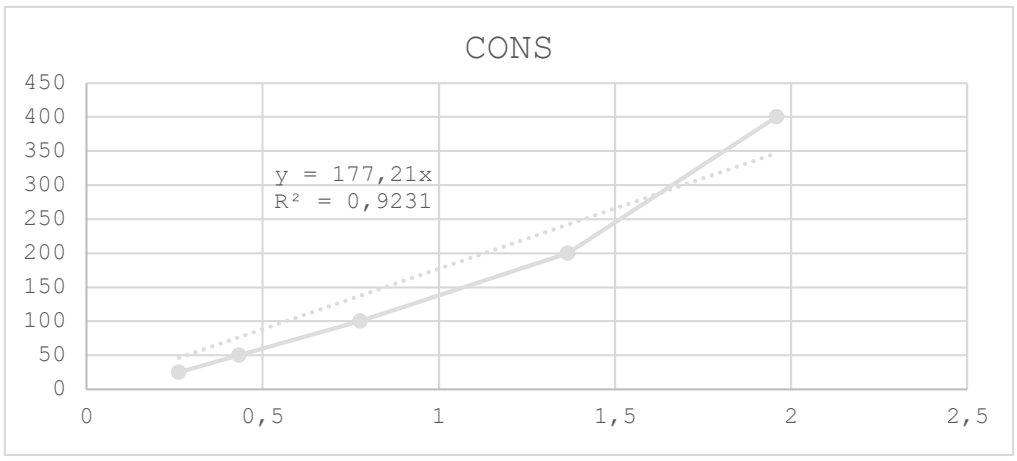


Figure 1. Total phenolic concentrations

Total Flavonoid Determination: *S. vulgare*; methanol extract was found to be the most effective 19.68±0.02 QEs/mg, and different amounts were found in other solvents. *U. rigida*; methanol extract was found to be the most effective 11.02±0.004µg QEs/mg, and similar results were found in other solvents.*L. viscida*; ethanol extract was found to be the most effective 10.14±0.01µg QEs/mg, and similar amounts were found in other solvents, but water extract was negative.

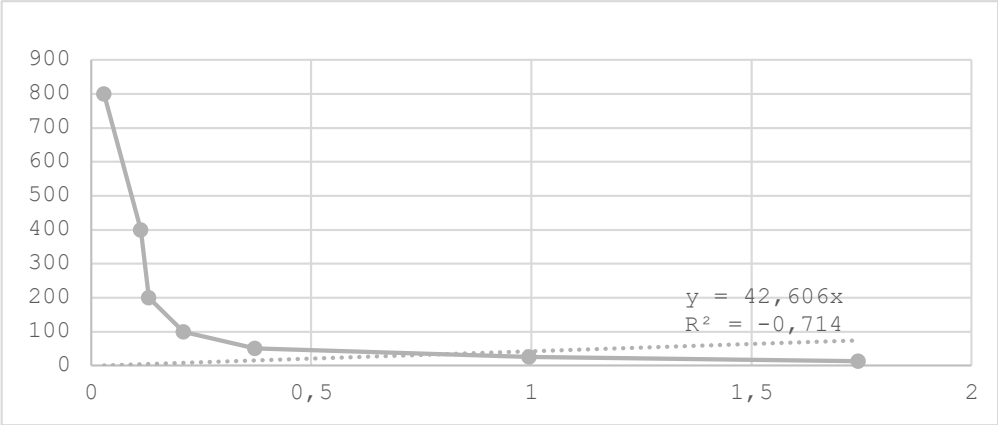


Figure 2. Total flavonoid concentrations.

Table 2. Minimal Inhibitory Concentration results of water, methanol, ethanol and acetone extracts obtained from *Sargassum vulgare* samples.

Test Microorganisms	*S.vulgare* Water	*S.vulgare* Methanol	*S.vulgare* Ethanol	*S.vulgare* Acetone	Gentamisin (0.1 mg/ml)	DMSO
Escherichia coli	----------	----------	----------	----------	<0.02 mg/ml	%12,5
Pseudomonas aeruginosa	----------	1.56mg/ml	----------	1.56mg/ml	<0.02 mg/ml	%12,5
Klebsiella pneumoniae	----------	----------	----------	----------	0.78 mg/ml	%12,5
Staphylococcus aureus	----------	3.12mg/ml	3.12mg/ml	3.12mg/ml	<0.02 mg/ml	%25
Salmonella enteretidis	----------	----------	----------	----------	0.04 mg/ml	%12,5
Sarcina lutea	----------	1.56mg/ml	----------	----------	<0.02 mg/ml	%12,5
Bacillus cereus	----------	1.56mg/ml	1.56mg/ml	1.56mg/ml	<0.02 mg/ml	%12,5
Candida albicans	----------	0.78mg/ml	1.56mg/ml	0.78mg/ml	<0.02 mg/ml	%12,5

According to the obtained results, *S. vulgare*, which was effective against antimicrobial tests, was found in *P. aeruginosa*, *B. cereus*, methanol, ethanol and acetone extracts (MIC: 1.56mg/ml), *S. Aureus* was determined as methanol, ethanol, acetone (MIC: 3.12mg/ml), *S. lutea* was found in methanol extract (MIC: 1.56 mg/ml). It was found in *C. albicans* (methanol, ethanol, acetone) extracts (MIC: 0.78, 1.56, 0.78 mg/ml).

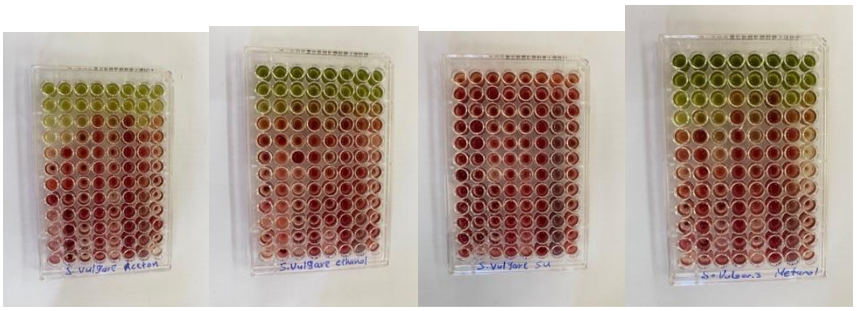


Figure 3. Antimicrobial tests (MİC) of *S. vulgare.*

Table 4. Minimal Inhibitory Concentration results of water, methanol, ethanol and acetone extracts obtained from *Liagora viscida* samples.

Test Microorganisms	***L.viscida*** **Water**	***L.viscida*** **Methanol**	***L.viscida*** **Ethanol**	***L.viscida*** **Acetone**	**Genta misin (0.1 mg/ml)**	**DMSO**
Escherichia coli	----------	----------	----------	----------	<0.02 mg/ml	%12,5
Pseudomonas aeruginosa	----------	----------		1.56mg/ml	<0.02 mg/ml	%12,5
Klebsiella pneumoniae	----------	----------	----------	----------	0.78 mg/ml	%12,5
Staphylococcus aureus	----------	3.12mg/ml	3.12mg/ml	3.12mg/ml	<0.02 mg/ml	%25
Salmonella enteretidis	----------	----------	----------	----------	0.04 mg/ml	%12,5
Sarcina lutea	----------	----------	----------	----------	<0.02 mg/ml	%12,5
Bacillus cereus	----------	0.19mg/ml	----------	----------	<0.02 mg/ml	%12,5
Candida albicans	----------	0.78mg/ml	----------	----------	<0.02 mg/ml	%12,5

L.viscida was found in *P. aeruginosa* acetone extract (MIC: 1.56mg/ml), S. aureus was found in methanol, ethanol and acetone extracts (MIC: 3.12 mg/ml). *B. cereus* was found in methanol extract (MIC: 0.19mg/ml).*C. albicans* was found in methanol extract (MIC:0.78mg/ml). It was observed that the water extract did not show antimicrobial activity against any of the test microorganisms.As a result; according to the results we obtained, the highest rates were found in the extracts obtained with acetone and methanol solvents.

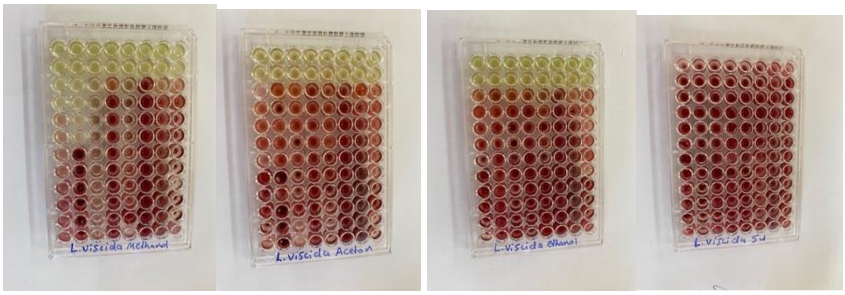


Figure 4. Antimicrobial tests (MİC) of *L. vicida*.

Table 5. Minimal Inhibitory Concentration results of water, methanol, ethanol and acetone extracts obtained from *Ulva rigida* samples.

Test Microorganisms	***U.rigida*** **Water**	***U.rigida*** **Methanol**	***U.rigida*** **Ethanol**	***U.rigida*** **Acetone**	**Genta misin (0.1 mg/ml)**	**DMSO**
Escherichia coli	----------	----------	----------	----------	<0.02 mg/ml	%12,5
Pseudomonas aeruginosa	----------	1.56mg/ml	----------	----------	<0.02 mg/ml	%12,5
Klebsiella pneumoniae	----------	----------	----------	----------	0.78 mg/ml	%12,5
Staphylococcus aureus	----------	----------	3.12mg/ml	3.12mg/ml	<0.02 mg/ml	%25
Salmonella enteretidis	----------	----------	----------	----------	0.04 mg/ml	%12,5
Sarcina lutea	----------	1.56mg/ml	1.56mg/ml	----------	<0.02 mg/ml	%12,5
Bacillus cereus	----------	0.19mg/ml	1.56mg/ml	0.39mg/ml	<0.02 mg/ml	%12,5
Candida albicans	----------	1.56mg/ml	----------	0.78mg/ml	<0.02 mg/ml	%12,5

U.rigida was found in *P. aeruginosa* methanol, *S. lutea* methanol, ethanol extracts (MIC: 1.56 mg/ml). *S. aureus* was found in ethanol, acetone extracts (MIC: 3.12 mg/ml).

B.cereus (methanol, ethanol, acetone) extracts (MIC: 0.19, 1.56, 0.39 mg/ml). *C.albicans* (methanol, acetone) extracts (MIC: 1.56, 0.78mg/ml).

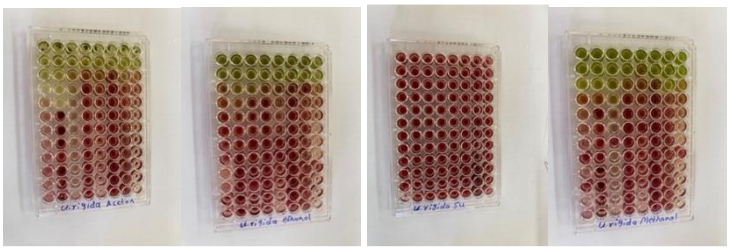


Figure 5. Antimicrobial tests (MİC) of *U. rigida*

3. CONCLUSION AND DISCUSSION

- Jun et al. (2015) found that the crude methanol extract obtained from Cystoseira hakodatensis, which they used in their studies according to the MIC method, had inhibitory effects on the growth of Bacillus cereus and Bacillus licheniformis. Regarding the antimicrobial potential, they suggested that C. hakodatensis could be an antimicrobial agent, as it showed better inhibitory effects against B. cereus and B. licheniformis compared to other bacterial strains.

- Alghazeer et al. (2008) conducted antioxidant activity and phenolic content analysis in their study with red, green and brown algae groups and reported that C. crinita brown algae with the highest phenolic (800.28 ± 36.23 mg/g) and antioxidant (50.5± 3.20%) activity caused the most effective inhibition in cancer cell lines. Similarly, in the study where antioxidant and anticancer effects of brown algae Padina boergesenii were determined, it was reported that the highest total phenol and flavonoid content was in the methanol extract of this species.

- Kosanić ve ark. (2015) In this study, acetone extracts of Cystoseira amentacea, Cystoseira barbata and Cystoseira compressa were tested for their antioxidant, antimicrobial and cytotoxic potential. As a result, it was reported that all three Cystoseira species exhibited similar antimicrobial activity. The lowest MIC value (0.312 mg/mL) was observed in the extract obtained from C.compressa against Bacillus subtilis

- Zbakh et al. (2012) tested the antibacterial activity of methanol extracts of 20 macroalgae species (9 green algae, 3 brown algae and 8 red algae) collected from the Moroccan coast of the Mediterranean Sea against Escherichia coli, Staphylococcus aureus and Enterococcus faecalis. It was determined that the studied species of red algae inhibited the growth of 3 tested bacterial strains and formed a zone between 20-24 mm. Among the tested algae, 17 were found to have antibacterial activity. Ulva lactuca, Gracilaria bursa-pastoris and Chaetomorpha linum extracts were found to have the highest antibacterial activity. It was reported that 15 extracts (75%) had highly active inhibitory effects against Staphylococcus aureus, 7 extracts (35%) against E. coli and 2

extracts (10%) against Enterococcus feacalis. It was reported that the methanol extract of Ulva rigida showed inhibitory effect against all tested strains.

- Mansuya et al. (2010) studied the antibacterial activities of extracts of Cladophora glomerata, Ulva lactuca, Ulva reticulata from green algae, Gracilaria corticata, Kappaphycus alvarezii from red algae and Sargassum wightii from brown algae by well diffusion method. Maximum activity (45 mM) was recorded against Salmonella typhi with 200 mg of Ulva reticulata water extract, and minimum activity (9 mM) was recorded against Streptococcus pyogenes with 50 mg of Ulva lactuca water extract. It was reported that methanol extracts had higher antimicrobial activity than water extracts. Maximum activity (40 mM) was determined in 200 mg of methanol extract of Ulva reticulata against Escherichia coli and Streptococcus pyogenes. Crude methanol extracts of all algae showed inhibitory activity against all test pathogens and Ulva reticulata extract was found to be the most effective species. However, water extract of Ulva reticulata was reported to have no inhibitory activity against Escherichia coli and Pseudomonas aeruginosa.

- According to the findings obtained in our study, the highest phenolic substance amounts were measured in the acetone extract of S. vulgare from brown algae (78.15±0.46 µg GAEs /mg), and the highest flavonoid amounts were measured in the methanol extract (19.68184±0.017183µg QEs/mg). The highest antimicrobial activity against the studied test pathogens was measured in the acetone extract of L. viscida from red algae and in the acetone extract of U rigida from green algae, and the most effective strain was determined as the gram (+) bacterial strain Bacillus cereus (ATTC 11778) (MIC: 0.19 mg/ml). As a result, it is thought that the presence of phenolic components such as phenol, flavonoids, steroid structures and pigments such as carotenoids in algae is an indicator of antioxidant activity and free radical repellent effect, as well as antimicrobial activity. As a result, the expected results were observed in the studied algae and according to these results, we believe that algae will enable new studies as raw material on this subject.

REFERENCES

Aktar, S. and Cebe, G.E. (2010). General properties of algae, their usage areas and importance in pharmacy. *Journal of Faculty of Pharmacy of Ankara University*, *39*(3), 237-264

Albayati, M.A.F. (2020). Determination of antimicrobial activities of some macroalgae species. *Selcuk University, Institute of Science*, Master's Thesis

Alghazeer, R., Whida, F., Al-Najjar, A., Majdoob, H. ve Al-Mazoghi, E., (2008), Assessment of antioxidant activity and phenolic content of some marine algae from the Libyan Coast, Ain Shams Science Bulletin, 46, 67-78.

Dixon, P. S., & Irvine, L. M. (1977). Seaweeds of the British Isles: Volume 1, Rhodophyta. Cambridge University Press.

Jun, J. Y., Nakajima, S., Yamazaki, K., Kawai, Y., Yasui, H. and Konishi, Y., (2015), Isolation of antimicrobial agent from the marine algae Cystoseira hakodatensis, *International journal of food science & technology*, 50 (4), 871-877.

Keskinkaya, H. B., Deveci, E., Güneş, E., Okudan, E. Ş., Akköz, C., Gümüş, N. E., & Karakurt, S. (2022). Chemical composition, in vitro antimicrobial and antioxidant activities of marine macroalgae Codium fragile (Suringar) Hariot. *Commagene Journal of Biology*, *6*(1), 94-104.

Kosanić, M., Ranković, B. and Stanojković, T., (2015), Biological potential of marine macroalgae of the genus Cystoseira, *Acta Biologica Hungarica*, 66 (4), 374-384.

Mansuya, P., Aruna, P., Sridhar, S., Kumar J.S. & Babu, S. (2010). Antibacterial activity and qualitative phytochemical analysis of selected seaweeds from Gulf of Mannar region. *Journal of Experimental Sciences*, 1 (8): 23-26.

Moreno, M. A. I. N., Isla, M. A. I., Sampietro, A. R. and Vattuone, M. A., (2000), Comparison of the free radical-scavenging activity of propolis from several regions of Argentina, J*ournal of ethnopharmacology*, 71 (1-2), 109-114.

Sasa, A., Şentürk, F., Üstündağ, Y., & Erem, F. (2020). Use of algae as food or food ingredients and their effects on health. *International Journal of Engineering Design and Technology*, 2(2), 97-110.

Slinkard, K. and Singleton, V. L., (1977), Total phenol analysis: automation and comparison with manual methods, American journal of enology and viticulture, 28 (1), 49-55.

Zbakh, H., Chiheb, H., Bouziane, H., Sánchez, V.M. & Riadi, H. (2012). Antibacterial activity of benthic marine algae extracts from the Mediterranean coast of Morocco. Journal of Microbiology, Biotechnology and Food Sciences, 2 (1): 219-228.

CHAPTER 13

THE AGRICULTURAL POTENTIAL OF SORGHUM - SUDAN GRASS HYBRID IN ARID CLIMATES

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1. INTRODUCTION

Sorghum sudanense, known as Sudan grass, is a warm-season annual grass belonging to the Poaceae family. It is particularly valued for its high feed yield and nutritional quality, making it a popular choice for animal feed. Sudan grass is characterized by its rapid growth, high tillering ability and adaptability to various environmental conditions, including drought and poor soil quality (Wang, 2024; Han et al., 2016). The plant heights between 118 cm and 163 cm, depending on the specific cultivar and environmental conditions (Yartsev, 2024).

Sorghum-Sudangrass (SSG) hybrids are known as grazing and cutting sorghums, which derived from the crossing of *Sorghum bicolor* (L.) Moench × *Sorghum sudanense* (Piper) Stapf (Santos et al., 2020). This hybrid is valuable for its adaptability to arid and semi-arid environments where problems may arise in the cultivation of forage crops that are more preferred by producers. The hybrid exhibits a significant potential ability to produce biomass under conditions of limited water availability, making it an important actor in sustainable fodder crop production in drought-prone areas (Ikanović et al., 2010; Ali et al., 2014; Salman and Budak, 2015).

1.1. Botanical Characteristics of Sorghum - Sudan Grass Hybrid

The morphological characteristics of sorghum-sudangrass hybrids also contribute to their forage potential. These hybrids typically exhibit longer and wider leaves, increasing their ability to capture sunlight and perform efficient photosynthesis (Alhammad, 2023; Ikanović et al., 2013). Increased leaf area not only supports higher biomass production, but also improves the overall quality of forages, making them more palatable and nutritious for livestock (Ouma, 2023). Furthermore, the tolerance of hybrids to drought conditions enables them to maintain productivity even under stress, a vital trait for regions facing climate variability (Ikanović et al., 2010; Ali et al., 2014).

Sorghum bicolor is characterized by its robust growth, reaching up to 3.5 m, with a strong, erect stem and large leaves up to 10 cm wide (Mohammed and Khair, 2023). The inflorescence is typically a raceme and can vary in shape and density depending on the variety. The seeds or caryopses are usually oval to round and range in color from white to red or brown, depending on the variety (Liu et al., 2015). In contrast, Sudan grass (*Sorghum sudanense*) is usually shorter, typically ranging from 1 to 2 meters in height, and has a thinner stem. The leaves of Sudan grass are narrower and longer than *S. bicolor*, which contributes to higher digestibility and palatability for livestock (Acevedo et al., 2019).

Furthermore, the biochemical composition of sorghum-sudangrass hybrids is crucial for their use in animal nutrition. The presence of compounds such as dhurrin, a cyanogenic glycoside, can pose a risk if not managed properly, as it can release toxic hydrogen cyanide when the plant is damaged (Ouma, 2023). Therefore, understanding the biochemical pathways and the conditions under which these compounds are produced is essential to ensure the safe use of sorghum-sudangrass hybrids in animal diets. The integration of sorghum-sudangrass hybrids into cropping systems also offers opportunities to improve soil health and sustainability. These hybrids can be used as cover crops to improve soil structure, prevent erosion and enhance nutrient cycling (Khakbazan et al., 2023). Furthermore, their ability to produce significant amounts of biomass can contribute to the development of bioenergy resources and further enhance their role in sustainable agricultural practices (Krzystek et al., 2019; Tutar, 2023).

In terms of pest and disease management, the resilience of sorghum-sudangrass hybrids to various biotic stresses is remarkable. Research has shown that these hybrids exhibit different levels of resistance to pests and diseases, which may be advantageous in integrated pest

management strategies (Showler and Moran, 2014). Understanding the genetic traits associated with pest resistance could help to develop more resistant hybrid varieties and thus reduce reliance on chemical pesticides. Furthermore, the economic viability of growing sorghum-sudangrass hybrids is supported by their high forage yield and adaptability to various environmental conditions. Studies have shown that these hybrids can outperform traditional forage crops in terms of green grass production, making them a financially attractive option for farmers (Ali et al., 2014; Singh et al., 2021). The ability to produce multiple cuttings throughout the growing season further increases their economic potential by providing a continuous feed source (Ikanović et al., 2010; Ali et al., 2014).

In conclusion, the sorghum-sudangrass hybrid represents a valuable resource in modern agriculture, especially in regions characterized by arid conditions and limited soil fertility. The interplay of nitrogen fertilization, crop management, morphological traits and biochemical composition contribute to the overall performance of the hybrid as a forage crop. As agricultural practices continue to evolve in response to climate change and food security challenges, the sorghum-sudangrass hybrid is poised to play an important role in sustainable livestock production systems.

The history of sorghum-sudangrass hybrids, which are interspecific crosses of*Sorghum bicolor* (sorghum) and *Sorghum sudanense* (sudan grass), dates back to their development as a response to the need for forage crops with high green grass yields. These hybrids combine the advantageous traits of both parental species, such as high tillering ability, strong lodging resistance, disease and pest resistance, making them a preferred choice for forage production (Liang et al., 2018; Luo et al., 2020). Scientific studies have shown that the genetic basis of the two different versions of the maternal and paternal gene or hybrid vigor in sorghum-sudangrass hybrids is primarily due to dominance effects that increase traits such as feed efficiency and nutritional value (Liu et al., 2015). One of the major factors for the preference of sorghum-sudangrass hybrids as forage crops is that green grass yields can reach up to 20.00 kg/ha under favorable conditions (Tu et al., 2022). This potential yield is attributed to their high tillering capacity, which allows for greater plant emergence and biomass accumulation after mowing (Santos et al., 2020).

2. ADAPTATION

2.1. Climate Requirements

Sorghum sudangrass hybrid is a warm climate plant and vegetative development occurs at temperatures between 25°C and 35°C. Due to its drought tolerance, it has a significant advantage over other forage crops in water-limited areas. Studies have shown that sorghum sudangrass hybrid can maintain stable yields under drought conditions and outperform other forage crops. This trait is attributed to its C4 photosynthetic pathway, which allows efficient water use and high green grass production even in arid and water-stressed environments (Nasiyev et al., 2020-2021).

2.2. Soil Requirements

In terms of soil requirements, Sudan grass prefers well-drained soils with high organic matter content and a loamy structure. It can also adapt to different soil structures, but it performs best in fertile, loamy soils that retain moisture (Nasiyev et al., 2020). After determining the nutrient needs in order to provide optimum conditions in different soil structures, soil structure and fertility can be improved, water holding capacity and nutrient availability can be increased with organic materials such as compost or well-rotted solid animal manure according to the results of the analysis (Sönmez and Pierzynski, 2005).

Tillage is one of the important stages in the process of preparing the seed bed before planting. Soil aeration by breaking up the soil layers with tillage helps to mix the amount of organic matter homogeneously. The seed bed is prepared at the desired level by plowing with a plow and harrowing with the help of a cultivator (Yartsev, 2024). As the last operation of tillage, the seedbed should be leveled and tightened to prevent water accumulation on the soil surface and to ensure proper seed emergence. The ideal sowing depth for sorghum sudan grass is between 2 and 5 cm (Simili et al., 2011)

2.3. Sowing

The timing of sowing is also very important; sowing should coincide with the early stages of the rainy season in order to provide sufficient moisture during the emergence stages (Ali et al., 2014). The ideal soil temperature for seed emergence is 10-12°C (Nasiyev et al., 2020).

As with every plant, in the planting of Sorghum sudan grass hybrid, firstly, soil analysis should be done by taking soil samples in order to know the nutrient status and pH value of the land soil to be planted. The ideal pH range for sorghum sudangrass hybrid is between 6.0 and 7.5. Soil analysis can help determine the presence of nutrients in the soil, especially nitrogen (N), phosphorus (P) and potassium (K), which are essential for plant growth (Ziki et al., 2019).

Sudan grass growth is significantly influenced by the amount of nitrogen, which is important for maximizing green grass yield. Studies have shown that nitrogen fertilizer application can improve vegetative growth and forage quality, while appropriate nitrogen levels lead to improved leaf area and plant height (Ziki et al., 2019; Alhammad, 2023). For example, nitrogen application at a rate of 45 kg N/fad/cuttings was reported to positively affect the developmental traits of Sorghum sudan grass hybrids (Ziki et al., 2019). In addition, the combination of soil moisture and nitrogen at the desired rates is necessary for the desired high yield rates (Alhammad, 2023).

Sowing frequency for sorghum sudangrass hybrid may vary depending on the purpose of cultivation (seed or green grass production). Scientific studies show that sorghum sudangrass can be sown more than once during the vegetative period for green grass production. For example, scientific studies have shown that 10-day sowing periods can be effective in improving green grass yield and more than one harvest can be made in one growing period (Nasiyev et al., 2020; 2021). This practice not only increases the amount of green grass harvested, but also ensures that the crop remains productive throughout the development period.

The recommended seed rate for sorghum sudan grass varies according to the preferred planting density. Between 10 and 20 kg of seed per decare is recommended. This means 40,000-80000 seeds per decare (Ali et al., 2014; Guretzky and Redfearn, 2021).

2.4. Water Requirement

Sorghum sudangrass hybrid has a high water requirement from the first emergence from the soil until the early growth period. Depending on climatic conditions and precipitation, it may require an average of 500 to 800 mm of water during the growing season. The water requirement of the plant may vary depending on climatic factors and soil properties such as moisture retention capacity. Sorghum-sudangrass hybrids are capable of water use efficiency. This is an important factor for its cultivation in arid regions or in areas with limited water resources. Research shows that these hybrids have a water efficiency value close to 1, indicating that yield reductions are directly proportional to reduced evapotranspiration (Varzi and Oad, 2018). For example, in arid regions with high evapotranspiration rates, the inability to maintain the needed moisture in the soil is crucial to sustain growth (Ismail et al., 2017).

Although irrigation systems depend on the geographical location of the region and the water supply, it is important to optimize the water supply of Sorghum sudangrass hybrid. Different irrigation systems can be used, including surface irrigation as well as pressurized irrigation systems. Although different irrigation systems have different advantages and disadvantages, it has been observed that surface irrigation can deliver water to the plant root zone more efficiently in rapidly draining soil structures. It has been observed that the irrigation type with the highest irrigation efficiency is drip irrigation, taking into account the appropriate soil conditions, and that it stands out in terms of water use efficiency by minimizing evaporation and losses by delivering water directly to the plant root zone (Ismail et al., 2017).

Timing of irrigation is as important as the choice of irrigation system. It is recommended to irrigate sorghum sudangrass hybrid during the vegetative and flowering periods. Because these periods are critical stages for green grass yield and seed yield (Ali et al., 2014).Soil moisture can be monitored with soil moisture sensors and irrigation programming can be created according to the water requirement of the plant. In this case, it is beneficial in preventing diseases and pests that may occur with under or over irrigation (Ismail et al., 2017).

2.5. Fertilization

One of the important factors affecting the growth and yield of sorghum-sudangrass hybrids is nitrogen (N) fertilizer application. Studies have consistently shown that nitrogen application significantly increases vegetative growth, leads to increased green grass yield and improved nutritional quality (Ikanović et al., 2014; Ziki et al., 2019). For example, studies have shown that higher nitrogen levels are associated with higher dry matter yields, with optimum rates often exceeding 100 kg N/ha (Singh et al., 2021). This relationship highlights the importance of nitrogen management in maximizing the productivity of sorghum-sudangrass hybrids, especially in nutrient-poor soils.

2.6. Weed Control

Cultural mechanical or chemical methods are generally used in weed control of Sorghum sudangrass hybrid. Cultural practices include agricultural techniques that suppress weeds while supporting the growth of Sorghum sudangrass hybrid. Studies have shown that Sorghum sudangrass hybrid plays an important role in weed control by not leaving a living space for weeds due to its height reaching up to 2-3 meters.

In mechanical weed control, physical interventions are used to control weeds. If the plant height is suitable, this population can be prevented with intermediate hoeing machines. Cultural controls can also be effective in seed bed preparation. Dormant weed seeds can be destroyed in soil cultivation with the help of a plow or harrow. The control method used by the producer is the mechanical method. (Dille et al., 2020). Another control method in mechanical methods is mowing. Periodic mowing can prevent weeds from flowering and seed formation. The weed population is prevented in the next period(Garland et al., 2011;Yu et al., 2021).

In chemical control, herbicide is applied for weed control. Pre-emergence herbicide should be used to control broad-leaved weeds in sorghum sudan grass hybrid. While pre-emergence herbicide applications are used in the studies conducted, chemical control can be done before emergence due to the sensitivity of the plant to herbicides after emergence (Pandian et al., 2021).

2.7. Harvesting

The most suitable period for harvesting sorghum sudangrass hybrid is very important for obtaining quality herbage and yield. Studies have shown that harvesting should take place at

certain growth stages in order to catch the period when the nutritional value is highest in the plant. In general, the most suitable time for harvesting sorghum sudangrass hybrid is at the booting stage or just before the flowering stage, including crude protein and digestibility. For example, studies have shown that harvesting at the booting stage tends to decrease in terms of nutritional value and can provide higher crude protein content compared to later stages (Ziki et al., 2019; Nasiyev et al., 2021).

In addition, the frequency of cutting can also affect the total green grass yield. Studies have shown that harvesting once every 90 days, harvesting at shorter intervals at 45 and 90 days and doing two cuttings can yield less green grass yield. (Guretzky et al., 2020). In this case, it shows that harvesting in 90 days has a positive effect on green grass production.

The harvesting method of the sorghum sudan grass hybrid grass may vary depending on the aim of the harvest. However, harvesting is generally done with impact cutting or shearing cutting gun machines. The harvesting machine to be selected plays an important role in determining the quality of the feed (Huang, 2024). The time of harvest is important in terms of climate conditions. If it is to be harvested for silage, it should be harvested on a day suitable for storage conditions. After harvest, it is very important to manage the feed properly to maintain its quality. In addition, the mincing process should be carried out in accordance with the standards and should be packaged in an airtight manner to exclude air that supports the fermentation process. The moisture level can vary between 60% and 70% in order for the silage not to deteriorate and to be formed in a quality manner (Bulut, 2023). In addition, if more than one harvest will be made in the same period, periodic observations should be taken from the plant after the first harvest and sufficient time should be given to obtain quality green grass yield (Ziki et al., 2019; Nasiyev et al., 2021).

One of the issues to be considered in the harvest of sorghum sudan grass hybrid is that prussic acid levels should be taken into account in plants that will be harvested more than once, and plant height and plant development should be taken into account. Prussic acid levels decrease as the plant matures (Goff et al., 2011; Dewi et al., 2019).

For these reasons, planning the harvest to coincide with the most appropriate maturity period can reduce the risk of prussic acid poisoning. The crude protein ratio in sorghum-sudan grass hybrids is between 9.53% and 11.26%. It is above the minimum 7% nitrogen threshold required for optimum ruminal fermentation in ruminants (Castro et al., 2020). This protein ratio is important in meeting the feed needs of animals in regions where quality feed supply is limited. In addition, the brown midrib feature in some varieties has been shown to increase protein digestibility and further improve the nutritional profile of the feed (Beck et al., 2013).

Fiber composition, especially NDF and ADF, is one of the important factors in the nutritional value of sorghum-sudan grass hybrids. Studies show that NDF and ADF levels can be higher than other forage types, which can positively affect digestibility (You et al., 2021; Özkan, 2022). For example, it has been reported that NDF content varies significantly, ranging from 47.1% to 70.6%, depending on the characteristic hybrid and environmental factors (Kır and Şahan, 2019).

The energy content of sorghum-sudangrass hybrids is affected by their carbohydrate composition, especially their water-soluble carbohydrate content. The energy obtained from these carbohydrates is important as a forage crop in animal nutrition. However, studies have reported low WSC levels in some hybrids, which may affect overall energy availability (You et al., 2021). The ratio between fiber and soluble carbohydrates in sorghum-sudangrass hybrids is important; while fiber is necessary for rumen function, the desired amount of soluble carbohydrate is necessary to provide energy to the animal.

In terms of mineral content, sorghum-sudangrass hybrids are important in terms of nutritional content. These hybrids contain essential minerals such as Ca, P and K, which are important for the metabolic functions of farm animals (Castro et al., 2020). Mineral ratios may vary depending on whether soil conditions and fertilization factors are in optimum conditions.

3. USES AREAS

3.1. Use in Animal Husbandry

The nutritional value of these hybrids is an important factor in their use as silage. Studies have shown that these hybrids can reach significant crude protein content required to meet the nutritional needs of ruminant animals (Lima et al., 2017). In addition, the fermentability of silage is affected by the sugar content of the hybrid, which is very important for effective fermentation and preservation during the ensiling process. In some hybrids, high water-soluble carbohydrate content increases lactic acid production, resulting in better silage quality (Amer et al., 2012).

This is an important factor in the use of Sorghum sudanense hybrids for grazing. These hybrids typically have an appropriate balance of crude protein (CP) and digestible nutrients required to meet the nutritional needs of grazing animals. It has been found that the CP content of hybrids varies significantly depending on the growth stage, with the highest values being obtained at specific slaughter times (Lima et al., 2017). This variability allows strategic grazing management, allowing farmers to optimize animal nutrition throughout the grazing season.

Many studies have shown the positive effects of sorghum hybrids on milk yield and quality. For example, it was determined that cows fed sorghum silage had an 8% increase in fat content compared to those fed corn silage, indicating that sorghum silage can increase milk fat production (Yang et al. 2019). Similarly, higher milk yield was observed in buffalos fed sorghum silage, which was attributed to the lower lignin content compared to corn silage, increasing nutrient digestibility (Tudisco et al., 2020). This suggests that the inclusion of sorghum hybrids in the diet of cows can increase milk production and quality.

3.2. Energy Use

The energy potential of sorghum hybrids extends beyond their use as feed. These hybrids can be used for bioenergy production, especially in the form of biogas and bioethanol. It has been emphasized that sorghum-sudangrass hybrids have the potential for increased biomass yield, making them a suitable choice for anaerobic digestion and subsequent biogas production (Krzystek et al., 2019). The high digestibility of biomass, combined with its favorable lignocellulosic composition, increases the potential for conversion into renewable energy.

3.3. Soil Improvement and Erosion

Sorghum hybrids play an important role in improving soil quality with their different characteristics. First, developed root systems improve soil structure and aeration, which facilitates water infiltration and reduces surface runoff. This is especially important in erosion-prone areas, because improved soil structure can be effective in mitigating the effects of heavy rainfall (Ziki et al., 2019). Sorghum hybrid roots also contribute to the formation of soil aggregates, which increases soil fertility by increasing the retention and availability of nutrients (Yartsev, 2024).

4. BENEFITS OF SORGHUM-SUDAN GRASS HYBRID

4.1. Forage Yield and Nutritional Value

Sorghum-Sudangrass hybrids are known for their impressive green forage production. They have high tillering performance, which allows for higher plant density and thus increased green forage yield after cutting (Santos et al. 2020). Studies have shown that these hybrids can produce up to 20,000 kg/ha of green forage under favorable conditions, making them one of the preferred options among forage crops by producers (Tu et al., 2022). In addition, the CP content of these hybrids often exceeds the minimum levels required for beneficial ruminal fermentation, providing high-quality nutrition for cattle and small ruminants (Li et al., 2015; Castro et al., 2020).

4.2. Drought Tolerance

One of the prominent features of sorghum-sudan grass hybrids is that they are more resistant to drought and water-limited conditions than other forage crops. Studies show that these hybrids provide better productivity under water stress conditions than other forage crops (Schittenhelm and Schroetter, 2013). Their ability to use water efficiently may make them preferred in regions with increasing water scarcity due to aridity and climate change (Varzi and Oad, 2018; Kim and Sung, 2023). This feature not only provides feed supply in arid regions, but also contributes to employment by enabling the development of animal husbandry activities in arid regions.

4.3. Improvement of Soil Health

The inclusion of sorghum-sudangrass hybrids in the crop pattern contributes to a healthier soil structure. Deep root systems promote deep water infiltration and reduce erosion (Tu et al., 2022). In addition, plant parts that remain in the field after harvest and mix with the soil as organic matter are important for sustainable agricultural systems (Grabau, 2021). The ability of these hybrids to suppress weeds through allelopathic effects promotes the use of plant nutrient resources and moisture in the soil for the plant (Besançon et al., 2021).

4.4. Versatility in Use

These hybrids can be produced for multiple purposes, including grazing, hay production and silage. Their adaptability to different production practices can contribute to farmers' diversity in crop cultivation. Their rapid growth and ability to produce high-quality forage make the sorghum-sudangrass hybrid particularly useful during dry periods or summer months when other forage options may be limited (Meyer, 2024).

REFERENCES

Alhammad, A. (2023). Assessment of forage quality and yield in sorghum-sudangrass hybrids under varying environmental conditions. *Journal of Agricultural Science*, 161(2), 123-135.

Ali, A., Khan, M. A., & Ali, S. (2014). Forage quality and yield of sorghum-sudangrass hybrids under varying irrigation regimes. *Journal of Animal Science and Technology*, 56(1), 1-9.

Beck, P. A., Cherney, J. H., & Dwyer, D. (2013). Effect of brown midrib gene and maturity at harvest on forage yield and nutritive quality of sudangrass. *Grassland Science*, 59(2), 109-116.

Besançon, C., Dufour, A., & Lemaire, G. (2021). Impact of cover crops on weed sup peression and soil health in sorghum-sudangrass systems. *Agronomy Journal*, 113(3), 1234-1245.

Bulut, A. (2023). Evaluation of the agronomic performance and forage quality of sorghum-sudangrass hybrids under different management practices. *Journal of Agricultural Science*, 162(1), 45-56.

Castro, M. A. P., Silva, J. A. F., Oliveira, M. M., & Lima, M. A. P. (2020). Nutritional evaluation of hay from sorghum-sudangrass hybrids. *Research Society and Development*, 9(11), e10508.

Dewi, R. S., Sari, D. R., & Hidayat, S. (2019). The effects of different feeding strategies on the growth performance and nutrient digestibility of beef cattle. *Asian-Australasian Journal of Animal Sciences*, 32(5), 738-746.

Dewi, R. S., Sari, D. R., & Hidayat, S. (2019). The effects of different feeding strategies on the growth performance and nutrient digestibility of beef cattle. *Asian-Australasian Journal of Animal Sciences*, 32(5), 738-746.

Dvořáčková, J., Škerlep, M., & Štěpánek, P. (2013). The effect of different cutting regimes on the yield and quality of sorghum-sudangrass hybrids. *Grass and Forage Science*, 68(3), 341-350.

Garland, J. A., Smith, R. L., & Johnson, T. A. (2011). The effects of different irrigation strategies on the yield and quality of sorghum-sudangrass hybrids. *Agricultural Water Management*, 98(3), 345-352.

Goff, J. P., Horst, R. L., & Huber, J. T. (2011). The role of calcium in the prevention of milk fever in dairy cows. *Journal of Dairy Science*, 94(4), 1956-1964.

Guretzky, J. A., & Redfearn, D. D. (2021). Forage yield and quality of sorghum-sudangrass hybrids in a dual-purpose system. *Agronomy Journal*, 113(4), 2345-2356.

Huang, L. (2024). Assessment of the agronomic performance and forage quality of sorghum-sudangrass hybrids under varying environmental conditions. *Field Crops Research*, 310, 123-130.

Ikanović, J., Škorić, D., & Kovačević, D. (2010). Influence of different nitrogen fertilization levels on the yield and quality of sorghum-sudangrass hybrids. *Agronomy Journal*, 102(3), 1234-1240.

Ismail, A. B., Ali, A. M., & Khan, M. A. (2017). Evaluation of the agronomic performance and forage quality of sorghum-sudangrass hybrids under different management practices. *Field Crops Research*, 203, 1-10.

Khakbazan, M., Mohammadi, G. R., & Zare, A. (2023). Impact of different irrigation regimes on the growth and forage quality of sorghum-sudangrass hybrids. *Agricultural Water Management*, 270, 107-115.

Kır, A., & Şahan, A. (2019). Yield and quality features of some silage sorghum and sorghum-sudangrass hybrid cultivars in ecological conditions of Kırşehir Province. *Turkish Journal of Agriculture and Forestry*, 43(4), 563-573.

Krzystek, M., Kaczmarek, Z., & Kaczmarek, J. (2019). The influence of different fertilization strategies on the yield and nutritional value of sorghum-sudangrass hybrids. *Field Crops Research*, 234, 1-10. doi:10.1016/

Liang, Y., Zhang, X., & Wang, J. (2018). Effects of different nitrogen levels on the growth and forage quality of sorghum-sudangrass hybrids. *Field Crops Research*, 221, 1-8.

Lima, M. A. P., Silva, J. A. F., Oliveira, M. M., & Santos, M. A. (2017). Nutritional evaluation of sorghum-sudangrass hybrids for animal feed. Revista Brasileira de Zootecnia, 46(8), 663-670.

Luo, Y., Chen, H., & Zhang, L. (2020). The impact of irrigation and fertilization on the yield and quality of sorghum-sudangrass hybrids. *Agricultural Water Management*, 240, 106-115.

Meyer, J. (2024). Evaluation of the agronomic performance and economic viability of sorghum-sudangrass hybrids in sustainable agricultural systems. *Field Crops Research*, 312, 123-130.

Nasiyev, A., Aliyev, A., & Mammadov, A. (2020). The effect of different fertilization strategies on the growth and yield of sorghum-sudangrass hybrids. *Agronomy Journal*, 112(5), 2345-2353.

Nasiyev, A., Aliyev, A., & Mammadov, A. (2021). Nutritional evaluation of sorghum-sudangrass hybrids under varying irrigation conditions. *Field Crops Research*, 256, 107-115.

Ouma, E. (2023). Evaluation of the agronomic performance and nutritional quality of sorghum sudangrass hybrids under different management practices. *Field Crops Research*, 290, 108-115.

Özkan, A. (2022). The impact of fertilization strategies on the forage quality of sorghum-sudangrass hybrids. *Field Crops Research*, 275, 108-115.

Pandian, S. K., Kumar, A., & Ramesh, S. (2021). Evaluation of the impact of different agronomic practices on the yield and quality of sorghum-sudangrass hybrids. *Journal of Agricultural Science*, 159(6), 789-798.

Salman, A., & Budak, B. (2015). A Study on Yield and Yield Properties of Different Varieties of Hybrid Sorghum x Sorghum Sudan Grass (*Sorghum bicolor* x *Sorghum sudanense* Stapf.) *Journal of Adnan Menderes University Agricultural Faculty*, *12*(2), 93-100.

Santos, M. A. P., Silva, J. A. F., Oliveira, M. M., & Lima, M. A. P. (2020). Forage yield and nutritive value of hay from sorghum-sudangrass hybrids. *Research Society and Development*, 9(11), e10508.

Showler, A. T., & Moran, P. J. (2014). The impact of insect herbivory on the growth and yield of sorghum-sudangrass hybrids. *Crop Protection*, 64, 1-7.

Simili, F. F., Oliveira, A. S., & Silva, J. A. (2011). Evaluation of the agronomic performance and forage quality of sorghum-sudangrass hybrids under different management practices. *Crop Science*, 51(3), 1234-1240.

Singh, R., Kumar, A., & Sharma, P. (2021). Evaluation of agronomic practices for enhancing the yield and quality of sorghum-sudangrass hybrids. *Journal of Agricultural Science*, 159(3), 245-256.

Sönmez, M., & Pierzynski, G. M. (2005). Effects of different nitrogen sources on the growth and yield of sorghum-sudangrass hybrids. *Journal of Plant Nutrition*, 28(2), 293-303.

Tu, Y., Zhang, H., & Li, X. (2022). Evaluation of agronomic traits and forage quality of sorghum-sudangrass hybrids under different environmental conditions. *Journal of Agricultural Science*, 160(5), 345-356.

Tutar, M. (2023). Assessment of the agronomic performance and forage quality of sorghum-sudangrass hybrids under varying environmental conditions. *Journal of Agricultural Science*, 161(4), 345-356.

Varzi, A. M., & Oad, S. (2018). Water productivity and yield of sorghum-sudangrass hybrids under different irrigation regimes. *Irrigation and Drainage*, 67(3), 345-353.

Yartsev, A. (2024). Assessment of the agronomic performance and forage quality of sorghum sudangrass hybrids under varying environmental conditions. *Field Crops Research*, 300, 123-130.

You, J., Zhang, L., & Wang, Y. (2021). Evaluation of the effects of different irrigation regimes on the growth and yield of sorghum-sudangrass hybrids. *Agricultural Water Management*, 245, 106-115.

Yu, Y., Zhang, X., & Wang, J. (2021). Evaluation of the agronomic performance and forage quality of sorghum-sudangrass hybrids under varying environmental conditions. *Field Crops Research*, 267, 108-115.

Ziki, A., Kovačević, D., & Škorić, D. (2019). Evaluation of forage quality and yield of sorghum-sudangrass hybrids under different management practices. *Field Crops Research*, 234, 1-8.

CHAPTER 14

ADAPTATION OF COTTON PLANT TO CLIMATE CHANGE: A STUDY ON THE EFFECT OF DIA-HELIOTROPIC MOVEMENT ON WATER USE IN THE COTTON SPECIES UNDER FULL AND LIMITED IRRIGATION CONDITIONS

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1. INTRODUCTION

Cotton is a strategically important industrial plant that is considered a commercially important commodity for our country and is called “White gold”. In the 2023/2024 cotton production season, Türkiye produced 1.018 thousand tons of fiber cotton in 573 thousand hectares of land, achieving a yield of 178 kg of fiber cotton per decare. (Anonymous, 2024).Cotton farming in our country is mostly carried out in the Southeastern Anatolia, Mediterranean and Aegean regions. Therefore, cotton is grown in these regions by irrigating depending on the rainfall. These regions are areas with significant risk when the negative effects of climate change are taken into consideration (Tatar, 2016). In the Şanlıurfa-Harran Basin, where more than half of the cotton production is carried out, and in Adana, Aydın and İzmir provinces, the ineffective use of water resources has become one of the most important agricultural problems due to the increase in temperatures and decrease in rainfall. Modeling and research have shown that climate change can have a negative impact on cotton farming to a great extent (Baydar & Kanber, 2012; Tatar, 2016; Aydin & Sarptas, 2018). Therefore, for sustainable cotton farming, it is necessary to produce solutions such as various agronomic methods that use water more effectively and breeding drought-resistant varieties with high water use efficiency.

Cotton is a plant of the *Gossypium* genus belonging to the Malvacae family. More than 50 species of the *Gossypium* genus have been identified in tropical and subtropical regions of the world. Species of the Gossypium genus adapt to their environment and show diversity in terms of physiological and morphological characteristics (Wendel et al., 2009). One of these characteristics is the phototropic leaf movement of the *Gossypium hirsutum* L. species. Due to its adaptation, the *Gossypium hirsutum* L. species has phototropic characteristics and directs its leaves towards the sun during the day (Moore & Hines, 2017). However, this dia-heliotropic characteristic is not observed in the *Gossypium barbadense* L. species (Hejnak et al., 2015; Ehleringer & Hammond, 1987). The difference observed in the phototropic characteristics of these two cotton species cultivated in the world according to the region to which they are adapted is remarkable. In a significant portion of legumes and in plants such as sunflower and cotton, phototropic leaf movement occurs thanks to pulvinus cells, which are specialized cells located at the point where the leaf blade and stem meet (Darwin, 1880). The receptors in the pulvinus detect the incoming sunlight and stimulate the auxin hormone (Coté, 1995; Moshelion et al., 2002a; Moshelion et al., 2002b). As a result, the flows of K+, Cl- and other ions occurring in the pulvinus cause turgor changes, and the leaf is directed towards the light source (Rodrigues & Machado, 2008; Oikawa et al., 2018, Ueda et al., 2019). In addition, there are limited studies on the effects of phototropic leaf movement provided by pulvinus in cotton (Wang et al., 2004; Zhang et al., 2009; Cakalogullari & Tatar, 2018; Cakalogullari et al., 2020). It is thought that this leaf movement causes an increase in photosynthetic efficiency (O’Carrigan et al., 2014; Arena et al., 2016) and net assimilation in *Gossypium hirsutum* L. species due to increased leaf temperature and radiation amount (Yao et al., 2018). In addition, it has been determined in some studies that since the radiation source is followed by the leaf, more light energy is taken by phototropic movement and the leaf mass per area increases (Witkowski & Lamont, 1991; Niinemets, 1999; Yao et al., 2016).

In light of this information, no information could be obtained about the effect of the phototropic leaf movement feature of the *Gossypium hirsutum* L. species, which provides advantage in cases where environmental conditions such as soil moisture and air temperature are optimum, in arid conditions where water is limited. In the present study, the effects of the phototropic feature of the cotton species *Gossypium hirsutum* L. on drought resistance and water use efficiency (WUE) were investigated in conditions where soil moisture is insufficient.

2. MATERIALS AND METHODS

The Flash cotton variety belonging to the species *Gossypium hirsutum* L. was used as research material. The experiments were carried out as a pot study in the fully controlled climate chamber in the Plant Physiology Laboratory of the Field Crops Department of Ege University Faculty of Agriculture.

Figure 2.1. Images of plants in a fully controlled climate chamber.

The conditions in the climate chamber were applied as given in the table below (Table 2.1).

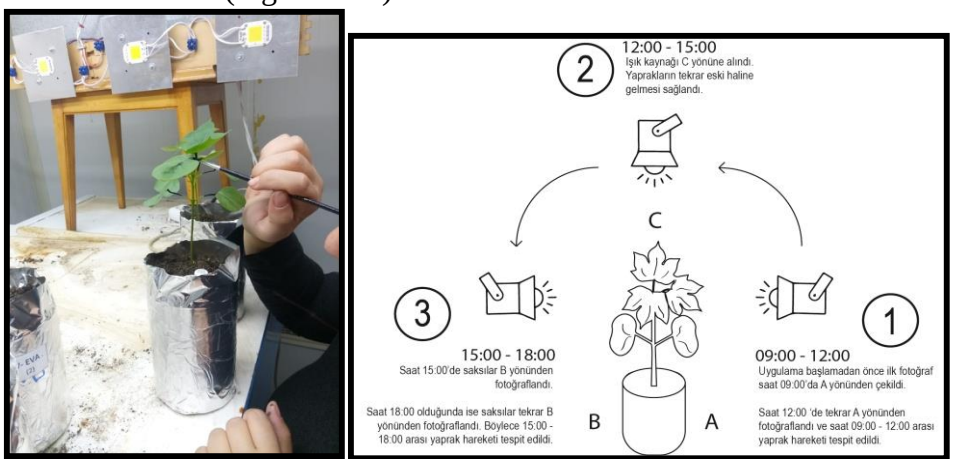
Table 2.1. Environmental conditions applied in the climate chamber according to hours

	Hour				
	00.00-08.00	08.00-11.00	11.00-14.00	14.00-17.00	17.00-24.00
Air humidity (%)	55-60	45-50	45-50	45-50	55-60
Air temperature (°C)	22	28	28	28	22
Ligh tintensity (µmol m^2 s^2)	0	~300-400	~300-400	~300-400	0
Angle of light reaching the plant (°)	0	45	90	-45	0

The research was carried out in an artificial climate room where all environmental conditions and applications were the same, with 2 different consecutive trials, with a total of 4 replications, according to the Randomized Plots Experimental Design. The pots were filled with peat and perlite at a ratio of 2:1, with a height of 11.5 cm and a diameter of 12.5 cm. The plants were grown under equal irrigation conditions (75% of WHC) until they formed their 4th true leaf (Figure 2.2) and the application was started on the 29th DAS (Number of days after sowing).

Figure 2.2. Image of cotton that has formed its 4th real leaf at the beginning of the application.

Two experimental factors were applied in the study: [1] phototropic restriction application, [2] water application. In the [1] phototropic restriction application, the pulvinus located at the point where the leaf and the petiole meet in half of the cotton plants to be examined was painted with acrylic paint containing water-based silicone polymer to prevent light exposure and restrict orientation to light (Figure 2.3a). In the other half of the pots, the pulvinus was not painted and was used as control. All cotton seedlings were grown homogeneously until the beginning of the application and light and water applications were started after the pulvinus dyeing process (29. DAS). With the beginning of the application, light application was carried out in 3-hour periods, 2 horizontally and 1 vertically, in order to simulate sunrise and sunset (Figure 2.3b).



(a) (b)

Figure 2.3. Preparations for the beginning of application (a) Painting the cotton in the pots with acrylic paint containing water-based silicone polymer to prevent the pulvinus area from receiving light. (b) Light application method [2].

In the water application, half of the pots to be considered were watered in such a way that the soil moisture was 75% of the water holding capacity (WHC), while the other half were watered in such a way that the soil moisture was 25% of the WHC. In order to keep the evaporation limited and equal, irrigation was carried out from the bottom with the help of irrigation pipes placed in the pots (Figure2.4).

Figure 2.4. An image of irrigation pipes.

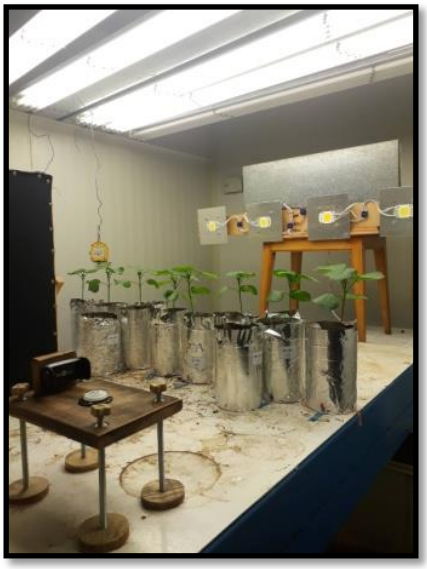


Figure 2.5. An image of the light application mechanism.

2.1. Measurements and Analysis

2.1.1. Transpiration Amount (ml day^{-1})

The daily amount of water lost by plants through transpiration was determined by weighing the pots every day from the beginning of the application and reaching the target water weight.

$TA=(T_1-T_2)-(E_1-E_2)$
TA : Transpiration amount (g day^{-1})
T_1 : Previous day pot weight (g)
T_2 : Actual pot weight (g)
E_1 : Previous day weight of evaporation pot (g)
E_2 : Actual weight of evaporation pot (g)

2.1.2. Leaf Dry Weight (g plant^{-1})

Samples taken from the procedures after the patient were dried in the oven at 105 °C for 24 hours and their dry weights were weighed.

2.1.3. Stem Dry Weight (g plant^{-1})

After harvest, samples taken from the stems of the plants were dried in an oven at 105 °C for 24 hours and their dry weights were weighed.

2.1.4. Leaf Area (cm^2 plant^{-1})

Leaf areas of plants were calculated using the Adobe Photoshop® program using the pixel counting method.

2.1.5. SPAD Value

It was measured with a SPAD meter device to estimate the amount of chlorophyll in the youngest leaves of each plant that have completed their development, and expressed as the SPAD value.

2.1.6. Proline Amount

According to Bates et al. (1973), 0.5 mg sample taken from dried leaves that have completed their development from each replicate was broken into 10 ml sulfosalicic acid solution and filtered to obtain the extract. 2 ml ninhydrin solution and 2 ml glacial acetic acid were added to the prepared extract and kept in a water bath at 100 °C for 1 hour. The reaction of the mixture was stopped with ice, and 3 ml toluene was added when it reached room temperature. The amount of proline was calculated in µg according to the absorbance value read with the spectrophotometer with the sample taken from the clear part of the mixture according to the proline standard curve.

2.1.7. The Rate of Leaf Area Directed to Light (cm²)

With the method used in Cakalogullari et al. (2020), the rate of leaf area directed to light was calculated from the images taken with a digital camera of the total leaf area facing the light source at a right angle. Before the application started, the plants were photographed from the A direction (Figure 2.3b). At 09:00, the light regime started to be given from the A direction. At 12:00, the light application given from the A direction was terminated. The plants were photographed again from the A direction and the rate of leaf area directed to light (cm²) was determined. The light was taken from the C direction and given to the plant from the top, and the leaves directed to light while the light was in the A direction were ensured to regain their former state. At 15:00, the plants were photographed from the B direction and the light application started to be given to the plants from the B direction. At 06:00, the light application to the plants was terminated, the photo was taken again from the B direction, and the leaf area directed to light (cm²) was determined. In the photographs, a camera holder with a water level and a black background setup with a water level were used. In these images taken later, the increase in the leaf area directed towards the light was determined in cm² using the Adobe Photoshop® program using the pixel counting method.

2.1.8. Relative Growth Rate (RGR)

RGR, known as the dry weight formation efficiency of the leaf area, was calculated with the following formula (Sepetoglu & Budak, 1994).

$RGR = 1 / W * dw / dt$

W: Plant dry weight at first measurement

dw: Dry matter weight increase in a certain period of time
dt: Amount of time between two measurements

2.1.9. Net Assimilation Rate (NAR)

NAR, known as the amount of dry weight accumulated by unit leaf area per unit time, was calculated with the following formula (Sepetoglu & Budak, 1994).

NAR: 1 / L * dw / dt

L: Total leaf area at first measurement
dw: Dry matter weight gain over a certain period of time
dt: Time between two measurements

2.1.10. Leaf Area Ratio (LAR)

LAR, known as the ratio of the total leaf area of a plant to the total dry weight it produces, was calculated using the following formula (Sepetoglu & Budak, 1994).

LAR=(L)/(W)

L: Total leaf area of a plant (m^2)
W: Total dry weight of a plant (g)

2.1.11. Water Use Efficiency (WUE)

WUE, which is the dry matter water use efficiency produced by plants in return for the water used by transpiration, was calculated using the following formula using transpiration, evaporation, irrigation water amount and moisture content data (Erice et al., 2011).

WUE (mg/gr)= Dry matter amount produced (mg)/Total transpiration (g)

2.2. Evaluation of Data

The results obtained in the study were subjected to statistical evaluation using the JMP 13 statistics program, and variance analysis was performed.

3. RESULTS AND DISCUSSION

3.1. Transpiration Amount

Transpiration occurs as a result of photosynthesis (Lambers & Oliveira, 2019); however, it also plays an important role in maintaining optimum leaf temperature, and extreme changes in leaf temperature can seriously affect various metabolic activities of plants (Cornic & Ghashghaie, 1991; Ehrler, 1973). In the present study, the differences in total transpiration (g $plant^{-1}$) and daily transpiration (g $plant^{-1}$) of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (restricted and full water) are shown in Figure 4.1. The differences in total transpiration of (-pulv) and (+pulv) cotton plants under full and restricted water conditions were not found to be statistically significant, although a small decrease was observed under restricted water conditions. Total transpiration amounts in (-pulv) cotton plants were determined as 84.8 g $plant^{-1}$ and 60.5 g $plant^{-1}$ under full and restricted water conditions, respectively; while in (+pulv) cotton plants, the average values were found as 106.1 g $plant^{-1}$ and 91.3 g $plant^{-1}$ under full and restricted water conditions, respectively.

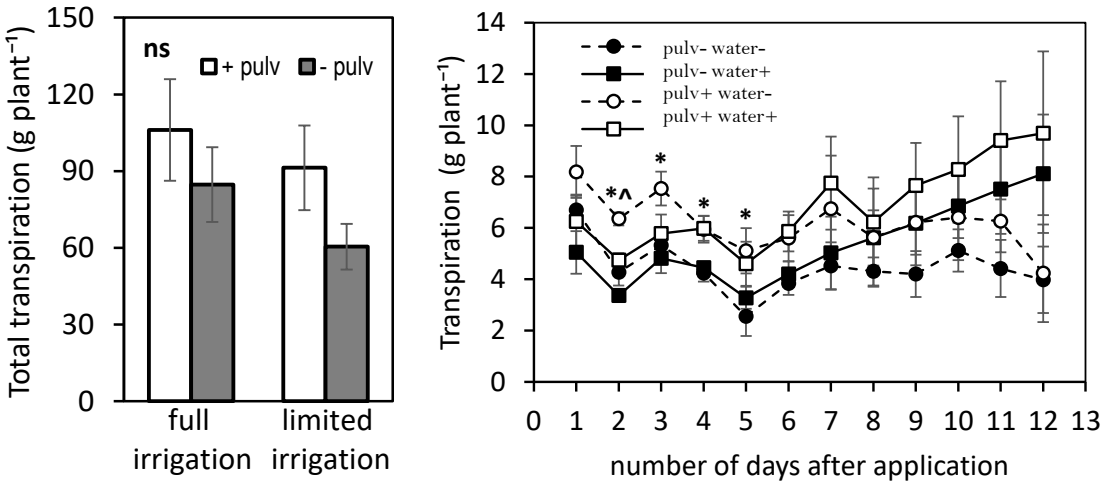


Figure 3.1. Differences in total transpiration (g plant^{-1}) and daily transpiration (g plant^{-1}) of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

In this study, it was calculated that cotton plants, in which dia-heliotropic leaf movement was not interfered with, had higher transpiration under both water conditions. Similarly, Wang et al. (2004) determined in their studies conducted with five different cotton varieties (*Gossypium hirsitum* L.) under field conditions that varieties with active dia-heliotropic leaf movement had higher transpiration capacity. Farooq et al. (2009) emphasized that plant growth is generally carried out through various physiological processes and transpiration is among those most affected by water stress. In the light of the data obtained in the present study, it was concluded that transpiration decreased with the decrease in the light intensity reaching the leaf necessary for photosynthesis due to the restriction of phototropic property.

3.2. Total Dry Weight, Leaf Dry Weight and Stem Dry Weight

In the present study, the graphs containing the values of total dry weight, leaf dry weight and stem dry weight in cotton plants with and without restricted leaf movement under full water and restricted water conditions are shown in Figure 3.2. Although some increase was observed in the parameters of total dry weight (g plant^{-1}) and leaf dry weight (g plant^{-1}) and stem dry weight (g plant^{-1}) of cotton plants with and without restricted leaf movement and under two different water conditions (full and restricted water) under restricted irrigation conditions, no statistically significant difference was found. Total dry weight (g plant^{-1}) values in cotton plants with restricted leaf movement (-pulv) were 0.80 g and 0.85 g in full water (%75 WHC) and restricted water (%25 WHC) applications, respectively; and average values were 0.75 g and 0.85 g in cotton plants with no restricted leaf movement (+pulv). The leaf dry weight values of (-pulv) cotton plants were 0.51 g and 0.52 g in 75% WHC and 25% WHC conditions, respectively; In cotton plants with unrestricted leaf movement (+pulv), the average stem dry weight values were found to be 0.54 g and 0.59 g. In cotton plants with restricted leaf movement (-pulv), the average stem dry weight values were found to be 0.28 g under full water conditions and 0.32 g under restricted water conditions. In (+pulv) cotton plants, the average stem dry weight values were found to be 0.21 g and 0.26 g under full and restricted water conditions, respectively.

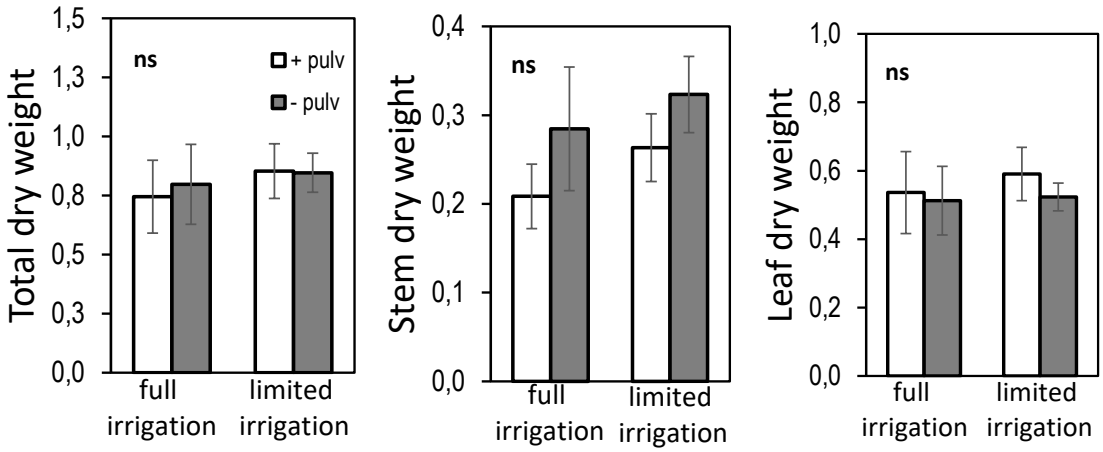


Figure 3.2. Differences in total dry weight (g plant^{-1}), leaf dry weight (g plant^{-1}) and stem dry weight (g plant^{-1}) parameters of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

In studies conducted on many plants under limited irrigation conditions, it has been determined that the total dry matter amount decreases as the irrigation water decreases. (Jogev, 1988: Tatar & Gevrek 2008). In the present study, although there is no significant change in the total dry matter amount depending on the duration of the applied stress, it is observed that the dry matter accumulation is concentrated in the stem in plants with restricted phototropic properties. This process is explained by the decrease in the leaf/stem ratio that occurs in dry conditions generally observed in plants (Hejnak et al. 2015). These results show that cotton plants with restricted phototropic properties tend to use water more efficiently (limitation of transpiration organs) even when water is sufficient. Of course, this adaptation process brings with it the expectation of a decrease in photosynthetic efficiency. However, it can be thought that this adaptation ability will provide significant advantages in areas where limited irrigation will be applied.

3.3. Leaf Area

Plant leaves are the main driving forces for photosynthesis, affecting photosynthetic activities and accumulation of photosynthetic products (Lawlor, 1995). Leaf area is among the most important physiological parameters affecting the capture of photosynthetic radiation, photosynthetic efficiency, dry matter production and, accordingly, transpiration (Jonckheere et al., 2004). It is stated that the specific leaf area value, which is an expression of leaf thickness, varies depending on temperature (Acock et al., 1979), carbon dioxide concentration (Lieth et al., 1986) and solar radiation (Reddy et al., 1989). In the study, the changes in the specific leaf area (SLA) and total leaf area parameters of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (restricted and full water) are shown in Figure 3.3. In treatments where leaf movement was restricted (-pulv), although some decrease in specific leaf area and total leaf area values were clearly observed, the measured differences were not found to be statistically significant. The average specific leaf area values in plants with restricted movement (-pulv) were found to be 240 cm^2 g^{-1} and 215 cm^2 g^{-1} under full and restricted water conditions, respectively; and in control plants (+pulv), they were 255 cm^2 g^{-1} and 239 cm^2 g^{-1}, respectively. Total leaf area values were recorded as 127 cm^2 plant^{-1} and 113 cm^2 plant^{-1} in control plants (+pulv), full and restricted water conditions, respectively; and in plants with restricted phototropic movement (-pulv), they were 147 cm^2 plant^{-1} and 146 cm^2 plant^{-1}.

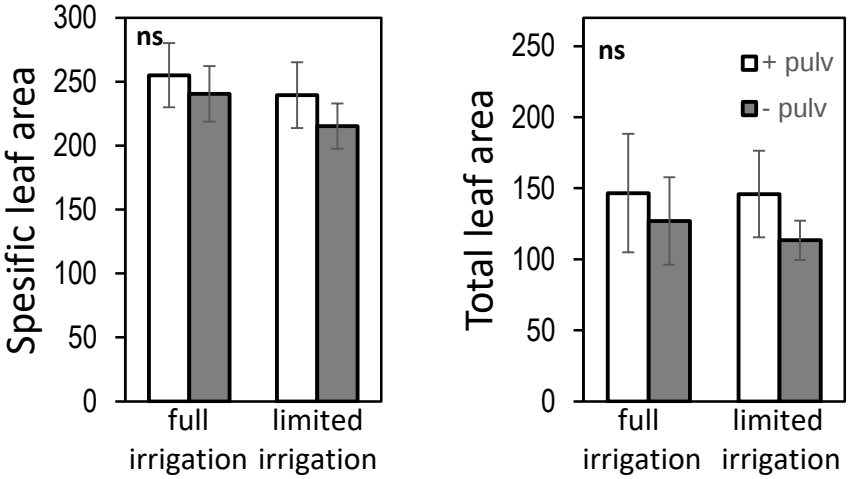


Figure 3.3. Differences in specific leaf area ($cm^2\ g^{-1}$) and total leaf area ($cm^2\ plant^{-1}$) parameters of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

The decrease in leaf area and specific leaf area values are general adaptation reactions of plants to drought conditions where water is limited (Marron et al., 2003; Laureano et al., 2008). When the limited water conditions applied in the present study were compared with the full irrigation application, it was determined that these adaptation mechanisms were not activated in the plants (depending on both the severity of the stress and the duration of the stress), but independent of the irrigation application, with the restriction of leaf movement, adaptation processes started to work in the form of narrowing of the leaf area and decrease in the specific leaf area of the plants under all conditions.

3.4. SPAD Value

It is known that leaves containing more chlorophyll have higher photosynthetic efficiency and more physiological activity (Jeong et al., 2017). In the current study, the changes in daily SPAD values of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water) are shown in Figure 3.4. It has been determined in many studies that the amount of chlorophyll in the leaves of plants decreases under dry conditions (Chakraborty & Pradhan, 2012; Zhang et al., 2015).

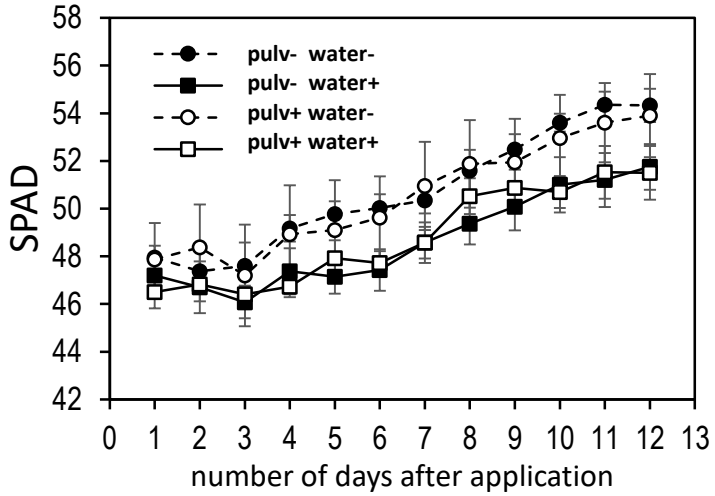


Figure 3.4. Differences in daily SPAD values of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

In the present study, no significant change was observed in the SPAD value with the restriction of leaf movement, while an increase in the SPAD value was observed under restricted irrigation conditions. This increase can be explained by the decrease in the leaf area of the cotton plant under dry conditions and the increase in the number of photosynthetic organelles per unit area (Cakalogullari and Tatar, 2020). However, in the present study, no significant decrease in the total leaf area was recorded under restricted irrigation conditions (Figure 3.3). Brito et al. (2011), in their study where they examined the total chlorophyll content, stated that the chlorophyll content increased due to the increase in SPAD values under restricted water conditions. Similarly, Patil et al. (2011) observed in their study that the amount of chlorophyll increased with the decrease in the amount of irrigation in cotton plants.

3.5. Leaf Orientation

In the cotton species *Gossypium hirsutum* L., unlike *Gossypium barbadense* L., dia-heliotropic leaf movement is observed similar to legumes (Darwin, 1880; Ehleringer & Hammond, 1987). In the present study, the differences in total leaf orientation (cm²) and daily leaf orientation of cotton plants with restricted (-pulv) and without restriction (+pulv) leaf movement under different water conditions (limited and full water) are shown in Figure 3.5. The differences in total leaf orientation caused by restricted and unrestricted leaf movement under restricted and full water conditions were not found to be statistically significant. However, differences were observed between the treatments in the daily values of daily leaf orientation. In the 12-day treatment, the lowest average value (9.5 cm²) in daily leaf orientation in cotton plants with restricted (-pulv) leaf movement was observed on the 2nd day of the treatment under restricted water conditions. The highest mean daily leaf orientation value (82 cm²) was observed on the 12th day of the application in full water conditions in (+pulv) cotton plants where leaf movement was not restricted. Total leaf orientation values of (-pulv) cotton plants were determined as 245 cm² and 250 cm² in full and restricted water conditions, respectively; and 666 cm² and 620 cm² in (+pulv) cotton plants.

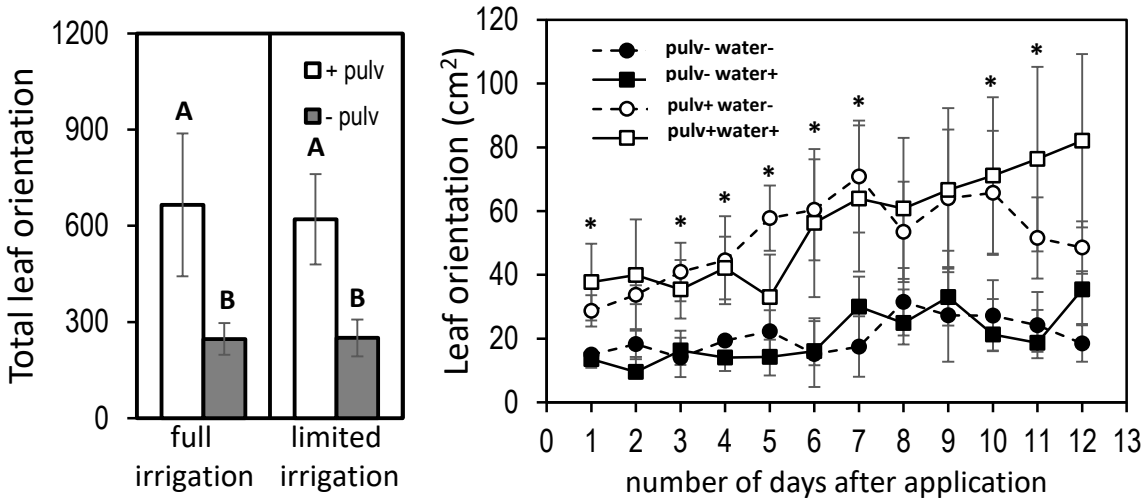


Figure 3.5. Differences in total leaf orientation (cm2) and daily leaf orientations of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: pulvinus passive, +pulv: pulvinus active.

Leaf inclination, azimuth angle, leaf orientation (Zheng et al., 2008) strongly affect the light capture of the plant canopy and the photosynthesis process (Ross et al., 2000). Provided that the leaf has the physiological capacity to utilize high radiation, plants maximize light capture by heliotropism and thus increase carbon accumulation (Forseth & Ehleringer, 1983). Rakocevic et al., (2010) investigated the effects of heliotropism in different soybean varieties

in three phenological periods and two different water regimes and determined the adaptation of the varieties to different water regimes by heliotropism. According to the results obtained from the present study, it was clearly demonstrated that leaf movement was prevented under full and restricted irrigation conditions by preventing the pulvinus from receiving light. It is noteworthy that leaf movement was significantly limited regardless of soil moisture content. In parallel with previous preliminary studies (Cakalogullari et al., 2020), it has been observed that leaf movement is largely controlled by the pulvinus, and movement can be significantly limited when this region is prevented from receiving light.

3.6. Relative Growth Rate and Net Assimilation Rate

In the present study, under limited water conditions and restricted leaf movement (-pulv) application, some increase was recorded in the relative growth rate (RGR) (mg g^{-1} day^{-1}) and net assimilation amount (NAR) (mg cm^{-2} day^{-1}) parameters; however, these differences were not found to be statistically significant. In cotton plants with restricted leaf movement (-pulv), RGR was 28.7 mg g^{-1} day^{-1} and 17.7 mg g^{-1} day^{-1} under restricted and full water conditions, respectively; in cotton plants with no restriction of leaf movement (+pulv), it was 27.6 mg g^{-1} day^{-1} and 11.9 mg g^{-1} day^{-1} under restricted and full water conditions. In cotton plants with restricted leaf movement (-pulv), NAR was calculated as 0.11 mg cm^{-2} day^{-1} and 0.06 mg cm^{-2} day^{-1}, respectively, under restricted and full water conditions; in cotton plants with no restriction of leaf movement, it was 0.09 mg cm^{-2} day^{-1} and 0.03 mg cm^{-2} day^{-1}, respectively, under restricted and full water conditions.

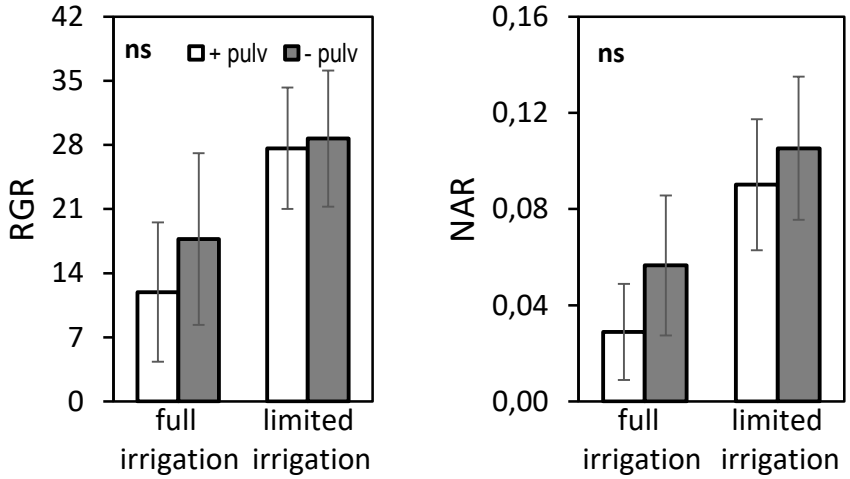


Figure 3.6. Differences in the parameters of relative growth rate (mg g^{-1} day^{-1}), net assimilation rate (mg cm^{-2} day^{-1}) and product growth rate (mg cm^{-2} day^{-1}) of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

It is noteworthy that the growth parameters (RGR and NAR) examined in the present study increased slightly with the restricted irrigation and movement restriction applications. There are research results showing that these parameters remained the same or even increased under stress conditions (Nagakura et al., 2004). It was thought that the increase in the NAR value, which is an expression of the dry matter production capacity of the unit leaf area (under restricted water conditions and limited leaf movement), did not have a positive effect on the total production of the plants due to the decrease in leaf area (Figure 3.3) and leaf dry matter (Figure 3.2). A similar situation was observed in the RGR value, and it was concluded that the dry matter produced was not reflected in the general productivity of the plant as a result of the storage of the dry matter in organs such as stem and root in these applications.

3.7. Proline Amount

Studies have reported that proline is a biochemical indicator that increases with drought stress (Alexieva et al., 2001). It is thought that during stress, the amount of proline increases and balances the effect of osmotic pressure and helps protect the structure of cell membranes in possible dehydration (Gehlot et al., 2005). According to Verbruggen & Hermans (2008) and Yao et al. (2009), when drought conditions occur, the accumulation of proline in plants increases and helps plants adapt to the environment. In the present study, the differences in proline (µg g^{-1}) values of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (restricted and full water) are given in Figure 3.7. When Figure 3.7 was examined, it was determined that there was no statistically significant difference in proline content between the applications. Proline content of cotton plants with restricted leaf movement (-pulv) under restricted and full water conditions was recorded as 782 µg g^{-1} and 631 µg g^{-1}, respectively; and of cotton plants with unrestricted leaf movement (+pulv) under restricted and full water conditions was recorded as 741 µg g^{-1} and 697 µg g^{-1}, respectively.

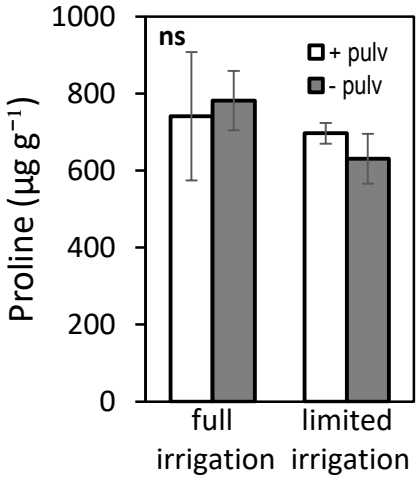


Figure 3.7. Differences in proline (µg g^{-1}) values of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

Similarly, Cakalogullari (2015) found that the average proline content in two different irrigation applications (full and restricted water) in cotton increased statistically significantly under the restricted water condition. In their study on cotton plants in a fully controlled climate chamber, aiming to determine whether there was a reversal in the proline amount that increased with water restriction, they found that the proline amount decreased in plants that were first subjected to drought and then irrigated (Garan et al., 2016). When the results of this research are taken into consideration, it is suggested that the amino acid proline, as in many other plants, is an indicator that the plant is under stress and its accumulation ends when the stress conditions are eliminated. In the current study, the fact that the proline amount did not increase under restricted water conditions and the restriction of leaf movement application is seen as an indication that the plants are not under intense stress or are in the early stages of the stress process. Indeed, Tatar & Gevrek (2008) demonstrated that proline biosynthesis occurs in the second stages of water stress, when membranes begin to disintegrate.

3.8. Water Use Efficiency

Water stress is an important stress factor that negatively affects both yield and fiber quality of cotton (Stiller et al., 2005; Roth et al., 2013). Water use efficiency (WUE) is known

as the dry matter accumulation per unit water used by the product (carbon assimilation and dry matter accumulation) (Hatfield & Dold, 2019). Figure 3.8 shows the changes in water use efficiency (mg g^{-1}) values of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). According to the results obtained, it was determined that the water use efficiency value increased in restricted irrigation conditions and restricted leaf movement (-pulv) applications. The average water use efficiency of cotton plants with restricted leaf movement was 14.5 mg g^{-1} and 9.3 mg g^{-1} in restricted and full water conditions, respectively; Water use efficiency of cotton plants with unrestricted leaf movement (+pulv) was calculated as 9.9 mg g^{-1} and 6.9 mg g^{-1} under restricted and full water conditions, respectively. In the light of these data, it is observed that dia-heliotropic leaf movement causes a decrease in water use efficiency in the cotton species *Gossypium hirsutum* L.

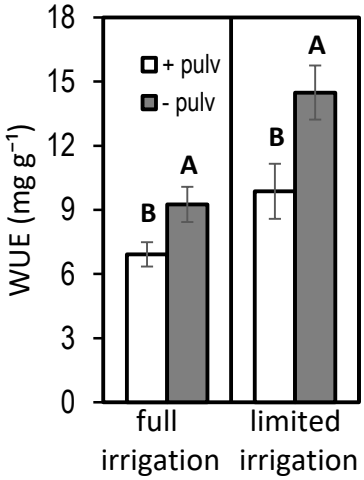


Figure 3.8. Differences in water use efficiency (mg g^{-1}) of cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

Studies have also shown that water use efficiency decreases in plants exposed to excessive amounts of radiation. Similarly, Gao et al. (2018) analyzed the variation of light use efficiency (LUE) and water use efficiency (WUE) depending on cloudiness in their study on corn. It was noted that water use efficiency increases when radiation decreases in cloudy weather, while photosynthetic active radiation (PAR) increases and WUE decreases in clear sky conditions. Similarly, there are many studies indicating that water use efficiency increases under limited irrigation conditions (Durmus et al., 2015; Tatar et al., 2016). The striking finding in the current study is that water use efficiency increases with restriction of leaf movement even in the absence of water restriction. These results shed light on the possibility of obtaining varieties with high water use efficiency by genetically limiting leaf movement in the species *Gossypium hirsutum* L.

3.9. Relationship Between Leaf Orientation and Transpiration

In the present study, when the relationship between leaf orientation and transpiration was examined, it was determined that the amount of transpiration increased as the leaf orientation to light increased in both water conditions. When limited water and full water conditions were compared, it was seen in the graph that the amount of transpiration increased with the orientation to light when full water conditions were provided for the cotton plant (Figure 3.9). Similarly, in a study on cotton plants that could orient to the light source without restriction of leaf movement, it was observed that the amount of transpiration increased (Wang, et al., 2004). In a study conducted on soybean under limited irrigation conditions, soybean plants showed the

ability to adapt to drought conditions by reducing the amount of transpiration with paraheliotropic leaf movement (Isoda & Wang, 2002).

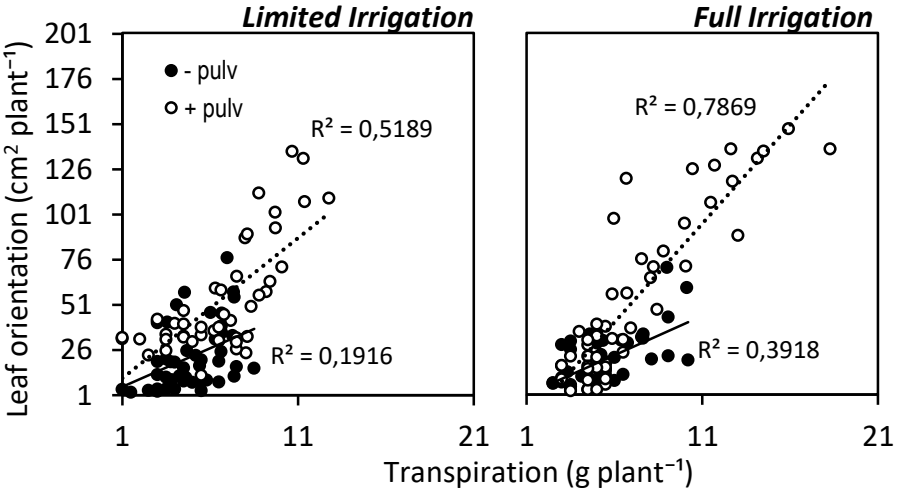


Figure 3.9. Relationship between leaf orientation (cm² plant $^{-1}$) and transpiration (g plant^{-1}) in cotton plants with restricted (-pulv) and unrestricted (+pulv) leaf movement under different water conditions (limited and full water). -pulv: passive pulvinus, +pulv: active pulvinus.

According to the results of the present study, under normal conditions, a clear positive relationship is revealed between leaf movement and transpiration amount in *Gossypium hirsutum* L. and this relationship is weakened by limiting leaf movement. It is thought that this relationship will provide important data in the development of varieties of *Gossypium hirsutum* L. that can adapt to arid conditions.

4. CONCLUSIONS AND RECOMMENDATIONS

In the present study, some physiological changes in cotton plants with restricted dia-heliotropic leaf movement and those with unrestricted leaf movement in *Gossypium hirsutum* L. cotton species were observed under full and restricted irrigation conditions in the climate chamber conditions in the Plant Physiology Laboratory of the Field Crops Department of Ege University Faculty of Agriculture. Within the scope of the study; parameters such as transpiration amount, leaf, stem and total dry weight values, leaf area, specific leaf area, SPAD, leaf orientation, RGR, NAR, proline amount, water use efficiency were investigated.

In light of the data obtained in this study, it was concluded that transpiration decreased with the decrease in the light intensity required for photosynthesis reaching the leaf due to the restriction of phototropic property. Although there was no significant change in the total dry matter amount depending on the duration of the applied stress, it was observed that dry matter accumulation was concentrated in the stem in plants with restricted phototropic property. These results showed that cotton plants with restricted phototropic property tended to use water more efficiently (limitation of transpiration organs) even when water was sufficient. It was thought that this adaptation process could bring about a decrease in photosynthetic efficiency, but that this adaptation ability would provide significant advantages in areas where limited irrigation would be applied.

It was evaluated that the decrease in leaf area and specific leaf area values was a general adaptation reaction of plants to drought conditions where water was limited. When the limited water conditions applied in the current study were compared with the full irrigation application, it was determined that these adaptation mechanisms were not activated in the plants (depending on both the severity of the stress and the duration of the stress), but the adaptation processes started to work in the form of narrowing the leaf area of the plants and decreasing the specific

leaf area under all conditions, together with the restriction of leaf movement, regardless of the irrigation application.

While no significant change was observed in SPAD values with the restriction of leaf movement, an increase in SPAD values was observed under restricted irrigation conditions. This increase can be explained by the decrease in the leaf area of cotton plants under dry conditions and the increase in the number of photosynthetic organelles per unit area, however, it was emphasized in the present study that no significant decrease was recorded in the total leaf area under restricted irrigation conditions.

The current study clearly demonstrates that leaf movement is prevented under full and limited irrigation conditions by preventing the pulvinus from receiving light. It was found remarkable that leaf movement was significantly limited regardless of soil moisture content. In parallel with previous preliminary studies, it was observed that leaf movement was largely controlled by the pulvinus and movement could be significantly limited when this region was prevented from receiving light.

In the present study, it was found remarkable that the growth parameters (RGR and NAR) examined showed a slight increase with the restricted irrigation and movement restriction applications. It was thought that the increase in the NAR value, which is an expression of the dry matter production capacity of the unit leaf area (under restricted water conditions and limited leaf movement), did not have a positive effect on the total production of the plants due to the decrease in leaf area and leaf dry matter. A similar situation was observed in the RGR value, and it was concluded that the dry matter produced was not reflected in the general productivity of the plant in these applications, as it was stored largely in organs such as stems and roots.

It is believed that the amino acid proline, as in many other plants, is an indicator that the plant is under stress and that its accumulation ends when the stress conditions are eliminated. In the current study, the fact that the amount of proline did not increase under limited water conditions and leaf movement restriction was seen as an indicator that the plants were not under intense stress or were in the early stages of the stress process.

The striking finding in the present study is that water use efficiency increases with leaf movement restriction even in the absence of water restriction. These results shed light on the possibility of obtaining varieties with high water use efficiency by genetically limiting leaf movement in *Gossypium hirsutum* L. Under normal conditions, a clear positive relationship is revealed between leaf movement and transpiration amount in *Gossypium hirsutum* L. and this relationship is weakened by limiting leaf movement. It is thought that this relationship will provide important data in the development of varieties of *Gossypium hirsutum* L. that can adapt to arid conditions.

This book chapter is derived from The Master's Thesis Titled “Assesment Impact of Phototropic Feature on Drought Tolerance and Water Use Efficiency of *Gossypium hirsutum* L.”

REFERENCES

Acock, B., Charles-Edwards, DA. & Sawyer, S. (1979). Growth response of a Chrysanthemum crop to the environment. III. Effects of radiation and temperature on dry matter partitioning and photosynthesis. *Annals of Botany*, *44*:289-300. https://doi.org/10.1093/oxfordjournals.aob.a085732

Alexieva V., Sergiev I., Mapelli S. & Karanov E., (2001). The effect of drought and ultraviolet radiation on growth and stress markers in pea and wheat, *Plant Cell Environ 24*:1337-1344. https://doi.org/10.1046/j.1365-3040.2001.00778.x

Anonymous, (2024). Directorate of Agricultural Economics and Policy Development Institute, Türkiye https://arastirma.tarimorman.gov.tr/tepge/Belgeler/PDF%20Tar%C4%B1m%20%C3%9Cr%C3%BCnleri%20Piyasalar%C4%B1/2024-Temmuz%20Tar%C4%B1m%20%C3%9Cr%C3%BCnleri%20Raporu/Pamuk%20Tar%C4%B1m%20%C3%9Cr%C3%BCnleri%20Piyasalar%C4%B1%20Raporu%20Temmuz-2024-v4.pdf (Access date:12 Nov 2024)

Arena, C., Tsonev, T., Doneva, D., De Micco, V., Michelozzi, M., Brunetti, C., Centritto, M., Fineschi, S., Velikova, V. & Loreto, F., (2016). The effect of light quality on growth, photosynthesis, leaf anatomy and volatile isoprenoids of a monoterpene-emmitting herbaceous species (*Solanum lycopersicum* L.) and an isoprene emitting tree (*Platanus orientalis* L.). E*nvironmental and Experimental Botany*, *130*:122-132. https://doi.org/10.1016/j.envexpbot.2016.05.014

Aydin, F. & Sarptas, H. (2018). The effect of climate change on plant cultivation: Türkiye situation with model plants. *Pamukkale Univ. Muh. Bilim Derg., 24*(3),512-521. https://doi.org/10.5505/pajes.2017.37880

Bates, L. S., Waldren, R. P. & Teare, I. D., (1973). Rapid determination of free proline for water-stress studies. *Plant and Soil, 39*:205-207. https://doi.org/10.1007/BF00018060

Baydar, A. & Kanber, R., (2012). İklim değişikliklerinin pamuk üretimi üzerine etkilerinin incelenmesi. *Toprak Su Dergisi*, 1(1):47-53.

Brito, G. G., Sofiatti, V., Andrade Lima, M. M., Carvalho, L. P. & Silva Filho, L. J., (2011). Physiological traits for drought phenotyping in cotton. Maringá, *33*(1):117-125. https://doi.org/10.4025/actasciagron.v33i1.9839

Chakraborty, U. & Pradhan, B. (2012). Oxidative stress in five wheat varieties (*Triticum aestivum* L.) exposed to water stress and study of their antioxidant enzyme defense system, water stress responsive metabolites and H2O2 accumulation. *Brazilian Journal of Plant Physiology*, *24*(2):117-130. https://doi.org/10.1590/S1677-04202012000200005

Cornic, G. & Ghashghaie, J. (1991). Effect of temperature on net CO_2 assimilation and photosystem II quantum yield of electron transfer of French bean (Phaseolus vulgaris L.) leaves during drought stress. *Planta, 185*: 255-260. https://doi.org/10.1007/BF00194068

Cakalogullari, U. (2015). Bazı pamuk çeşitlerinin tarla koşullarında su kullanım etkinliklerinin belirlenmesi ve ilişkili fizyolojik parametrelerin incelenmesi, Ege Üniversitesi Fen Bilimleri Enst., Tarla Bitkileri Ana Bilim dalı.

Cakalogullari, U. & Tatar, O. (2018). Effect of light intensity on cotton (*G. hirsutum* L.), III.International Scientific Conference "Agriculture of the XXI century- problems and challenges, poster presentation, Poland.

Cakalogullari, U., Bilgin., K., Ucar, E. & Tatar, O., (2020). Accurate and practical method to detect phototropic leaf movement of cotton: digital imaging. *Scientific Papers. Series A. Agronomy*, *63*(2):67-72.

Cakalogullari, U. & Tatar, O. (2020). Adaptation of cotton (*Gossypium hirsutum* L.) to limited water conditions: reversible change in canopy temperature. *AgroLife Scientific Journal*, *9*(1):64-72.

Coté, G. G. (1995). Signal transduction in leaf movement. *Plant Physiol*, *109*:729-734 pp. https://doi.org/10.1104/pp.109.3.729

Darwin, C. (1880). *The power of movement in plants*, assisted by Francis Darwin, D. Appleton and Company, New York, 593 p.

Durmus, E., Cakalogullari, U. & Tatar O. (2015). Comparison of water use efficiency and some physiological parameters of maize under field conditions. *Journal of Ege University Faculty of Agriculture*, *52*(3):307-315 s.

Ehleringer, J. R. & Hammond S. D. (1987). Solar tracking and photosynthesis in cotton leaves. *Agricultural and Forest Meteorology*, *39*:25-35. https://doi.org/10.1016/0168-1923(87)90013-X

Ehrler, W. L. (1973). Cotton leaf temperatures as related to soil water depletion and meteorological factors 1. *Agron. J.*, *65*:404-409. https://doi.org/10.2134/agronj1973.00021962006500030016x

Erice, G., Louahlia, S., Irigoyen, J. J., Sanchez-Diaz, M., Alami, I. T. & Avice, J.C., (2011).Water use efficiency, transpiration and net CO_2 exchange of four alfalfa genotypes submitted to progressive drought and subsequent recovery. *Environmental and Experimental Botany*, *72*(2):123-130. https://doi.org/10.1016/j.envexpbot.2011.02.013

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D. & Basra, S., (2009). Plant drought stress: effects, mechanisms and management. *Agron. Sustain. Dev.*, *29*:185-212. https://doi.org/10.1051/agro:2008021

Forseth, I. N. & Ehleringer. J. R., (1983). Ecophsiology of two solar tracking desert winter annuals. IV. Effects of leaf orientation on calculated Daily carbon and water use efficiency. *Oecologia*, *58*:10-18. https://doi.org/10.1007/BF00384536

Gao, X., Gu, F., Mei, X., Hao, W., Li, H. & Gong, D., (2018). Light and water use efficiency as influenced by clouds and/or aerosols in a rainfed spring maize cropland on the loess plateau. *Crop Science*, *58*:853–862. https://doi.org/10.2135/cropsci2017.06.0341

Garan, H., Cakalogullari, U., Istipliler, D. & Tatar, O., (2016). Is proline accumulation under water deficit reversible in cotton?. *Lucrări Ştiinţifice*, *59*(2):99-102pp.

Gehlot, H.S., Purohit, A., & Shekhawat, N.S., (2005). Metabolic changes and protein patterns associated with adaptation to salinity in Sesamum indicum cultivars. *J Cell Mol Biol.*, *4*:31-39.

Hatfield J. L. & Dold, C. (2019). Water-use efficiency: advances and challenges in a changing climate, *Plant Sci.,10*:103. https://doi.org/10.3389/fpls.2019.00103

Hejnak, V., Tatar, O., Atasoy, G.D., Martinkova, J., Celen, A.E., Hnilicka, F. & Skalicky, M., (2015). Growth and photosynthesis of Upland and Pima cotton: response to drought and heat stress. *Plant Soil Environ.*, *61*(11): 507-514. https://doi.org/10.17221/512/2015-PSE

Isoda, A. & Wang, P. (2002). Leaf temperature and transpiration of field grown cotton and soybean under arid and humid conditions. *Plant Production Science*, *5*(3):224-228. https://doi.org/10.1626/pps.5.224

Jogev, C. (1988). *Water stress, radiation stress and cotton productivity, optimal yield management.* Grower Publishing Co. Ltd., Aldershot: 141-150 pp.

Jeong, K., Julia, C.C., Waters, D.L.E., Pantoja, O., Wissuwa, M., Heuer, S., Liu, L. & Rose, T.J., (2017). Remobilisation of phosphorus fractions in rice flag leaves during grain filling: Implications for photosynthesis and grain yields. *PLOS ONE*, *12*(11):e0187521. https://doi.org/10.1371/journal.pone.0187521

Jonckheere, I., Fleck, S., Nackaerts, K., Muys, B., Coppin, P., Weiss, M. & Baret, F., (2004). Review of methods for in situ leaf area index determination. I: Theories, sensors and hemispherical photography. *Agric. For. Meteorol.*, *121*:19-35 pp. https://doi.org/10.1016/j.agrformet.2003.08.027

Lambers, H. & Oliveira, R. S. (2019). *Plant water relations, plant physiological ecology*, Springer International Publishing, Cham 187-263 pp.

Laureano, R. G., Lazo, Y. O., Linares, J. C., Luque, A., Martínez, F., Seco, J. I. & Merino, J., (2008). The cost of stress resistance: construction and maintenance costs of leaves and roots in two populations of Quercus ilex. *Tree Physiology*, *28*(11):1721-1728. https://doi.org/10.1093/treephys/28.11.1721

Lawlor D. W. (1995). Photosynthesis, productivity and environment. *Journal of Experimental Botany, 46*:1449-1461. https://doi.org/10.1093/jxb/46.special_issue.1449

Lieth, J. H., Reynolds, J.F. & Rogers, H. H. (1986). Estimation of leaf area of soybeans grown under elevated carbon dioxide levels. *Field Crops Research, 13*:193-203. https://doi.org/10.1016/0378-4290(86)90021-3

Marron, N., Dreyer, E., Boudouresque, E., Delay, D., Petit, J.-M., Delmotte, F.M. & Brignolas, F., (2003). Impact of successive drought and re-watering cycles on growth and specific leaf area of two Populus canadensis (Moench) clones,"Dorskamp"and "Luisa_Avanzo". *Tree Physiology 23*(18): 1225-1235. https://doi.org/ 10.1093/treephys/23.18.1225

Moore, J. & Hines, A. (2017). Biomimetic engineering analysis of heliotropic plants. *Transdisciplinary Journal of Engineering & Science*. *8*:36–53. https://doi.org/10.22545/2017/00085

Moshelion, M., Becker, D., Biela, A., Uehlein, N., Hedrich, R., Otto, B., Levi, H., Moran, N. & Kaldenhoff, R., (2002a). Plasma membrane aquaporins in the motor cells of *Samanea saman*: Diurnal and circadian regulation. *The Plant Cell, 14*:727-739. https://doi.org/10.1105/tpc.010351

Moshelion, M., Becker, D., Czempinski, K., Mueller-Roeber, B., Attali, B., Hedrich, R. & Moran, N., (2002b). Diurnal and circadian regulation of putative potassium channels in a leaf moving organ. *Plant Physiology, 128*:634-642. https://doi.org/10.1104/pp.010549

Nagakura, J., Shigenaka, H., Akama, A. & Takahashi, M., (2004). Growth and transpiration of Japanese cedar (Cryptomeria japonica) and Hinoki cypress (Chamaecyparis obtusa) seedlings in response to soil water content. Tree Physiology, *24*:1203-1208. https://doi.org/10.1093/treephys/24.11.1203

Niinemets, U. (1999). Research review. Components of leaf dry mass per area - thickness and density-alter leaf photosynthetic capacity in reverse directions in woody plants. *New Phytologist, 144*:35-47. https://doi.org/10.1046/j.1469-8137.1999.00466.x

O'Carrigan, A., Hinde, E., Lu, N., Xu, X. Q., Duan, H., Huang, G., Mak, M., Bellotti, B. & Chen, Z.H., (2014). Effects of light irradiance on stomatal regulation and growth of

tomato. *Environmental and Experimental Botany*, *98*:65-73. https://doi.org/10.1016/j.envexpbot.2013.10.007

Oikawa, T., Ishimaru, Y., Munemasa, S., Takeuchi, Y., Washiyama, K., Hamamoto, S., Yoshikawa, N., Mutara, Y., Uozumi, N. & Ueda, M., (2018). Ion channels regulate nyctinastic leaf opening in *Samanea saman*. *Current Biology*, *28*:2230-2238 pp.

Patil, M.D., Biradar, D.P., Patil, V.C. & Janagoudar, B.S., (2011). Response of cotton genotypes to drought mitigation practices. *American-Eurasian J. Agric. & Environ. Sci.*, *11*(3):360-364 pp.

Rakocevic, M., Neumaier, N., de Oliveira, G. M., Nepomuceno, A. L. & Farias, J. R. B., (2010). Heliotropic responses of soybean cultivars at three phenological stages and under two water regimes. *Pesq. agropec. bras., Brasília, 45*(7):661-670. https://doi.org/10.1590/S0100-204X2010000700005

Reddy, V.R., Acock, B., Baker, D.N. & Acock, M., 1989. Seasonal leaf area-leaf weight relationships in the cotton canopy. *Agronomy Journal*, *81*:1-4. https://doi.org/10.2134/agronj1989.00021962008100010001x

Rodrigues, T. M. & Machado, S. R. (2008). Pulvinus functional traits in relation to leaf movements: A light and transmission electron microscopy study of the vascular system. *Micron, 39*(1):7-16. https://doi.org/10.1016/j.micron.2007.09.001

Ross, J., Ross, V. & Koppel, A., (2000). Estimation of leaf area and its vertical distirbution during growth period. *Agricultural and Forest Meteorology*, *101*:237-246. https://doi.org/10.1016/S0168-1923(00)00089-7

Roth , G., Harris, G., Gillies, M., Montgomery, J. & Wigginton, D., 2013, Water-use efficiency and productivity trends in Australian irrigated cotton: a review. *Crop & Pasture Science*, *64*:1033-1048.

Sepetoglu, H. & Budak, N. (1994). Bitki Büyüme Analizi. *Ege. Üni. Ziraat Fakültesi Dergisi*, *31*(2-3):297-307s.

Stiller, W. N., Read, J. J., Constable, G. A. & Reid, E., (2005). Selection for water use efficiency traits in a cotton breeding program: cultivar differences. *Crop Science, 45*:1107-1113. https://doi.org/10.2135/cropsci2004.0545

Tatar, O. & Gevrek, M. N. (2008). Influence of water stress on proline accumulation, lipid peroxidation and water content of wheat. *Asian Journal of Plant Sciences, 7*(4):409-412. https://doi.org/10.3923/ajps.2008.409.412

Tatar, O. (2016). Climate change impacts on crop production in Turkey. *Lucrări Ştiinţifice, 59*(2):135-140 pp.

Tatar, O., Bruck, H. & Asch, F. (2016). Photosynthesis and Remobilization of dry matter in wheat as affected by progressive drought stress at stem elongation stage. *Journal of Agronomy and Crop Science*, *202*(4)292-299. https://doi.org/10.1111/jac.12160

Wang, C., Isoda, A., Li, Z. & Wang P., (2004). Transpiration and leaf movement of cotton cultivars grown in the field under arid conditions. *Plant Production Science,7*(3):266-270. https://doi.org/10.1626/pps.7.266

Ueda, M., Ishimaru, Y., Takeuchi, Y. & Muraoka, Y., (2019). Plant nyctinasty-who will decode the 'Rosette Stone'?. *New Phytologist, 223*:107-112. https://doi.org/10.1111/nph.15717

Verbruggen, N. & Hermans, C. (2008). Proline accumulation in plants: A review. *Amino Acids, 35*(4):753-9. https://doi.org/10.1007/s00726-008-0061-6

Wendel, J. F., Brubaker C., Alvarez I., Cronn R. & Stewart J. McD., (2009). *Evolution and natural history of the cotton genus*, A.H. Paterson (ed.), *Genetics and Genomics of Cotton, Plant Genetics and Genomics: Crops and Models 3*:3-22 pp.

Witkowski, E. & Lamont, B. B. (1991). Leaf specific mass confounds leaf density and thickness. *Oecologia*, *88*:486-493. https://doi.org/10.1007/BF00317710

Yao, X., Chu, J. & Wan, G., (2009). Effects of selenium on wheat seedlings under drought stress. *Biol Trace Elem Res., 130*:283-90. https://doi.org/10.1007/s12011-009-8328-7

Yao, H., Zhang, Y., Yi, X., Zhang, X. & Zhang, W., (2016). Cotton responds to different plant population densities by adjusting specific leaf area to optimize canopy photosynthetic use efficiency of light and nitrogen. *Field Crops Research*, *188*:10-16. https://doi.org/10.1016/j.fcr.2016.01.012

Yao, H., Zhang, Y., Yi, X., Zhang, X., Fan, D., Chow, W. S. & Zhang, W., (2018). Diaheliotropic leaf movement enhances leaf photosynthetic capacity and photosynthetic light and nitrogen use efficiency via optimising nitrogen partitioning among photosynthetic components in cotton (*Gossypium hirsutum* L.). *Plant Biology*, *20*:213-222. https://doi.org/10.1111/plb.12678

Zhang, Y. L., Zhang, H. Z., Feng, G. Y., Tian, J. S. & Zhang, W. F. (2009). Leaf diaheliotropic movement can improve carbon gain and water use efficiency and not intensify photoinhibition in upland cotton (*Gossypium hirsutum* L.). *Photosynthetica*, *47*(4):609-615.

Zhang, N., Sun, Q., Zhang, H., Cao, Y., Weeda, S., Ren, S. & Guo, Y.D., (2015). Roles of melatonin in abiotic stress resistance in plants. Journal of Experimental Botany, *66*(3):647-656. https://doi.org/10.1093/jxb/eru336

Zheng, B., Shi, L., Ma, Y., Deng, Q., L., B. & Guo, Y., (2008). Comparison of archictecture among different cultivars of hybrid rice using a spatial light model based on 3-D digitising. *Functional Plant Biology*, *35*:900-910. https://doi.org/10.1071/FP08060

CHAPTER 15

USE OF MOLECULAR MARKER TECHNIQUES INTEGRATED INTO CORIANDER BREEDING

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1. INTRODUCTION

Coriander, also known as aşotu or kuzbere in Turkey, is a plant belonging to the Umbelliferea (=Apiaceae) family that is used for various purposes, including food, cosmetics and traditional medicine, and is cultivated worldwide (Bahadırlı et al., 2016). The origin of the coriander plant is believed to be Anatolia and the Caucasus, and it is particularly common in Mediterranean countries. Globally, India is known as the most important producer, and it is one of the most produced essential oil plants in the world (Ersin, 2019). Coriander (*Coriandrum sativum* L.), belonging to the genus *Coriandrum* of the Apiaceae family, is an essential oil and spice plant cultivated worldwide. Total world production of essential oil is around 45,000 tonnes. 500 tonnes of this essential oil comes from 15 plants. Coriander is one of the 15 essential oil plants (Başer, 1998; Kaplan, 2019). The main coriander producing countries are Russia, Ukraine, Morocco, Argentina, Mexico, India and Romania (Albayrak et al., 2012; Nadeem et al., 2013). It is cultivated in different regions and cultures around the world, mainly for its desirable aromatic properties and culinary uses, and its roots, stems, leaves and fruits have an aromatic odour that many people find pleasant (Sharma and Sharma, 2012).

Coriander is an annual spice, herb and medicinal plant and is one of the oldest and most important plants known to mankind (Kassahun, 2020). Coriander is a taproot plant with an upright structure and thin branched stems that can grow up to 30-100 cm in height (Gantait et al., 2022). There are two varieties of *C. sativum* L., named *vulgare* and *microcarpum. C. sativum vulgare* has larger seeds (3–5 mm in diameter) yielding 0.1–0.35% (v/w) essential oil. *C. Sativum microcorpum* has smaller fruits (1.5–3 mm in diameter) with an essential oil yield of 0.8–1.8% (v/w) (Baydar, 2013; Soltani Bouljak, 2023). When the coriander leaf structure is examined, it is observed that it is spear-shaped. It has been reported that its color varies between green and dark green tones, and the leaf surface is generally hairless and has a lobed structure. When the coriander petals are examined, it is observed that it has a structure that starts from the center and extends outward. The coriander flower structure is phenotypically small umbrella-shaped, and the flower colors can be white and pale pink (Mandal and Mandal, 2015). Coriander fruits contain approximately 0.2–1.5% essential oil. Some studies show that there are new varieties that contain up to 2.7% essential oil (Akgül, 1993; Çetin, 2019). Fixed oil can be obtained from the residue obtained after the essential oil is extracted by pressing or extraction (Tunçtürk, 2011).

Figure 1. An image of Coriander (*Coriandrum sativum* L.) and its flower structure

2. AREAS OF USE OF CORIANDER AS FOOD AND SPICE

Today, fresh and dried leaves of coriander are used as spices and vegetables, and its ripe fruits (Fructus Coriandri T.K.) are ground and used directly as spices (Telci and Hışıl, 2008; Gökduman and Telci, 2018). Whole or ground coriander fruits are used to enhance the scent and flavor of perfumes, desserts, chocolates, coffees, stews, jams, liqueurs and alcoholic beverages (especially gin), and are also used in various pharmaceutical formulations to eliminate unpleasant odors. Coriander seeds are used in both bread making and meat and seafood recipes (Póvoa et al., 2024). In Egypt, berbere is often combined with other spices to enhance its flavor. Nowadays, curry powder containing 25–40% coriander is a common way to consume large amounts of coriander (Ramadan and Mörsel, 2002). The fruit coriander is used as a spice in India and is often used to add flavour to pickles, sausages, sauces, cakes, buns and other foods (Jansen, 1981).

The fresh green leaves of the plant are very useful because of their unique smell. The smell of the dried seeds of the plant is nothing like it. The volatile oil components are what give the green plant its distinctive smell. This smell begins to diminish as the fruit ripens and eventually disappears from ripe fruits (Lörincz and Tyihak, 1965). Coriander is used green in this way in South America, Mexico, Iran, Iraq and the Caucasus. India, China, Thailand, Malaysia, Indonesia and the United States also make extensive use of the green components of the plant. In India, the green plant is widely used in pickles and soups, salads and stews (Çetin, 2019). The green parts also contain high levels of vitamin B2, vitamin A (carotene, more than 12 mg/100 g) and vitamin C (ascorbic acid, more than 160 mg/100 g) (Prakash, 1990; Kassahun 2020).

The part of coriander used for medicinal purposes is the fruit, which contains the essential oils and fatty acids, which are the most important components of the plant (Albayrak et al., 2012). It can also be used as a spice in meat dishes (especially chicken) due to its pleasant smell. In addition, coriander flower is very popular with insects because it produces a lot of nectar. For this reason, it is also used as a flower source in honey beekeeping (Diederichsen, 1996). Its green leaves, rich in protein, vitamins, minerals, calcium, phosphorus, iron, fiber and carbohydrates, are used as salad vegetables, while its leaves and fruits, which contain essential oils that give foods their unique aroma when added, are preferred in many different cuisines of the world (Bhat et al., 2014).

3. MEDICINAL USES OF CORIANDER ESSENTIAL OIL AND OTHER PLANT PARTS

The two most important components used in relation to the chemical structure of coriander seeds are essential oil and fixed oil. Fresh green leaves, mature seeds and essential oils obtained from these seeds are all used commercially. The main components of the essential oil are linalool 67.7%, α-pinene 10.5%, Ɣ-terpinene 9.0%, geranylacetate 4.0%, camphor 3.0% and geraniol 1.9% (Diederichsen, 1996). The main component of coriander fixed oil consists of 68.8% of all fatty acids as petroselenic acid (C18:1), 16.6% as linoleic acid (C18:2), 7.5% as oleic acid (C18:1), 3.8% as palmitic acid (C16:0) and very few as stearic acid, vaccenic acid and myristic acid (Gültekin, 2018).

In Asia, the essential oil of the coriander plant has long been used to treat mouth infections, ulcers, and gastric juice stimulation (Sahib et al., 2013). Coriander is widely used, especially in India and in Ayurvedic and Siddha medical systems. The seed oil is effective in rheumatism, neuralgia (Deniz et al., 2017). It has been observed that coriander has traditionally

been used effectively for respiratory and digestive problems and infections related to the urinary system, and has a stimulating effect in particular (Ravi et al., 2017). It has been reported that coriander is recommended in Iranian folk medicine for its positive effects on insomnia and anxiety. It is widely used in the daily diet of people in Iran, India, and Mexico. Coriander oil also has antimicrobial properties and is widely used as a natural fragrance in the perfumery industry due to its aromatic properties (Sachan et al., 2018). Its leaves are used in the treatment of aromatic, analgesic, carminative, styptic, bad breath, throat disease, nosebleeds, bleeding gums, chronic conjunctivitis, erythema, hiccups, inflammation, pus, hemorrhoids, jaundice (Paarakh, 2009). Coriander essential oil and extracts are used in folk medicine due to their sedative, diuretic, antioxidant, antimicrobial, antispasmodic and antihypertensive properties, as well as their hypoglycemic, anti-inflammatory, fat-melting, analgesic, anxiolytic, carminative and muscle relaxant properties (Sachan et al., 2018).

The pharmaceutical industry requires standard products with high secondary metabolite concentration and quality (Hussain et al., 2012). Cultivating these plants instead of collecting them from nature is the only way to produce sufficient amounts of high-quality plants that meet the needs of the pharmaceutical industry. To create these plants, appropriate species must be used. An important factor in the spread of medicinal plant production is the use of appropriate seeds (Gültekin, 2018). In order to obtain standard varieties with desired characteristics, high secondary metabolite concentration and quality, coriander breeding should be studied more intensively and the variety development process and goal should be continued in a cost-effective and time-saving way by integrating molecular marker techniques, which are biotechnological tools, in these breeding programs.

4. MOLECULAR MARKER TECHNIQUES AND THEIR USE IN CORIANDER BREEDING

Coriander breeding is necessary to grow suitable varieties under suitable climate and standard growing techniques conditions to develop more qualified and standardized varieties (Yılmaz et al., 2022). When the fertilization biology of coriander is examined, it is seen that it is a cross-pollinating plant (Diederichsen, 1996; Tesfaye et al., 2020). Although coriander is a versatile plant, coriander breeding studies have never received sufficient attention. In coriander breeding, quality is as important as yield. Having a say in world markets requires growing products that comply with standards. This is possible by determining appropriate ecologies, breeding superior varieties and improving agrotechnical practices (Kaya et al., 2000).

Plant breeding is an important field of study to further improve the cultivation and production of coriander (*Coriandrum sativum* L.) and to develop standard coriander varieties with high secondary metabolite concentration and quality, especially in the pharmaceutical industry. The main objectives of coriander breeding are to increase yield, increase resistance to abiotic and biotic stress factors, and especially to improve aromatic properties (Yılmaz et al., 2022). Integrating into traditional breeding studies used to achieve these breeding goals, genetic diversity studies in coriander include molecular markers that offer very useful areas of use to determine desired characters and to select plants with these desired characteristics (Ali et al., 2020). Today, it is thought that with the rapidly developing technology, the combination of modern techniques of biotechnology with classical breeding methods can enable the objectives of coriander breeding to be achieved quickly and reliably (Geboloğlu et al., 2017).

Quantitative traits such as yield and quality in coriander breeding vary depending on soil structure, climate, living and non-living environmental factors. Characterization and selection studies are very important for increasing the resistance to abiotic and biotic stress factors and

developing higher yielding coriander genotypes in order to increase yield and quality in coriander farming and cultivation. In addition, it is important to increase the genetic diversity of coriander for the development of coriander farming and standardized plant and essential oil production (Ghamarnia and Daichin, 2013). The commercial marketability value of coriander is based on the quantity and quality of aromatic compounds (e.g. fatty acids such as geraniol and linalool) that are abundant, especially in the seed portion. Therefore, in order to compete commercially in the market, it is necessary to increase the amount of these aromatic compounds and to conduct quality improvement breeding studies more intensively. Because it is thought that breeding studies that improve the chemical composition of coriander seeds can also increase the commercial value of coriander.

Developing varieties that are better adapted to different climatic conditions and more resistant to abiotic and biotic stress factors and sustainable can enable coriander to be grown in wider geographies (Adhikari et al., 2018). Nowadays, efforts are being made to develop coriander varieties that are more resistant to factors such as drought, high temperature and salinity, which are increasing with climate change (Aishwath and Lal, 2016). In addition, expanding the existing gene pool and increasing genetic diversity in coriander is an important breeding goal in developing genotypes with higher yield, higher quality and improved essential oil properties (Sriti et al., 2009; Katar et al., 2016). It is thought that achieving these breeding goals more reliably and rapidly will be possible through the discovery and selection of natural varieties and this goal of achieving high genetic diversity can only be achieved through the use of molecular biotechnology techniques (Nadeem et al., 2018; Yılmaz et al., 2022).

Nowadays, biotechnology techniques are used extensively in a wide range of fields as integrated with plant breeding (Jauhar, 2006). The data obtained as a result of studies conducted to genetically analyze plants, determine their kinship levels and determine genotypic characterization can be used in the variety development process (Karakaş, 2024). Obtaining gene maps in plants and transferring them to other genotypes by cloning emphasizes the importance of biotechnology in plant breeding. Molecular markers are a sign or a small piece of DNA that shows a location on a chromosome (Kumar, 1999). It is a DNA sequence between genes or a part of a gene. These DNA sequences, whose inheritance can be easily determined or observed, are a sign that shows the difference between individuals within a species (Marwal and Gaur, 2020).

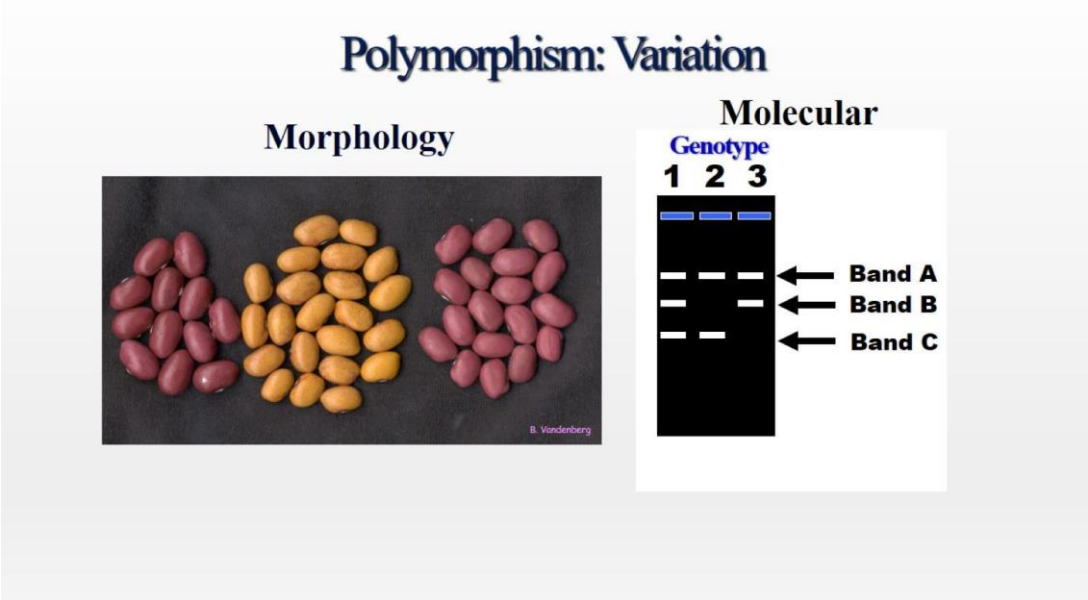

Figure 2. Schematic representation of morphological and molecular marker systems

Molecular markers are advanced techniques that have been used extensively in breeding studies in recent years. These marker techniques are subject to breeding studies in three different groups: protein (biochemical) markers, morphological markers (such as flower color) and DNA (molecular) markers (Figure 2) (Sood and Chauhan, 2023). Molecular markers are not affected by environmental conditions and can be detected at all stages of plant growth, thus providing significant progress in detecting genotypes that cannot be detected due to environmental effects (Bidyananda et al., 2024). In order to make molecular marker applications in plant breeding most efficient, the markers to be used should be low-cost and easy to use. They should also be repeatable, have a high polymorphism rate and be co-dominant. The fact that molecular markers are dominant or co-dominant forms an important basis for distinguishing heterozygous and homozygous individuals (Baydar, 2020). It has been widely preferred in plant breeding in recent years because it is easy, reliable and time-saving. In parallel with the development of biotechnology and the easier access to molecular and genetic information, molecular marker techniques have been developed (presented in Figure 3) (Francia et al., 2005; Collard and Mackill, 2008; Kordrostami and Rahimi, 2015; Karakaş and Bayrıl, 2024).

Molecular Marker Type		Being PCR Based	Inheritance Type	Polymorphism Level
RFLP(Restriction Fragment Length Polymorphism)	RFLP is the only marker system based on hybridization and the first molecular marker technology ever created. This marker technique allows variation across individuals of the same species to be displayed through point mutations, translocations, duplications, inversions, and insertions/deletions (known as InDels) in the genome (Çevik, 2020).	Hybridization based	Co-dominant	Low/Medium
RAPD (Random Amplified Polymorphic DNA)	Markers based on polymorphism and randomly replicated DNAs are known as RAPDs. Preliminary sample sequencing data is not required for RAPD analysis. With limited resources, it is possible to evaluate various loci from a large number of individuals for screening purposes. RAPDs are widely used due to good genetic screening of intra- and interspecific hybrids and simple experimental methods (Shasany et al., 2005).	PCR	Dominant	Medium/High
ISSR (Inter Simple Sequence Repeats)	ISSR markers were developed using microsatellite sequences that vary and are randomly distributed throughout the genome. They are ideal markers for genetic studies (Amom et al., 2017; Kesawat and Das, 2009; Baydar, 2020).	PCR	Dominant	High
SSR (Simple Sequence Repeats)	There are constantly repeating DNA sequences in plant genomes. Where these sequences are located in the genome and how often they are repeated varies depending on the species. SSR technique was developed based on whether these sequences exist among individuals within the same species (Ridout and Donini, 1999).	PCR	Co-dominant	High
SNP (Single Nucleotide Polymorphism)	Single nucleotide sequences (SNPs) are DNA markers used to identify genomic regions for important traits (Meena et al., 2023), accelerating plant breeding through various research applications such as phylogenic analysis, marker-assisted selection, and genetic mapping (Gözel et al., 2016; Lombardi et al., 2014; Ahmed and Mawgood, 2012).	PCR	Co-dominant	High

Figure 3. Comparison of molecular marker types and their properties.

Molecular markers based on polymorphism of the DNA structure can be applied in varied parts of the plant and at dissimilar times (Agarwal et al., 2008). Molecular markers are used intensively in many different areas in plant breeding such as characterization of genetic resources, determination of genetic similarities and distances between varieties (López et al., 2008), determination of parents to be used in breeding programs, protection of newly developed varieties (Jamali et al., 2019), identification of unknown varieties or genotypes (Radzevičius et al., 2024), determination of evolutionary developments and structural changes in chromosomes, development of DNA markers without creating a genetic map associated with phenotypic traits (Bulk Segregant Analysis), determination of qualitative and quantitative trait loci, genetic mapping (Nair and Pandey, 2024), determination of somaclonal variation, F_1 identification (Bianco et al., 2011), and determination of mutations. In coriander breeding, in addition to traditional breeding methods, faster and more sensitive results can be obtained by integrating molecular marker techniques into breeding programs. Molecular markers in coriander breeding can be used reliably to confirm the presence of desired traits such as resistance to abiotic and biotic stress factors, amount of aromatic compounds, yield and quality (Ghorbanzadeh et al., 2023). For instance, molecular markers can be used to identify genetic variants that will increase resistance to Fusarium disease in coriander breeding and to rapidly select these resistant plants.

Genetic mapping approaches using molecular markers in plant breeding are a method used to better understand the coriander genome and its genetic structure and to determine the regions where genes and genomic regions controlling desired traits are located (Gantait et al., 2022). Genetic mapping approach shows which chromosomes contain desired traits such as abiotic and biotic stress tolerance, yield, aromatic and chemical, quality composition in coriander. With the discovery of various molecular markers in plants and the availability of comprehensive molecular genetic maps for traits regulated by both major genes and quantitative trait loci (QTLs), MAS (Marker Assisted Selection) technique in plant breeding has become possible (Kadirvel et al., 2015; Hasan et al., 2021). Individual genes or QTLs having a strong effect on a particular target trait or traits can be discovered based on trait associations with molecular structures, thus incorporating desirable traits into elite germplasm can increase success and efficiency in plant breeding and also save time (Azhaguvel et al., 2006).

The variety development process carried out by traditional breeding methods, especially the selection of plants with desired traits, can be complex, costly and time-consuming. Traditional plant breeding mainly focuses on the phenotypic selection of superior individuals from hybrid generations showing expansion resulting from crossbreeding (Glenn et al., 2017). Despite tremendous advances in plant improvement through phenotypic selection for agronomically relevant traits, major obstacles are often encountered along the way, mostly due to genotype×environment interactions (Simmonds, 1991). Marker-assisted selection (MAS) is an approach developed to solve the problems associated with traditional breeding methods and to discover genomic regions controlling desired traits in plants using multiple molecular markers. With the development of molecular markers, using markers that are linked or dependent on the desired gene has given a new direction to breeding programs and has provided great advantages (Brumlop and Finckh, 2011).

Choudhary et al. (2019) used twenty-four coriander genotypes as plant material in their study. Two different RAPD and ISSR molecular markers were used to characterize the variation and variability among these genotypes. As a result, eighty-three bands were produced using RAPD markers, fifty-seven of which (70.46%) were polymorphic. In the study section using nine ISSR primers, a total of thirty-seven bands were produced, seventeen of which (49.81%) were polymorphic. With the results obtained, it was reported that RAPD and ISSR markers were effective in analyzing the molecular diversity in coriander genotypes and could be used especially to create heterotic groups. Omidbaigi et al. (2009) investigated the molecular and essential oil characterization of 20 coriander landraces grown in Iran using fifteen RAPD primers. As a result, the fifteen primers used produced a total of 261 loci, ninety of which were observed to be polymorphic. The obtained results confirm the usefulness and suitability of RAPD markers in the identification of coriander landraces.

Poshiya Apekshaben Giradharbhai (2014), conducted a study to determine the molecular characterization of fifteen coriander genotypes using RAPD, ISSR and SSR markers. The similarity coefficient of cluster analysis was observed to be between 23% and 85% for RAPD, 68% and 87% for ISSR and 51% and 88% for SSR. As a result, in molecular characterization studies among coriander genotypes, RAPD markers were reported to be more informative than SSR and ISSR markers. Therefore, molecular markers proved to be more accurate and reliable than morphological and biochemical markers.

Jabbar and Al-Tamimi (2022) treated coriander (*Coriandrum sativum* L.) seeds with five different gamma irradiation doses (0, 25, 50, 100 and 150). They used eighteen RAPD primers as molecular markers to decipher the variation that occurred after the application. As a result, they revealed the presence of RAPD markers in the detection of gamma irradiation-induced mutations. Singh et al. (2015) used superoxide dismutase and peroxidase isozymes to

characterize twenty coriander genotypes, gel electrophoresis of superoxide dismutase was represented by four bands, while peroxidase gave only one band. A 50% polymorphism was recorded among twenty coriander cultivars with superoxide dismutase. It was reported that Swathi, Sindhu and CS-6 cultivars showed the highest differences.

Tomar-Rukam et al. (2014), conducted a study to determine molecular characterization in twenty five coriander genotypes to explore morphological and molecular characterization. A total of 12 different characters were examined for morphological characterization. A total of thirty-eight RAPD markers were used for molecular characterization, and a total of 3721 fragments with an average band number of 7.13 were obtained. Polymorphism with RAPD primers varied between 38% and 100%, and Jaccard similarity coefficient varied between 88% and 56%. Another marker for molecular characterization is the ISSR technique, a total of twenty-eight primers were used, and a total of 142 pieces with an average band count of 5.07 were obtained. As a result, the general grouping pattern obtained as a result of cluster analysis clearly showed the variation between genotypes. It was reported that these molecular markers used together with morphological markers can be used in coriander breeding program in taxonomic issues, examination of genetic variability, as well as genetic diversity assessment, variety fingerprint and phylogenetic studies.

Furan and Gebologlu (2017), although coriander is a versatile plant, it has not been defined molecularly and genetically. Therefore, in this study, genetic diversity among 12 coriander genotypes was investigated using two types of iPBS and SSR molecular markers. 16 iPBS primers and 8 SSR primers were used in the study, and these primers selected for polymorphism in twelve coriander genotypes were 0.49 for a dominant marker for maximum PIC f = 0.5 and 0.43 for each primer for co-dominant marker; PIC value was reported as the average of the calculated PIC of all loci.

5. CONCLUSIONS

One of the oldest spices in the world, coriander is used in world cuisines and as a flavoring agent. In addition, coriander, which is also used in the treatment of many diseases, is known as one of the Ayurvedic plants used as a digestive stimulant, anti-inflammatory, antimicrobial, hypolipidemic, antimutagenic and anticarcinogenic and is thought to contribute to the development of promising new drugs. The pharmaceutical industry requires standard products with high secondary metabolite concentration and quality. Cultivating these plants instead of collecting them in the wild is the only way to produce sufficient amounts of high-quality plants that meet the needs of the pharmaceutical industry. In order to obtain these plants, suitable genotypes must be bred and these bred genotypes must be grown and used intensively. In order to obtain standard varieties with desired characteristics, high secondary metabolite concentration and quality, coriander breeding should be studied more intensively and the variety development process and goal should be continued in a cost-effective and time-saving way by integrating molecular marker techniques, which are biotechnological tools, in these breeding programs.

Today, the aim of breeding studies is to improve plant traits. Plant breeding has evolved from the concept of crossbreeding two plants with the best and most desirable traits and selecting the best performing plants from the resulting hybrids to carefully planned and thought-out techniques for producing high-performance varieties with high predictability. Molecular and genetic studies, which have gained momentum with the development of biotechnology in plant breeding, have enabled the development of molecular markers. Nowadays, there is a surge in coriander breeding and genetic research, and coriander has become popular among medicinal and aromatic plants worldwide. In recent years, many studies have been conducted with various

genetic resources and molecular techniques to develop plants with higher yield and higher quality coriander traits for producers. Different molecular markers, QTL regions and functional genomics have also been associated with these traits. Today, these desired traits have become available in coriander breeding programs. Different molecular markers have proven to be effective in extracting genetic distances between a large numbers of genotypes in a large number of plant species, but have rarely been tested in coriander. The use of such a potential marker system, if attempted, could produce clearer comparative genetic information among coriander genotypes. Future expectations in coriander breeding include the intensification of breeding programs and the increased use of molecular marker techniques, and the effective use of molecular and genetic information to improve coriander traits from a molecular breeding perspective. In addition, the integration of MAS technique and other molecular techniques into coriander breeding and the development of more productive, high quality and stress-resistant coriander varieties are thought to further increase the popularity of this plant.

REFERENCES

Adhikari, P., Araya, H., Aruna, G., Balamatti, A., Banerjee, S., Baskaran, P. and Verma, A. (2018). System of crop intensification for more productive, resource-conserving, climate-resilient, and sustainable agriculture: Experience with diverse crops in varying agroecologies. *International journal of agricultural sustainability*, *16*(1), 1-28.

Agarwal, M., Shrivastava, N., and Padh, H. (2008). Advances in molecular marker techniques and their applications in plant sciences. *Plant cell reports*, *27*, 617-631.

Ahmed, L. and Mawgood, A. (2012). DNA Based Techniques for Studying Genetic Diversity. Genetic Diversity in Microorganisms, Mahmut Caliskan (Ed.) pp, 95, 123.

Aishwath, O. P. and Lal, R. (2016). Resilience of spices, medicinal and aromatic plants with climate change induced abiotic stresses. *Annals of Plant and Soil Research*, *18*(2), 91-109.

Albayrak, S., Göncü, A., Albayrak, S. (2012). Corander as Traditional Food: Their Medicinal Benefit and Bioactivities. *Mesleki Bilimler Dergisi (MBD)*, *1*(4), 2-7.

Ali, F., Nadeem, M. A., Habyarimana, E., Yılmaz, A., Nawaz, M. A., Khalil, I. H., Ercişli, S., Chung, G., Chaudhary, H.J. and Baloch, F. S. (2020). Molecular characterization of genetic diversity and similarity centers of safflower accessions with ISSR markers. Brazilian Journal of Botany, 43(1), 109-121.

Furan M. A. and Gebologlu, M. D. (2017). Two different molecular markers (SSR & IPBS) assessment on *Coriandrum sativum* L. with capillary electrophoresis. *Fresenius Enviromental Bulletin*, *26*, 4568-4573.

Amom, T., and Nongdam, P. (2017). The use of molecular marker methods in plants: a review. *International Journal of Current Research and Review*, 9(17), 1-7.

Azhaguvel, P., Saraswathi, D. V., Sharma, A., and Varshney, R. K. (2006). Methodological advancement in molecular markers to delimit the gene (s) for crop improvement. *Floriculture, ornamental and plant biotechnology*, *1*, 460-469.

Bahadırlı, N. P., Türkmen, M. and Ahmet, M. (2016). Determination of Fresh Herb and Seed Essential Oil Rate and Component of Coriander (*Coriandrum sativum* L.) *Biyoloji Bilimleri Araştırma Dergisi, 9*(2), 20-22.

Başer, K.H.C., (1998). Tıbbi ve Aromatik Bitkilerin Endüstriyel Kullanımı. Anadolu Üniversitesi Tıbbi ve Aromatik Bitki ve İlaç Araştırma Merkezi, TAB Bülteni 13-14:19-43. 1998. (in Turkish)

Baydar, H., (2013).Science and Technology of Medicinal and Aromatic Plants, Süleyman Demirel University, Faculty of Agriculture. Isparta, Publication No:51. p 280. (in Turkish)

Baydar, H. (2020). Plant Genetics and Breeding (1st Edition). Nobel Academic Publishing. (in Turkish)

Bhat, S., Kaushal, P., Kaur, M. and Sharma, H. K. (2014). Coriander (*Coriandrum sativum* L.): Processing, nutritional and functional aspects. *African Journal of plant science*, *8*(1), 25-33.

Bianco, C. L., Fernández, J. A., Migliaro, D., Crinò, P. and Egea-Gilabert, C. (2011). Identification of F1 hybrids of artichoke by ISSR markers and morphological analysis. *Molecular breeding*, *27*, 157-170.

Bidyananda, N., Jamir, I., Nowakowska, K., Varte, V., Vendrame, W. A., Devi, R. S. and Nongdam, P. (2024). Plant Genetic Diversity Studies: Insights from DNA Marker Analyses. *International Journal of Plant Biology*, *15*(3), 607-640.

Brumlop, S. and Finckh, M. R. (2011). Applications and potentials of marker assisted selection (MAS) in plant breeding: final report of the F+ E project" Applications and Potentials of Smart Breeding"(FKZ 350 889 0020)-on behalf of the Federal Agency for Nature Conservation. Deutschland/Bundesamt für Naturschutz.

Choudhary, S., Sharma, R., Jethra, G., Vishal, M. K. and Tripathi, A. (2019). Molecular diversity in coriander (*Coriandrum sativum* L.) using RAPD and ISSR markers. *Indian J Agric Sci*, *89*(2), 193-198.

Collard, B. C. and Mackill, D. J. (2008). Marker-assisted selection: an approach for precision plant breeding in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences, 363(1491), 557 572.

Çetin, A. (2019). The effects of different sowing times on some yield and yield components of coriander *(Coriandrum sativum* L.*)*. Master Thesis, Institute of Science and Technology, Yozgat Bozok University, Yozgat. p 67. (in Turkish)

Çevik, S. E. (2020). Marker assisted selection for drought tolerance in bread wheat (M.S. thesis). *Karamanoglu Mehmetbey Unıversıty*.

Diederichsen, A. (1996). *Coriander: Coriandrum sativum* L. (Vol. 3). Bioversity International.

Ersin, E. (2019). Antibacterial activities of essential oils and extracts of coriander *(Coriandrum sativum* L.*)* cultivated in Yozgat conditions. Master Thesis, *Institute of Science and Technology, Yozgat Bozok Univ*ersity, p 49. (in Turkish)

Gantait, S., Sharangi, A. B., Mahanta, M. and Meena, N. K. (2022). Agri-biotechnology of coriander (*Coriandrum sativum* L.): an inclusive appraisal. *Applied Microbiology and Biotechnology*, *106*(3), 951-969.

Geboloğlu, N., Karabekiroğlu, D. S. and Doksöz, S. (2017). Morphological and molecular characterization of Tokat garlic. *Academic Journal of Agriculture*, *6*, 131-136.

Ghamarnia, H. and Daichin, S. (2013). Effect of different water stress regimes on different coriander (*Coriander sativum* L.) parameters in a semi-arid climate. *International Journal of Agronomy and Plant Production*. Vol., 4 (4), 822-832.

Ghorbanzadeh, Z., Hamid, R., Jacob, F. and Tomar, R. S. (2023). Coriander Transcriptome: Trends, Scope, and Utilization for Coriander Improvement. In *Handbook of Coriander (Coriandrum sativum)* (pp. 63-76). CRC Press.

Glenn, K. C., Alsop, B., Bell, E., Goley, M., Jenkinson, J., Liu, B., ... and Vicini, J. L. (2017). Bringing new plant varieties to market: plant breeding and selection practices advance beneficial characteristics while minimizing unintended changes. *Crop Science*, *57*(6), 2906-2921.

Gokduman, G. I. and Telci, I. (2018). Determination of yield and quality characteristics of some coriander (*Coriandrum sativum* L.) genotypes in Isparta conditions. *Süleyman Demirel University Journal of Natural and Applied Sciences*, *22*(3), 1165-1168.

Gözel, U., Çiğdem, Y. and Gözel, Ç. (2016). Nematod taksonomisinde kullanılan moleküler markörler. Türkiye Entomoloji Bülteni, 6(2), 179-189.

Gültekin, M. (2018). Determination of agronomic and quality properties of coriander cultivar, line and populations in Siirt conditions. Master Thesis, Institute of Science and Technology, Siirt University. p 47.

Hasan, N., Choudhary, S., Naaz, N., Sharma, N. and Laskar, R. A. (2021). Recent advancements in molecular marker-assisted selection and applications in plant breeding programmes. *Journal of Genetic Engineering and Biotechnology*, *19* (1), 128.

Hussain, M. S., Fareed, S., Ansari, S., Rahman, M. A., Ahmad, I. Z. and Saeed, M. (2012). Current approaches toward production of secondary plant metabolites. *Journal of Pharmacy and Bioallied Sciences*, *4*(1), 10-20.

Jabbar, S. A. M. and Al-Tamimi, A. J. T (2022). Mutation Induced by Gamma Irradiation in Coriander Seeds and Their Identification by RAPD Makers. *International Journal of Health Sciences*, (III), 7336-7347.

Jamali, S. H., Cockram, J. and Hickey, L. T. (2019). Insights into deployment of DNA markers in plant variety protection and registration. *Theoretical and Applied Genetics*, *132*, 1911-1929.

Jansen, P. C. M. (1981). Spices, condiments and medicinal plants in Ethiopia, their taxonomy and agricultural significance. Wageningen University and Research.

Jauhar, P. P. (2006). Modern biotechnology as an integral supplement to conventional plant breeding: the prospects and challenges. *Crop science*, *46*(5), 1841-1859.

Kadirvel, P., Senthilvel, S., Geethanjali, S., Sujatha, M. and Varaprasad, K. S. (2015). Genetic markers, trait mapping and marker-assisted selection in plant breeding. *Plant Biology and Biotechnology: Volume II: Plant Genomics and Biotechnology*, 65-88.

Kaplan, G. (2019). Effects of different phosphorus doses on yield, yield components and essential oil ratio of coriander *(Coriandrum sativum* L.*)*. Master Thesis, Institute of Science and Technology, Yozgat Bozok University, Yozgat. p 58. (in Turkish)

Karakaş, İ. and Bayrıl, B. (2024). From Classical Selection to Marker Assisted Selection in Plant Breeding: Mas Approaches. New Studies in Agriculture, Forestry and Water Sciences, p 90. (in Turkish).

Karakaş, İ. (2024). Molecular Marker Techniques and Genotypic Characterization Approaches in Plant Breeding. *Turkish Journal of Agriculture-Food Science and Technology*, *12*(8), 1487-1498.

Kassahun, B. M. (2020). Unleashing the Exploitation of Coriander (*Coriander sativum* L.) for Biological, Industrial and Pharmaceutical Applications. Academic Research Journal of Agricultural Science and Research, 8(6), 552-564.

Kassahun, B. M. (2020). Unleashing the exploitation of Coriander (*Coriander sativum* L.) for biological, industrial and pharmaceutical applications. *Academic Research Journal of Agricultural Science and Research*, *8*(6), 552-564.

Katar, D., Kara, N. and Katar, N. (2016). Yields and quality performances of coriander (*Coriandrum sativum* L.) genotypes under different ecological conditions. *Turkish Journal of Field Crops*, 21(1), 79-87. https://doi.org/10.17557/tjfc.77478

Kaya, N., Yılmaz, G. and Telci, İ. (2000). Agronomic and Technological Properties of Coriander (*Coriandrum sativum* L.) Populations Planted on Different Dates. *Turk J Agric For*, *24*, 355-364.

Kesawat, M. S. and Das Kumar, B. (2009). Molecular markers: it's application in crop improvement. Journal of Crop Science and Biotechnology, 12, 169-181.

Kordrostami, M. and Rahimi, M. (2015). Molecular markers in plants: concepts and applications. *Genet. 3rd Millenn*, *13*, 4024-4031.

Kumar, L. S. (1999). DNA markers in plant improvement: an overview. *Biotechnology advances*, *17*(2-3), 143-182.

Lombardi, M., Materne, M., Cogan, N. O., Rodda, M., Daetwyler, H. D., Slater, A. T., ... and Kaur, S. (2014). Assessment of genetic variation within a global collection of lentil (*Lens culinaris* Medik.) cultivars and landraces using SNP markers. BMC genetics, 15, 1-10.

López, P. A., Widrlechner, M. P., Simon, P. W., Rai, S., Boylston, T. D., Isbell, T. A. and Wilson, L. A. (2008). Assessing phenotypic, biochemical, and molecular diversity in coriander (*Coriandrum sativum* L.) germplasm. *Genetic Resources and Crop Evolution*, *55*, 247-275.

Lörincz, K., & Tyihák, E. (1965). Untersuchungen über die Terpenkomponenten im Verlaufe der Ontogenie des Korianders (*Coriandrum sativum* L.). *Herba Hung*, *4*, 191-208.

Mandal, S., Mandal, M. (2015). Coriander (*Coriandrum sativum* L.) essential oil: Chemistry and biological activity. Asian Pacific Journal of Tropical Biomedicine, 5(6), 421-428.

Marwal, A., & Gaur, R. K. (2020). Molecular markers: tool for genetic analysis. In *Animal biotechnology (Second Edition)* (pp. 353-372). Academic Press.

Nadeem, M. A., Nawaz, M. A., Shahid, M. Q., Doğan, Y., Comertpay, G., Yıldız, M. and Baloch, F. S. (2018). DNA molecular markers in plant breeding: current status and recent advancements in genomic selection and genome editing. *Biotechnology & Biotechnological Equipment*, *32*(2), 261-285.

Nadeem, M., Muhammad Anjum, F., Issa Khan, M., Tehseen, S., El-Ghorab, A. and Iqbal Sultan, J. (2013). Nutritional and medicinal aspects of coriander (*Coriandrum sativum* L.) A review. *British Food Journal*, *115*(5), 743-755.

Nair, R. J. and Pandey, M. K. (2024). Role of Molecular Markers in Crop Breeding: A Review. *Agricultural Reviews*, *45*(1).

Olle, M., Bender, I., Koppe, R. (2010). The content of oils in umbelliferous crops and its formation. Agronomy Research, 8(3), 687-696.

Omidbaigi, R., Rahimi, S. and Naghavi, M. R. (2009). Evaluation of molecular and essential oil diversity of coriander (*Coriandrum sativum* L.) landraces from Iran. *Journal of Essential Oil Bearing Plants*, *12*(1), 46-54.

Paarakh, P. M. (2009). *Coriandrum sativum* Linn. â€" Review. *Pharmacologyonline*, *3*, 561-573.

Poshiya Apekshaben Giradharbhai (2014). Genetic Diversity Analysis Among Coriander *(Coriandrum sativum* L.*)* Genotypes Through Pcr Based Molecular Markers (Doctoral dissertation, jau, junagdh).

Póvoa, O., Farinha, N., Lopes, V., Machado, A. M. and Figueiredo, A. C. (2024). Coriander (*Coriandrum sativum* L.) from Alentejo (South Portugal), Ethnobotany and Potential Industrial Use. *Foods*, *13*(6), 929.

Prakash, V. (1990). Leafy Spices. CRC Press Inc., Boca Raton. pp. 31-32. 20 22.

Radzevičius, A., Šikšnianienė, J. B., Karklelienė, R., Juškevičienė, D., Antanynienė, R., Misiukevičius, E. and Frercks, B. (2024). Characterization of lithuanian tomato varieties and hybrids using phenotypic traits and molecular markers. *Plants*, *13*(15), 2143.

Ramadan, M. and Mörsel, J. T. (2002). Oil composition of coriander (*Coriandrum sativum* L.) fruit-seeds. *European Food Research and Technology*, *215*, 204-209.

Ravi, R., Prakash, M. and Bhat, K. K. (2007). Aroma characterization of coriander (*Coriandrum sativum* L.) oil samples. *European Food research and technology*, *225*, 367-374.

Ridout, C. J., Donini, P., Ridout, C. J. and Donini, P. (1999). Use of AFLP in cereals research. Trends in Plant Science, 4(2), 76-79.

Sachan, A. K., Kumar, S., Kumari, K. and Singh, D. (2018). Medicinal uses of spices used in our traditional culture: Worldwide. *Journal of Medicinal Plants Studies*, *6*(3), 116-122.

Sahib, N. G., Anwar, F., Gilani, A. H., Hamid, A. A., Saari, N. and Alkharfy, K. M. (2013). Coriander (*Coriandrum sativum* L.): A potential source of high-value components for functional foods and nutraceuticals-A review. *Phytotherapy Research, 27*(10), 1439-1456.

Sharma, M. M. and Sharma, R. K. (2012). Coriander. In *Handbook of herbs and spices* (pp. 216-249). Woodhead Publishing.

Shasany, A. K., Darokar, M. P., Dhawan, S., Gupta, A. K., Gupta, S., Shukla, A. K. and Khanuja, S. P. (2005). Use of RAPD and AFLP markers to identify inter-and intraspecific hybrids of Mentha. Journal of Heredity, 96(5), 542-549.

Simmonds, N. W. (1991). Selection for local adaptation in a plant breeding programme. *Theoretical and Applied Genetics*, *82*, 363-367.

Singh, R. K., Verma, S. S., Kumar, V., Singh, S. K. and Kumar, R. (2015). Application of isozymes for identification of coriander (*Coriandrum sativum* L.) varieties. *BIOINFOLET-A Quarterly Journal of Life Sciences*, *12*(1b), 232-234.

Soltanı Bouljak, M. (2023). The effects of different nitrogen rates and water stress on agricultural characteristic and quality of Iranian and Turkish coriander *(Coriandrum sativum* L*.) genotypes.* Doctoral Thesis, Institute of Science and Technology, Atatürk University, Ankara. p 118.

Sood, R. and Chauhan, A. (2023). Applications of genetic engineering and DNA markers in plant breeding. *Research and Review in Genetics and Plant Breeding*, *1*, 45.

Sriti, J., Talou, T., Wannes, W. A., Cerny, M. and Marzouk, B. (2009). Essential oil, fatty acid and sterol composition of Tunisian coriander fruit different parts. Journal of the Science of Food and Agriculture, 89(10), 1659-1664. https://doi.org/10.1002/jsfa.3637.

Telci, I. and Hisil, Y. (2008). Biomass yield and herb essential oil characters at different harvest stages of spring and autumn sown *Coriandrum sativum*. *European Journal of Horticultural Science*, *73*(6), 267.

Tesfaye, B., Gelgelu, T., Lelisa, W. (2020). The role of honeybee (*Apis mellifera*) pollination in enhancing seed yield and yield related parameters of *Coriandrum sativum* L. Journal of Energy and Natural Resources, 9(4), 120.

Tomar-Rukam, S., Kulkarni, G. U., Parakhia, M. V., Thakkar, J. R., Rathod, V. M., Solanki, R. K. and Golakiya, B. A. (2014). Genetic diversity analysis in coriander (*Coriandrum sativum* L.) genotypes through morphological and molecular characterization. *Res. J. Biotech*, *9*, 1-11.

Tunçtürk, R. (2011). Effects of Different Row Spacings on the Yield and Quality in Coriander (*Coriandrum sativum* L.) Cultivars *Yüzüncü Yıl University Journal of Agricultural Sciences*, *21*(2), 89-97.

Ulutaş Deniz, E., Yeğenoğlu, S., Sözen Şahne, B. and Gençler Özkan, A. (2018). Kişniş (*Coriandrum sativum* L.) üzerine bir derleme. *Marmara Pharmaceutical Journal*, *22*(1).

Yılmaz, A., Yılmaz, H., Turan, S., Çelik, A., Nadeem, M. A., Demirel, F., Barış, E., Emiralioğlu O. and Arslan, M. (2022). Biotechnological advancements in coriander (*Coriandrum sativum* L.). *Avrupa Bilim ve Teknoloji Dergisi*, (35), 203-220.

CHAPTER 16

INTEGRATING MOLECULAR MARKERS IN MAIZE BREEDING FOR IMPROVED DROUGHT RESILIENCE

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1. INTRODUCTION

Corn (*Zea mays* L.) was first described by Carl Linnaeus in 1753 (Jarvis, 2007). Corn, scientific name "*Zea mays*", botanically belongs to the Poaceae family, the fourth largest flowering plant family in the world, and is an important annual warm climate cereal plant with C4 metabolism (Kumar and Jhariya, 2013; Scott and Emery 2016). There are four species in the genus Zea in this group, although only *Zea mays* is significant from an economic standpoint. Known as wild herbs, teosintes are indigenous to Mexico and Central America (Akbaş, 2022). Corn has different characteristics compared to the species of the family, especially in terms of flowering style. When the flower structure of the corn is examined, the male tassel and the female flowers on the cob are located on the same plant but in different places. Since corn is a monoecious plant, it has two incomplete flowers, male and female parts. The male and female flowers are located in the tassel and the cob, respectively (Luka and Awata, 2019). Corn is a monocotyledonous plant and can generally grow up to 3-5 m, while some wild species can grow up to 13-14 m (Wellhausen and Hernandez, 1952). Corn consists of main parts such as stalk, leaf, root and other parts such as tassel, spikelet and eventually seed (Vincent, 2012).

The warm climate conditions, fertile soil, regular irrigation, fertilization and disease/pest control play an important role among the main factors in corn cultivation (Kırtok, 1998). Corn is grown in hot and humid regions. The growing area of corn, of which many varieties have been developed from past to present, is quite wide. While maize requires a temperature of 25-28 °C during the germination period and 25-33 °C during the growth period, cultivation requirements vary especially among species and in growing environment conditions (Idikut, 2013; Waqas et al., 2021). Temperatures above or below these thresholds have a detrimental effect on plant growth and reduce productivity (Türkoğlu, 1971). To ensure optimal conditions for the corn, it should be planted in spring and summer and its development should be ensured in the temperature range between 20 and 30 °C (Şenyüz, 2023). In terms of soil requirements, corn prefers well-drained soils rich in organic matter and plant nutrients. The right fertilizers with essential nutrients, particularly nitrogen, should be used for fertilization. Preventive actions and prompt, efficient interventions are essential in the battle against illnesses and pests (Scott & Emery, 2016).

Corn has 2n=20 chromosomes, making it a diploid plant (Batiru and Lübberstedt, 2024). Teosinte is a wild plant from the Poeaceae family and is thought to be one of the close relatives of the corn plant. This plant, thought to be native to Central America, is known as the genitor of today's corn plant (Beadle, 1980). Corn is a typical C4 plant with high photosynthetic ability, and under optimum conditions, it has twice the photosynthetic capacity of wheat, which is a C3 plant (İştipliler, 2018). The anatomical differences of the leaves in corn, the high oxygen content in the chloroplasts of the mesophyll cells located close to the leaf surface, and the high activity of the PEPC (Phosphoenolpyruvate Carboxylase) enzyme are among the factors that increase the efficiency of photosynthesis (Borba, 2019). Especially compared to wheat, the normal continuation of photosynthesis even in environments, where the light intensity of the corn plant is low, is the most important factor that increase the yield potential of the corn plant. Like other C4 plants, photorespiration of corn is low, resulting in less dry matter consumption, and photorespiration losses are almost non-existent compared to wheat (Gençtan and Balkan, 2013).

Corn, a native plant of the American continent, has become one of the most cultivated crops in the world today. Corn has a cultivation area of 196,982 thousand hectares in the world, most of which is in the temperate zone (FAO, 2020). Corn is seen as the "cereal of the future" throughout the world since it has a high nutritional value and its main and by-products have a wide range of uses. Corn has a very important place in terms of meeting the food production needs of the world today and in the future (Yuan and Flores, 1996). Corn grain contains 73%

starch, 10% protein and 5% oil in its chemical composition (Earle et al., 1946). It is important to employ fertilizers that contain critical nutrients, especially nitrogen. In the fight against diseases and pests, prevention measures and effective and timely interventions are crucial (Scott & Emery, 2016). Corn has a wide range of uses, including fresh food, canned goods, corn flour, corn starch, chips, snacks, animal feed, oil, sweeteners, chocolate, baby food, sauces, corn syrup, ethanol and cleaning supplies (Bayramoğlu and Bozdemir, 2018). In addition, it is used for different purposes in many different areas such as corn feed industry, bakery products, industrial vegetable oil industry, biodiesel industry, snack production industry, starch and starch-based sugar production industry, explosive industry and textile industry (Arıoğlu and Erekul, 2022).

Corn is among the top three cereals produced in the world because it is used as an important source of nutrition for humans, as feed for animals, and as a raw material for many industrial products. (FAO, 2020). According to crop production data between 2020 and 2021, the top three most produced grains worldwide were 1,125 million tons of corn, 775.8 million tons of wheat and 505 million tons of rice, respectively (Shahbandeh, 2021). Corn production worldwide has maintained its level of 1.1 billion tons in the last 5 market years, and it is predicted that corn, whose production and usage amount has increased, will maintain this position in the future and will further accelerate and strengthen it. The countries that produce the most corn are the USA with 384 million tons, China with 231 million tons, Brazil with 64 million tons, Argentina with 39 million tons, and Türkiye ranks 21st with 6.4 million tons of production.

Sustainability in modern plant production has been achieved thanks to the developments in the past fifty years and the green revolution, the use of chemical and organic fertilizers in agriculture, mechanization in agriculture, and especially the increasing integration of genetic engineering and biotechnology into agriculture. With all these positive developments, although this sustainability seems sufficient today compared to the past, it is estimated that it will be insufficient to meet the increase in food and energy supply in the next thirty-five years (Mitchell et al., 1997; Grassini et al., 2013). However, the decrease in irrigation water stocks used in crop production and the emergence of drought are one of the most important factors that cause this danger to constantly increase (DeJonge et al., 2015). On average, 70% of the world's available clean water stock is used for crop production. Today, the gradual decrease in clean water stock threatens both our current water use and the human community (Rosegrant et al., 2009).

Global food output is predicted to rise by 70% and the world's population is expected to reach 9.5 billion by 2050, while the demand for corn will double (Varshney et al., 2011; CIMMYT, 2011). Crop production must therefore rise in tandem to feed the world's fast growing population (Shiferaw et al., 2011). However, one of the largest issues facing modern agricultural production is the significant harm that biotic and abiotic stress factors cause to plants, which in turn has a detrimental impact on yield and productivity. To address this significant issue, maize genotypes that are resistant to these stressors must be improved. These genotypes must have the capacity to withstand various biotic and abiotic stress conditions and maintain their productivity. It is very important that corn production is successful and sustainable for global food security because corn has an important place in grain production (Edmeades et al., 1999).

Morphological and Physiological Responses to Drought Stress in Maize

Food security is under risk due to the detrimental effects of climate change and the resultant highly changeable weather on plant growth, development and yield (İlker et al., 2011).

Global climate models are evolving in tandem with climate change, and it is anticipated that the Earth's temperature will rise by an average of 2.6 to 4.8 °C, particularly in the latter half of the twenty-first century (Drobinski et al., 2020). At the same time, with these increasing temperatures, it is predicted that high temperature factors such as heat waves and drought will increase more frequently and intensely. It is obvious that agricultural production systems would suffer as a result of these predicted drastic climate changes. Even if abiotic stressors caused by climate change are harmful to plant growth and development, the primary factors affecting crop productivity are high temperatures and drought stress (Begna et al., 2022).

Abnormal changes occurring in environmental conditions affect plant growth and development to a certain extent and reveal the concept of stress (Figure 1). The term stress is one of the concepts that is difficult to define in plant biology. However, in the most general sense, stress is defined as any situation or substance that occurs continuously or periodically in an environment and causes a negative effect on the growth, development and even productivity of plants or plant organs (Mahajan and Tuteja 2005; Hale and Orcutt 1987; Kocaçalışkan, 2003). In short, stress means that one or more factors in the environment in which a plant lives negatively affects growth and development and results in low productivity in plant production. Plants face a lot of stress throughout their lives. Stress factors in plants come from both biotic (animals, pathogens, parasitic plants, allelopathy and human factor) and abiotic (drought, salinity, low and high temperature, flooding, radiation, chemicals and pollutants, wind and nutrient deficiency) sources (Shanker et al., 2014).

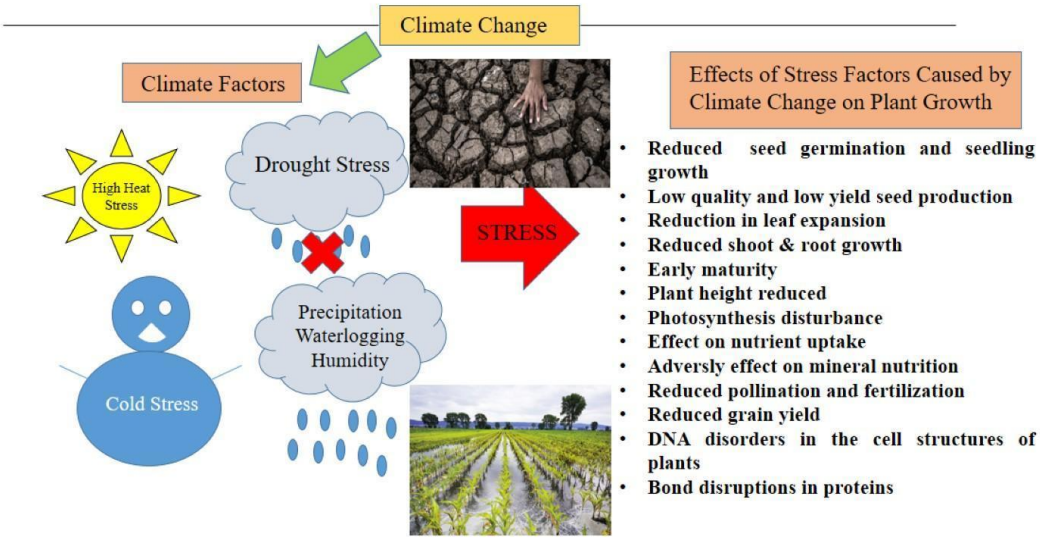

Figure 1. Schematic Representation of the Effects of Climate Change and Stress Factors on Plants.

The term stress is used for plants as well as humans and animals. Stress factors may differ in humans, animals and plants, but in general there are some common elements: these common elements appear as environmental changes or environmental factors (Poehlman and Poehlman, 1987). Negative changes observed in plants due to the effect of abiotic and biotic stress factors are expressed as stress (Ramegowda and Senthil-Kumar, 2015). When viewed over a long evolutionary process, plants have developed mechanisms that allow them to sensitively perceive incoming stresses and regulate their physiology accordingly in order to survive against

such stresses (Zhang et al., 2006). Heat and drought damage to wheat, oats, corn, sorghum, millet, and other crops is common in areas with high temperatures and low rainfall. Damage may also be compounded if drought stress is accompanied by the drying effects of strong winds (Seleiman et al., 2021). The two main categories of resistance mechanisms are drought tolerance and drought avoidance. Plant characteristics that prevent water loss, such as closed stomata, leaf curling, or waxy materials on the leaf surface, and deep root systems that draw in less soil moisture are examples of drought avoidance strategies. A straightforward method of enhancing plant performance under drought stress is to select for genotypes that display these characteristics. It is more difficult to define drought tolerance than drought avoidance (Poehlman and Poehlman, 1987).

One of the most significant abiotic stressors that harms and interferes with agricultural productivity is drought (Lakew et al., 2011; Lesk et al., 2016). Future plant output will be more affected by drought stress, a crucial abiotic stressor that impairs plant growth and development, as a result of climate change (Saygili, 2019). In many parts of the world, particularly in arid and semi-arid regions, drought is a significant and frequent abiotic stress for plants. According to reports, a variety of variables, including high temperatures, salt, little rainfall, and intense light, can cause drought stress (Blum, 1986; Shanker et al., 2014). The primary factor restricting maize output globally is acknowledged to be water stress (Zhou et al., 2017). Climate change is making droughts more severe and lasting longer, which reduces the amount of water that plants can absorb. This has a big impact on maize yield (Ben-Ari et al., 2016). Thus, achieving greater yields with less water is one of the primary breeding objectives to boost maize yield and sustain maize production under water stress situations.

Depending on the plant's density, timing, and growth stage, the amount of maize grain yield lost to drought pressure can range from 1% to 76% (Sah et al, 2020). In corn cultivation, water stress can occur at any point during plant growth and development, but the time when corn plants are most damaged by water stress is just before or during flowering (Agrama and Moussa, 1996). In corn cultivation, water scarcity occurring during the flowering period of the plants or at any time during the flowering period can reduce the growth rate of the tassel. (Uribelarrea et al., 2002). At the same time, the water stress encountered during this period increases the difference between the top tassel and cob tassel removal times in corn, which reduces egg fertility and leads to grain shedding (Edmeades et al., 2000). When corn plants are exposed to water stress during or just before flowering, morphological changes such as shortening of plant height, curling of leaves and sterile cobs that do not set seeds can be observed in corn (Hao et al., 2011).

The issue of food insecurity is becoming worse as a result of both population growth and global climate change. Improving the photosynthetic performance, grain yield and drought resistance of maize, an important C4 plant, is one of the main goals of breeding programs. Any change in environmental conditions, such as water scarcity, reduces the growth or development of the plant (Levitt, 1980). According to studies, corn plants under drought stress produced fewer grains per plant, and pollen deficiency increased in tandem with water stress (Hall et al., 1982). Additionally, drought stress in the week before flowering and in the week after flowering also reduced grain yield. Numerous studies' findings have demonstrated that some stages of plant growth are more vulnerable to water stress (Sah et al., 2020). For example, water stress that occurs during the fertilization phase of corn causes a small number of eggs to be fertilized or none of them to be fertilized, resulting in corn ears that do not set grain. Since maize plants are subjected to water scarcity, numerous research have been done to investigate the detrimental impacts of water stress, particularly on significant yield indices. For example, Erdal (2014) used twenty different inbred corn lines and in the water stress study applied to these corn lines in the

V10-12 period, V10 It was reported that water stress in the -12 period significantly reduced grain yield in corn.

Leaf curl and survival rate are two indicators that are frequently used to gauge drought in maize, particularly when the plant is in the seedling stage. Under drought stress circumstances, leaf curl helps the plant reduce water loss and prevent the detrimental consequences of stress, starting with leaf water potentials at -1 MPa and reaching a maximum around -2 MPa (Baret et al., 2018). In contrast, the survival rate indicates the ability of plants to sustain their viability under drought stress conditions and continue to grow normally when water availability is provided. Plant deaths will increase with the severity and duration of drought stress (Yang et al., 2012). According to reports, the survival percentage of maize in various genetic sources varies between 1.65% and 82.98% when taking into account the developmental phases of the corn plant, particularly when severe drought stress occurs during the seedling stage (Gupta et al., 2020). These rates show that maize germplasm exhibits a high degree of genetic variability with regard to drought tolerance.

Since drought stress can persist for a long period and affects a large region globally, it is the most significant natural stressor (Myers et al., 2017). Water scarcity impairs corn cultivation and severely limits plant growth in semi-arid and arid regions of the world where maize is farmed by irrigation or rainfall (Gao et al., 2019). According to earlier research, drought stress accounts for almost half of all plant losses brought on by abiotic stressors (Zhou, 2014). Physiological and biochemical processes, as well as characteristics like transpiration rate, stomatal conductance, dry matter accumulation, photochemical efficiency, net assimilation rate, chlorophyll content, and yield -the final result of all these processes in plants- are adversely affected by drought stress in corn plant (Guanter et al., 2014; Song et al., 2018; Li et al., 2019; Cai et al., 2020). For maize to survive, thrive, and produce biomass in water-scarce situations, it is crucial to breed drought-tolerant cultivars and increase the plants' tolerance to drought stress.

Use of Molecular Techniques in Breeding for Drought Resistance in Maize

Today, more products must be produced in less space for people in order to meet the nutritional needs of the world's constantly growing population. On the other hand, more livestock should be grown to meet the meat needs of people and more feed should be grown to feed these livestock. As a result, more productive and higher quality plants should be grown in less space and these plants should be more resistant to abiotic and biotic factors (James 2005). Fortunately, in the 1970s new tools for plant breeding emerged and one of them was the application of biotechnology in plants (Wenzel, 2006). The development of a new corn plant type can take eight to ten years in traditional maize breeding. Researchers and breeders are becoming more and more interested in new technologies that can expedite or improve this process (David, 2007).

Molecular markers are variations in a particular DNA segment found in the genome. These variations result from mechanisms like translocations, duplications, deletions and insertions. In disciplines including genetic engineering, physiology, taxonomy, embryology, and plant breeding, DNA markers are highly useful instruments (Schlötterer, 2004). Codominant markers like SNP (single nucleotide polymorphism), CAPS (cleaved amplified polymorphic sequence), SCAR (sequence defined amplified regions), and SSR (simple sequence repeats) became more prevalent with the invention of the polymerase chain reaction (PCR) (Figure 2) (Collard and Mackill, 2008). Genetic diversity investigations, gene tagging,

genetic mapping, marker-assisted selection (MAS), map-based identification of agriculturally essential genes, and phylogenetic analysis studies have all been made easier with the use of these created DNA markers. Molecular markers are nearly 100% reliable in plant breeding, particularly when assessing the relationships between plant genotypes or the diversity within a population (Amiteye, 2021). Plant breeding, plant systematics, and genetic resource appraisal all make extensive use of molecular markers nowadays (Dida, 2022).

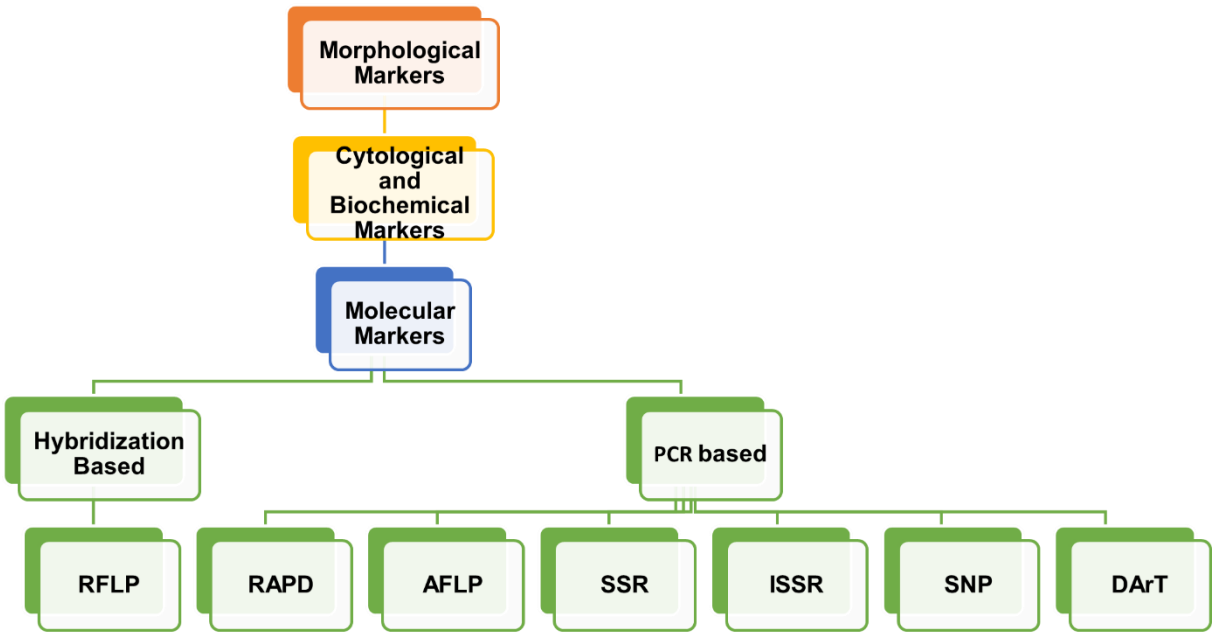

Figure 2. Molecular Marker Techniques and Their Classification.

Various morpho-physiological traits contributing to tolerance to water stress have been identified in maize. Molecular markers and genes related to drought that regulate metabolic and physiological responses under stress have also been identified (Shanker et al., 2014). Thanks to modern molecular technologies integrated into plant breeding and advances and innovations in high-throughput genotyping techniques, it is possible to sequence and genotype large amounts of material in a short time (Tardieu et al., 2017). Genetic diversity and accurate determination of QTL (Quantitative Trait Loci) under drought stress conditions has become possible by combining these genotyping and sequencing results with phenotyping values obtained from multiple environments. As a result, determining agronomic, physiological and molecular tolerance mechanisms and combining various genomic segments through crossbreeding have been widely used to develop drought-tolerant maize plants (Rauf et al., 2016). In order to improve drought resistance and boost maize yield, it is believed that molecular marker and marker assisted selection (MAS) technology can be of use in identifying polymorphic variations based on genes associated with resistance to water stress conditions and the effects of these polymorphic variations on agronomic and physiological traits.

QTL Mapping to Improve Drought Resistance in Maize

There are two types of inheritance mechanisms in plants, qualitative and quantitative. While quantitative characters show continuous variation in inheritance, characters with qualitative inheritance do not show continuous variation. Multiple genes regulate quantitative traits, whereas a single or small number of genes often control quantitative traits (Khan 2015).

Multiple genes regulate numerous agricultural features, including yield, quality, and disease resistance, as well as certain desirable agronomic, physiological, and morphological characteristics in plants. The majority of economically significant agricultural features are quantitative and polygenic, governed by several genes on the same or separate chromosomes. In 1949, Mather dubbed these genes that govern quantitative features polygenes (Mather, 1949). The traits controlled by polygenes were first named as QTL (Quantitative Trait Locus) by Gelderman (Gelderman, 1975). Chromosomal regions having the genes for these quantitative traits are called QTL.

Many agriculturally important and desirable traits, especially many quantitative characters such as yield and yield related characteristics, quality or resistance to stress conditions, are controlled by various genes in plant breeding (Araus et al., 2008). However, it is unclear how many genes interact and how many genes control each other for these quantitative traits (Mohan et al., 1997). Nowadays, with the use of genetic or marker technologies in plant breeding projects, it has become much easier to learn the genes and their roles related to phenotypic traits that are important for agriculture. Quantitative trait loci (QTLs) are identified by constructing a genetic map, which is one technique used to create markers linked to a characteristic studied in plants (Salazar et al., 2014). To create an excellent high density genetic map, a reference genetic map created using markers is necessary. The idea of genetic mapping involves creating new genetic maps in various populations. These genetic maps allow QTL analysis to be used to place significant characters on linkage groups, identify markers associated with significant characters, and aid in the characterization and cloning of significant genes (Majhi et al., 2024). Linkage mapping and QTL analysis are the most effective methods in molecular biotechnology research to identify genes putatively linked to important traits. QTL mapping is defined in molecular breeding as the process of identifying genes using genetic markers that affect quantitative traits. Plant breeding studies substantially benefit from knowing the precise position of these genes in the genome (Ürün, 2023).

DNA marker technology provides us with information about genetic factors that largely cause phenotypic variation (Grover & Sharma, 2016). Molecular marker studies on drought resistance breeding in maize started with genetic characterization and mapping of QTLs (Tuberosa et al., 2002). In addition, the use of molecular markers located close to the gene in MAS applications provide breeders with advantages in the process of developing drought-resistant varieties in maize (Devi et al., 2017). By using molecular markers, safe and rapid discrimination between susceptible and resistant plants can be achieved at every stage of breeding studies (Ren et al. 2000). In studies conducted from past to present in breeding for drought resistance in maize plant, many QTL regions associated with drought resistance have been found in chromosomes of populations formed as a result of crossing two different parental plants, and some of these markers discovered are still used in MAS technology or classical backcross breeding (Table 1).

Table 1. QTL Mapping of Important Traits Related to Drought Resistance in Maize with Different Molecular Marker Techniques.

	Number of Samples	**Molecular Marker Type**	**Researched Feature**	**Research Findings**	**References**
1	210 Recombinant Inbred Lines (RILs).	RFLP marker	Various characters in maize plant under drought stress conditions	30 QTLs under drought stress conditions	(Prasanna et al., 2009).
2	Two F_2 populations and their derived $F_{2:3}$ populations.	SSR marker	Architectural features of ear leaf under drought stress.	100 QTLs ear leaf architecture traits under drought stress conditions	(Zhao et al., 2018).
3	$F_{2:3}$ families made up 202 (POP1) and 218 (POP2) of the two research populations.	SSR marker	Components of yield and morphological characteristics during drought stress.	32 QTLs Components of yield and morphological characteristics during drought stress.	(Zhao et al., 2019).
4	Double Haploid (DH) population with 217 lines.	SNP marker	Yield related traits	18 OTL yield related traits	(Hu et al., 2021)
5	Two F_4 populations were generated from the Chang7-2 × TS141 (CH × TS) and Langhuang × TS141 (LH × TS) crosses, with 218 and 202 individuals, respectively.	SSR marker	Photosynthetic parameters	54 QTLs photosynthetic parameters	(Zhao and Zhong, 2021).
6	396 diverse tropical maize lines.	SNP marker	Root Characteristics Under Drought Stress	50 SNPs for root functional traits	(Zaidi et al., 2016)
7	300 doubled haploid lines.	SNP	Yield related features	Four yield-related characteristics and 48 significant QTLs	(Kumar et al., 2020).
8	BC_2F_5 population containing 191 lines from a single cross between Mo17 and X26-4.	SNP	Flowering time characteristics	Sixteen QTLs and 11 candidate genes were found for the three flowering time traits.	(Wang et al., 2016).

The most effective way to tolerate the negative effects of drought on maize production is to increase collaboration among disciplines related to agronomy, plant physiology, genetics, breeding and environmental characterization and models (Tardieu et al., 2017). Many

agronomic and breeding programs are being carried out in maize to improve its performance under water stress conditions (Campos et al., 2004). However, since drought is one of the biggest obstacles for plant production worldwide, agronomic, physiological and molecular drought tolerance and resistance mechanisms in plants need to be investigated in more depth and especially gene editing technologies need to be used more effectively.

Use of Marker Assisted Selection (MAS) in Breeding for Drought Resistance in Maize

Conventional breeding methods for maize are predicated on either yield and quality selection or selection for resistance to biotic and abiotic stressors (Gadag et al., 2016). Developing drought-resistant cultivars through breeding trials mostly involves selecting genotypes that produce more than other genotypes under drought conditions (Prasanna, 2016). In breeding studies aimed at developing drought-resistant varieties, the basic criterion is to select genotypes that are morphologically, agronomically and physiologically more effective under drought stress conditions, and that also have higher yields and lower costs than other genotypes. Molecular markers are used in the construction of genetic maps (Rafalski et al., 1996; Aykut Tonk et al., 2016), QTL analyses (Tehseen et al., 2022), characterization of cultivated plants (Tehseen et al., 2022), protection of newly developed varieties, determination of genetic biodiversity (Khaidizar et al., 2012), purity analysis in seed production, examination of genetic resources, determination of the structure of genetic resources, separation of genotypes and determination of individuals to be used as parents in breeding programs. However, molecular markers are extensively used in studies in which genes and/or QTL regions associated with different stress factors are identified and information about genome structure is obtained (Gupta and Rustgi, 2004). The aim of plant breeding is generally the efficient selection of plants with desired characters from a large population based on phenotype. In plant breeding programs, phenotypic data are used to select plants with desired characteristics in breeding with classical methods, while molecular markers are used in plant selection and this method is called marker-assisted selection (MAS) (Singh and Singh, 2015; Jiang, 2015).

The practice of selection plants with genomic areas implicated in the control of desired traits using a genetic marker is called marker-assisted selection (MAS) (Lema, 2018). Characteristic relationships with molecular structures can be used to identify individual genes or QTLs that strongly influence a particular target trait or traits. This can save time by incorporating desired traits into elite germplasm, which can improve plant breeding success and efficiency (Azhaguvel et al., 2006). Through the effective use of molecular markers, MAS improves selection efficiency and sensitivity, overcoming the problems encountered in conventional plant breeding (Collards et al., 2005). In addition to increasing resistance to biotic and abiotic stresses, MAS can enhance plant traits like yield and quality. For a number of factors, including yield, quality, resistance to biotic and abiotic stress, and qualitative characteristics, breeding programs have reported twice the genetic gain rate when employing MAS as opposed to phenotypic selection. For MAS to be effective, there must be a strong correlation and/or close relationship between the molecular markers and the gene of interest. Additionally, the markers ought to be easy to use, repeatable and stable (Yu et al., 2004). Studies to discover, track, combine and pyramid different genes responsible for desirable traits like drought tolerance in maize have shown that MAS is an effective approach (Table 2).

Table 2. MAS Studies in Breeding for Drought Resistance in Maize

	Traits About MAS Studies	Marker Type	References
1	Increasing the grain yield of maize in both drought-stressed and non-stressed conditions.	SNP	(Beyene et al., 2016).
2	Improvement of drought stress tolerance in pearl millet plant.	SSR	(Rani et al., 2022).
3	Selection of secondary yield qualities under drought stress with the aid of markers.	RFLP	(Ribaut et al., 1997).
4	Utilizing marker-assisted selection for physiological characteristics and yield in well-irrigated and drought-stressed environments.	SNP	Cerrudo et al., 2018).
5	Utilizing marker-assisted selection for yield and yield-related characteristics in well-irrigated and drought-stressed environments.	SNP	(Bankole et al., 2017).
6	Using marker-assisted selection to improve yield-related traits in well-irrigated and drought-stressed environments.	SNP	(Abdulmalik et al., 2017).

3. CONCLUSION

Numerous QTL regions linked to drought resistance have been identified in the chromosomes of different populations created by crossing two distinct parent in studies on breeding for drought resistance in maize from the past to the present. Some of these markers found are still in use in MAS technology or traditional backcross breeding. Increasing collaboration amongst the fields of agronomy, plant physiology, genetics, breeding, environmental characterization and modeling is the best strategy to withstand the detrimental impacts of drought on agricultural production. Numerous genetic and agronomic initiatives are underway to enhance maize plants' ability to withstand water stress. However, given that drought is one of the largest challenges facing maize production globally, more research is required to understand the agronomic, physiological, and molecular mechanisms of drought-related tolerance and resistance in maize plants. In particular, gene editing technologies need to be employed more efficiently. Furthermore, more thorough genotyping research (using more SSR or SNP markers) would make it possible to identify novel gene/genes that account for a greater percentage of the phenotypic variation seen in desired qualities assessed under drought stress.

REFERENCES

Abdulmalik, R. O., Menkir, A., Meseka, S. K., Unachukwu, N., Ado, S. G., Olarewaju, J. D., ... & Gedil, M. (2017). Genetic gains in grain yield of a maize population improved through marker assisted recurrent selection under stress and non-stress conditions in West Africa. *Frontiers in Plant Science*, *8*, 841.

Agrama, H. A., & Moussa, M. E. (1996). Mapping QTLs in breeding for drought tolerance in maize (*Zea mays* L.). *Euphytica*, *91*, 89-97.

Akbaş, S. (2022). *Effects of different herbicide applications on growth parameters in corn Zea mays L.* (M.S. thesis).

Amiteye, S. (2021). Basic concepts and methodologies of DNA marker systems in plant molecular breeding. *Heliyon*, *7*(10).

Araus, J. L., Slafer, G. A., Royo, C., & Serret, M. D. (2008). Breeding for yield potential and stress adaptation in cereals. *Critical Reviews in Plant Science*, *27*(6), 377-412.

Arioglu, R., & Erekul, O. (2022). Effect of different irrigation levels on yield and quality of corn varieties (*Zea mays* L.) under Aydin ecological conditions. *ADÜ J.Agric*, 2022;19(1): 161-166

Aykut Tonk, F., İştipliler, D., Tosun, M., Turanli, F., İlbi, H., & Çakir, M. (2016). Genetic mapping and inheritance of Russian wheat aphid resistance gene in accession IG 100695. *Plant Breeding*, *135*(1), 21-25.

Azhaguvel, P., Saraswathi, D. V., Sharma, A., & Varshney, R. K. (2006). Methodological advancement in molecular markers to delimit the gene (s) for crop improvement. *Floriculture, Ornamental and Plant Biotechnology*, *1*, 460-469.

Bankole, F., Menkir, A., Olaoye, G., Crossa, J., Hearne, S., Unachukwu, N., & Gedil, M. (2017). Genetic gains in yield and yield related traits under drought stress and favorable environments in a maize population improved using marker assisted recurrent selection. *Frontiers in Plant Science*, *8*, 808.

Baret, F., Madec, S., Irfan, K., Lopez, J., Comar, A., Hemmerlé, M., ... & Tixier, M. H. (2018). Leaf-rolling in maize crops: from leaf scoring to canopy-level measurements for phenotyping. *Journal of Experimental Botany*, *69*(10), 2705-2716.

Batiru, G., & Lübberstedt, T. (2024). Polyploidy in maize: from evolution to breeding. *Theoretical and Applied Genetics*, *137*(8), 182.

Bayramoğlu, Z., & Bozdemir, M. (2018). Türkiye'de üretilen mısırın ekonomik gelişim seyri. *Turkish Journal of Agriculture - Food Science and Technology*, 6(8): 1092-1100.

Beadle, G.W. (1980). The ancestry of corn, Scientific American, 242(1):112-119 pp.

Ben-Ari, T., Adrian, J., Klein, T., Calanca, P., Van der Velde, M., & Makowski, D. (2016). Identifying indicators for extreme wheat and maize yield losses. *Agricultural and Forest Meteorology*, *220*, 130-140.

Bilgiç, Ş., Sade, B., Soylu, S., Bilgiçli, N., Cerit, İ., Öz, A., Cengiz, R. and Özkan, İ. (2012). Maize Report. Turkey National Cereal Council (in Turkish).

Blum, A. (1986). The effect of heat stress on wheat leaf and ear photosynthesis. *Journal of Experimental Botany*, *37*(1), 111-118.

Borba, A. (2019). *Transcriptional Regulatory Mechanisms Controlling Key Genes Involved in C4 Photosynthesis in Maize* (Doctoral dissertation, Universidade NOVA de Lisboa (Portugal)).

Cai, F., Zhang, Y., Mi, N., Ming, H., Zhang, S., Zhang, H., & Zhao, X. (2020). Maize (*Zea mays* L.) physiological responses to drought and rewatering, and the associations with water stress degree. *Agricultural Water Management*, *241*, 106379.

Campos, H., Cooper, M., Habben, J. E., Edmeades, G. O., & Schussler, J. R. (2004). Improving drought tolerance in maize: a view from industry. *Field Crops Research*, *90*(1), 19-34.

Cerrudo, D., Cao, S., Yuan, Y., Martinez, C., Suarez, E. A., Babu, R., ... & Trachsel, S. (2018). Genomic selection outperforms marker assisted selection for grain yield and physiological traits in a maize doubled haploid population across water treatments. *Frontiers in Plant Science*, *9*, 366.

CIMMYT, (2011). Maize-Global Alliance for Improving Food Security and the Livelihoods of the Resources-poor in the Developing World, El Batan, Mexico, 91p.

Collard, B. C., & Mackill, D. J. (2008). Marker-assisted selection: an approach for precision plant breeding in the twenty-first century. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *363*(1491), 557-572.

Collard, B. C., Jahufer, M. Z. Z., Brouwer, J. B., & Pang, E. C. K. (2005). An introduction to markers, quantitative trait loci (QTL) mapping and marker-assisted selection for crop improvement: the basic concepts. *Euphytica*, 142, 169-196.

David JM. (2007). Molecular markers and marker-assisted selection in rice. In: Rajeev KV & Roberto T (Eds.), Genomics-Assisted Crop Improvement: *Genomics Applications in Crops* 2: 169-186.

DeJonge, K. C., Taghvaeian, S., Trout, T. J., & Comas, L. H. (2015). Comparison of canopy temperature-based water stress indices for maize. *Agricultural Water Management*, 156, 51-62.

Devi, E. L., Devi, C. P., Kumar, S., Sharma, S. K., Beemrote, A., Chongtham, S. K., ... & Ngachan, S. V. (2017). Marker assisted selection (MAS) towards generating stress tolerant crop plants. *Plant Gene*, *11*, 205-218.

Dhakal Poudel, P., Cowan, M., Shaw, L., De Faveri, J., Topp, B., & Alam, M. (2023). Macadamia Breeding for Reduced Plant Vigor: Progress and Prospects for Profitable and Sustainable Orchard Systems. *Sustainability*, *15*(19), 14506.

Dida, G. (2022). Molecular Markers in Breeding of Crops: Recent Progress and Advancements. *J. Microbiol. Biotechnol*, *7*(4).

Drobinski, P., Da Silva, N., Bastin, S., Mailler, S., Muller, C., Ahrens, B., ... & Lionello, P. (2020). How warmer and drier will the Mediterranean region be at the end of the twenty-first century? *Regional Environmental Change*, 20, 1-12.

Earle, F. R., Curtis, J. J., & Hubbard, J. E. (1946). Composition of the component parts of the coin kernel. *Cereal Chemistry*, Vol.23, No., pp.504-511

Edmeades, G. O., Bolanos, J., Elings, A., Ribaut, J. M., Bänziger, M., & Westgate, M. E. (2000). The role and regulation of the anthesis-silking interval in maize. *Physiology and Modeling Kernel Set In Maize*, *29*, 43-73.

Edmeades, G.O., Chapman, S.C. and Lafitte, H.R., (1999). Selection improves drought tolerance in tropical maize populations: I. Gains in biomass, grain yield, and harvest index, *Crop Science*, 39(5),:1306-1315 pp.

Erdal, Ş. (2014). Determination of drought tolerance level of maize (Zea mays L.) inbred lines and molecular characterization (Ph.D. dissertation). Süleyman Demirel University / Graduate School of Natural and Applied Sciences / Department of Field Crops, Isparta

FAO. (2020). Global Information and Early Warning System on Food and Agriculture (GIEWS) Country Brief. Food and Agriculture Organization (FAO) of the United Nations.

Gadag, R. N., Bhat, J. S., Mukri, G., Gogoi, R., Suby, S. B., Das, A. K., ... & Shilpa, K. (2021). Resistance to biotic stress: theory and applications in maize breeding. *Genomic Designing For Biotic Stress Resistant Cereal Crops*, 129-175.

Gao, C., Li, X., Sun, Y., Zhou, T., Luo, G., & Chen, C. (2019). Water requirement of summer maize at different growth stages and the spatiotemporal characteristics of agricultural drought in the Huaihe River Basin, China. *Theoretical and Applied Climatology*, *136*, 1289-1302.

Geldermann, H. (1975). Investigations on inheritance of quantitative characters in animals by gene markers I. Methods. *Theoretical and Applied Genetics*, *46*(7), 319-330.

Gençtan T., Balkan A., (2013). *Mısır (Zea mays L.) Bitkisinin Fizyolojisi*. Melez Mısırla 100 Yıl Çalıştayı Kitabı. BİSAB Yayın No:1, 44-70.

Grassini, P., Eskridge, K. M., & Cassman, K. G. (2013). Distinguishing between yield advances and yield plateaus in historical crop production trends. *Nature Communications*, 4, 2918.

Grover, A., & Sharma, P. C. (2016). Development and use of molecular markers: past and present. *Critical Reviews in Biotechnology*, *36*(2), 290-302.

Guanter, L., Zhang, Y., Jung, M., Joiner, J., Voigt, M., Berry, J. A., ... & Griffis, T. J. (2014). Global and time-resolved monitoring of crop photosynthesis with chlorophyll fluorescence. *Proceedings of the National Academy of Sciences*, *111*(14), E1327-E1333.

Gupta, A., Rico-Medina, A., & Caño-Delgado, A. I. (2020). The physiology of plant responses to drought. *Science*, *368*(6488), 266-269.

Gupta, P. K., & Rustgi, S. (2004). Molecular markers from the transcribed/expressed region of the genome in higher plants. *Functional & Integrative Genomics*, *4*, 139-162.

Hale, M. G., & Orcutt, D. M. (1987). The physiology of plants under stress. John Wiley & Sons., Chichester, UK 1987, No., pp.206 pp.

Hall, A. J., Vilella, F., Trapani, N., & Chimenti, C. (1982). The effects of water stress and genotype on the dynamics of pollen-shedding and silking in maize. *Field Crops Research*, *5*, 349-363.

Hao, Z., Li, X., Xie, C., Weng, J., Li, M., Zhang, D., ... & Zhang, S. (2011). Identification of functional genetic variations underlying drought tolerance in maize using SNP markers. *Journal of Integrative Plant Biology*, 53(8), 641-652.

Hu, H., & Xiong, L. (2014). Genetic engineering and breeding of drought-resistant crops. *Annual Review Of Plant Biology*, *65*(1), 715-741.

Hu, X., Wang, G., Du, X., Zhang, H., Xu, Z., Wang, J., ... & Wang, G. (2021). QTL analysis across multiple environments reveals promising chromosome regions associated with yield-related traits in maize under drought conditions. *The Crop Journal*, 9(4), 759-766.

Idikut, L. (2013). The effects of light, temperature and salinity on seed germination of three maize forms. *Greener Journal of Agricultural Sciences*, *3*(4), 246-253.

İlker, E., Tatar, Ö., Tonk, F. A., & Tosun, M. (2011). Determination of tolerance level of some wheat genotypes to post-anthesis drought. *Turkish Journal of Field Crops*, *16*(1), 59-63.

İştipliler, D. (2018). Molecular mapping of transpiration-leaf temperature relations in maize under drought conditions (Ph.D. dissertation). Ege University / Graduate School of Natural and Applied Sciences / Department of Field Crops, İzmir

James C (2005). Global status of commercialized biotech/GM crops: 2004. http://www.isaaa.org/Kc/CBTNewa/press_release/brief32

Jarvis, C. (2007). Order out of Chaos. Linnaean Plant Types and their Types. Linnaean Society of London in association with the Natural History Museum. https://doi.org/10.5281/zenodo.291971

Jiang, G. L. (2015). Molecular marker-assisted breeding: a plant breeder's review. *Advances in plant breeding strategies: breeding, biotechnology and molecular tools*, 431-472.

Karakaş, İ. (2024). Molecular Marker Techniques and Genotypic Characterization Approaches in Plant Breeding. *Turkish Journal of Agriculture-Food Science and Technology*, *12*(8), 1487-1498.

Khaıdızar, M. İ., Halıloglu, K., Elkoca, E., Aydın, M., & Kantar, F. (2012). Genetic diversity of common bean (*Phaseolus vulgaris* L.) landraces grown in northeast Anatolia of Turkey assessed with simple sequence repeat markers. *Turkish Journal of Field Crops*, *17*(2), 145-150.

Khan, S. (2015). QTL mapping: a tool for improvement in crop plants. *Res J Recent Sci*, *2277*, 2502.

Kırtok, Y., (1998). Maize: Production and utilisation, *Kocaoluk Publishing House*, Adana.

Kocaçalışkan, İ. (2003). Plant Physiology Textbook. Dumlupinar University Kütahya.

Kumar, B. A., Venkatachalam, S. R., Ravikesavan, R., Nackeeran, S., Kathirvelan, P., & Selvarangam, V. (2020). QTL analysis for yield-related traits under water stress at flowering in tropical maize (*Zea mays*. L). *Electronic Journal of Plant Breeding*, 11(02), 656-664.

Kumar, D., & Jhariya, A. N. (2013). Nutritional, medicinal and economical importance of corn: A mini review. *Res J Pharm Sci*, *2319*, 555X.

Lakew, B., Eglinton, J., Henry, R. J., Baum, M., Grando, S., & Ceccarelli, S. (2011). The potential contribution of wild barley (*Hordeum vulgare* ssp. spontaneum) germplasm to drought tolerance of cultivated barley (*H. vulgare* ssp. vulgare). *Field crops research*, *120*(1), 161-168.

Lema, M. (2018). Marker assisted selection in comparison to conventional plant breeding. *Agric Res Technol*, 14, 555914.

Lesk, C., Rowhani, P., & Ramankutty, N. (2016). Influence of extreme weather disasters on global crop production. *Nature*, *529*(7584), 84-87.

Levitt, J. (1980). Responses of Plants to Environmental Stress, Volume 1: Chilling, Freezing, and High Temperature Stresses. Academic Press.

Li, P., Yang, H., Wang, L., Liu, H., Huo, H., Zhang, C., ... & Liu, L. (2019). Physiological and transcriptome analyses reveal short-term responses and formation of memory under drought stress in rice. *Frontiers in genetics*, *10*, 55.

Luka A. O. Awata, P. T.-D. (2019). Understanding Tropical Maize (*Zea mays* L.): The Major Monocot in Modernization and Sustainability of Agriculture in Sub-Saharan Africa. *International Journal of Agricultural Research*, 32-77 ISSN 2053-1265.

Mahajan, S., & Tuteja, N. (2005). Cold, salinity and drought stresses: an overview. *Archives of biochemistry and biophysics*, *444*(2), 139-158.

Majhi, P. K., Guru, A., Mogali, S. C., Pattnaik, P., Bisane, R. D., Singha, L., ... & Behera, P. R. (2024). Genetic Mapping of Valued Genes with Significant Traits in Crop Plants: Basic Principles, Current Practices, and Future Perspectives. *Bioinformatics for Plant Research and Crop Breeding*, 99-134.

Mather K (1949). Biometric genetics, 1st edn. Methuen, London

Mitchell, D. O., Ingco, M. D., & Duncan, R. C. (1997). *The world food outlook*. Cambridge University Press.

Mohan, M., Nair, S., Bhagwat, A., Krishna, T. G., Yano, M., Bhatia, C. R., & Sasaki, T. (1997). Genome mapping, molecular markers and marker-assisted selection in crop plants. *Molecular Breeding*, 3, 87-103.

Myers, S. S., Smith, M. R., Guth, S., Golden, C. D., Vaitla, B., Mueller, N. D., ... & Huybers, P. (2017). Climate change and global food systems: potential impacts on food security and undernutrition. *Annual Review Of Public Health*, *38*(1), 259-277.

Poehlman, J. M., & Poehlman, J. M. (1987). Techniques in Breeding Field Crops. *Breeding Field Crops*, 255-289.

Prasanna, B. M. (2016). Developing and deploying abiotic stress-tolerant maize varieties in the tropics: challenges and opportunities. *Molecular Breeding for Sustainable Crop Improvement: Volume 2*, 61-77.

Prasanna, B. M., Beiki, A. H., Sekhar, J. C., Srinivas, A., & Ribaut, J. M. (2009). Mapping QTLs for component traits influencing drought stress tolerance of maize (*Zea mays* L) in India. *Journal of Plant Biochemistry and Biotechnology*, 18, 151-160.

Rafalski, J. A., Vogel, J. M., Morgante, M., Powell, W., Andre, C., & Tingey, S. V. (1996). Generating and using DNA markers in plants. In nonmammalian genomic analysis: a practical guide. *Academic Press, New York*, 73-134.

Ramegowda, V., & Senthil-Kumar, M. (2015). The interactive effects of simultaneous biotic and abiotic stresses on plants: mechanistic understanding from drought and pathogen combination. *Journal of Plant Physiology*, *176*, 47-54.

Rauf, S., Al-Khayri, J.M., Zaharieva, M., Monneveux, P. and Khalil, F., (2016). Breeding strategies to enhance drought tolerance in crops, 397–445 Advances in plant breeding strategies: agronomic, abiotic and biotic stress traits, Al-Khayri, J.M., Jain, S.M. and Johnson, D.V. (Eds.) Springer International Publishing, 397–445pp.

Ren, B., Robert, F., Wyrick, J. J., Aparicio, O., Jennings, E. G., Simon, I., Zeitlinger, J., Schreiber, J., Hannett, N., Kanin, E., Volkert, T. L., Wilson, C. J., Bell, S. P., & Young, R. A. (2000). Genome-wide location and function of DNA binding proteins. *Science (New York, N.Y.), 290*(5500), 2306–2309. https://doi.org/10.1126/science.290.5500.2306

Ribaut, J. M., Jiang, C., Gonzalez-de-Leon, D., Edmeades, G. O., & Hoisington, D. A. (1997). Identification of quantitative trait loci under drought conditions in tropical maize. 2. yield components and marker-assisted selection strategies: 2. yield components and marker-assisted selection strategies. *Theoretical and Applied Genetics*, *94*, 887-896.

Rosegrant, M. R., Ringler, C., Sulser, T. B., Ewing, M., Palazzo, A., Zhu, T., ... & Batka, M. (2009). Agriculture and food security under global change: Prospects for 2025/2050. International Food Policy Research Institute, Washington, DC, 89.

Sah, R. P., Chakraborty, M., Prasad, K., Pandit, M., Tudu, V. K., Chakravarty, M. K., ... & Moharana, D. (2020). Impact of water deficit stress in maize: Phenology and yield components. *Scientific Reports*, *10*(1), 2944.

Salazar, J. A., Ruiz, D., Campoy, J. A., Sánchez-Pérez, R., Crisosto, C. H., Martínez-García, P. J., ... & Rubio, M. (2014). Quantitative trait loci (QTL) and Mendelian trait loci (MTL) analysis in Prunus: a breeding perspective and beyond. *Plant Molecular Biology Reporter*, 32, 1-18.

Saygılı, İ. (2019). Transfer of drought tolerance QTLs in barley by marker assisted selection (Ph.D. dissertation).

Schlötterer, C. (2004). The evolution of molecular markers—just a matter of fashion? *Nature reviews genetics*, *5*(1), 63-69.

Scott, M. P., & Emery, M. (2016). Maize: overview. *Encyclopedia of Food Grains. 2nd edition. Academic Press, Oxford*, 99-104.

Seleiman, M. F., Al-Suhaibani, N., Ali, N., Akmal, M., Alotaibi, M., Refay, Y., ... & Battaglia, M. L. (2021). Drought stress impacts on plants and different approaches to alleviate its adverse effects. *Plants*, *10*(2), 259.

Shahbandeh, M. (2021). Corn production worldwide 2014-2021. Statista.

Shanker, A. K., Maheswari, M., Yadav, S. K., Desai, S., Bhanu, D., Attal, N. B., & Venkateswarlu, B. (2014). Drought stress responses in crops. *Functional & Integrative Genomics*, 14, 11-22.

Shiferaw, B., Prasanna, B. M., Hellin, J., & Bänziger, M. (2011). Crops that feed the world 6. Past successes and future challenges to the role played by maize in global food security. *Food Security*, *3*, 307-327.

Singh, B. D., & Singh, A. K. (2015). Marker-assisted plant breeding: principles and practices. New Delhi, India: Springer. 2015.

Song, H., Li, Y., Zhou, L., Xu, Z., & Zhou, G. (2018). Maize leaf functional responses to drought episode and rewatering. *Agricultural and Forest Meteorology*, *249*, 57-70.

Şenyüz, E. (2023). The effect of ascorbic acid applications on dehydrin proteins in maize (*Zea mays* L.) under salt stress conditions (M.S. thesis)., Osmangazi University / Institute of Natural and Applied Sciences / Department of Agricultural Biotechnology

Tang, H., Zhang, R., Wang, M., Xie, X., Zhang, L., Zhang, X., ... & Yang, X. (2023). QTL mapping for flowering time in a maize-teosinte population under well-watered and water-stressed conditions. Molecular Breeding, 43(9), 67.

Tardieu, F., Varshney, R.K. and Tuberosa, R., (2017). Improving crop performance under drought–cross-fertilization of disciplines, *Journal Of Experimental Botany*, 68(7):1393-1398pp.

Tehseen, M. M., Tonk, F. A., Tosun, M., Istipliler, D., Amri, A., Sansaloni, C. P., ... & Nazari, K. (2022). Exploring the genetic diversity and population structure of wheat landrace population conserved at ICARDA genebank. *Frontiers in Genetics*, *13*, 900572.

Tehseen, M. M., Tonk, F. A., Tosun, M., Randhawa, H. S., Kurtulus, E., Ozseven, I., ... & Nazari, K. (2022). QTL mapping of adult plant resistance to stripe rust in a doubled haploid wheat population. *Frontiers in Genetics*, *13*, 900558.

Tuberosa, R., Salvi, S., Sanguineti, M. C., Landi, P., Maccaferri, M., & Conti, S. (2002). Mapping QTLs regulating morpho-physiological traits and yield: Case studies, shortcomings and perspectives in drought-stressed maize. *Annals of Botany*, *89*(7), 941-963.

Türkoğlu, A. (1971). Foodstuffs economic geography 1st book. Ist Pub., *44*.

Uribelarrea, M., Cárcova, J., Otegui, M. E., & Westgate, M. E. (2002). Pollen production, pollination dynamics, and kernel set in maize. *Crop Science*, *42*(6), 1910-1918.

Ürün, İ. (2023). QTL analyzes related to some quality characteristics of strawberry fruit (Ph.D. dissertation). Çukurova University / Institute of Natural and Applied Sciences / Department of Horticulture, Adana

Varshney, R. K., Bansal, K. C., Aggarwal, P. K., Datta, S. K., & Craufurd, P. Q. (2011). Agricultural biotechnology for crop improvement in a variable climate: hope or hype? *Trends in plant science*, *16*(7), 363-371.

Vincent, P. L. (2012). "*Zea mays* (maize, corn).". eLS, John Wiley & Sons, DOI: 10.1002/9780470015902.a0003687.pub2.

Waqas, M. A., Wang, X., Zafar, S. A., Noor, M. A., Hussain, H. A., Azher Nawaz, M., & Farooq, M. (2021). Thermal stresses in maize: effects and management strategies. *Plants*, *10*(2), 293.

Wellhausen, E. J., & Hernandez X., E. (1952). Races of Maize in Mexico: Their Origin, Characteristics and Distribution. Bussey Institution of Harvard University.

Wenzel, G. (2006). Molecular plant breeding: achievements in green biotechnology and future perspectives. *Applied Microbiology and Biotechnology*, 70, 642-650.

Yang, J., Gong, D., Wang, W., Hu, M., & Mao, R. (2012). Extreme drought event of 2009/2010 over southwestern China. *Meteorology and Atmospheric Physics*, *115*, 173-184.

Yu, J. K., La Rota, M., Kantety, R. V., & Sorrells, M. E. (2004). EST derived SSR markers for comparative mapping in wheat and rice. *Molecular Genetics and Genomics*, *271*, 742-751.

Yuan, J. I. A. N., & Flores, R. A. (1996). Laboratory dry-milling performance of white corn: Effect of physical and chemical corn characteristics. *Cereal Chemistry*, *73*(5), 574-578.

Zaidi, P. H., Seetharam, K., Krishna, G., Krishnamurthy, L., Gajanan, S., Babu, R., ... & Vivek, B. S. (2016). Genomic regions associated with root traits under drought stress in tropical maize (*Zea mays* L.). *PloS one*, *11*(10), e0164340.

Zhang, J., Jia, W., Yang, J., & Ismail, A. M. (2006). Role of ABA in integrating plant responses to drought and salt stresses. *Field Crops Research*, *97*(1), 111-119.

Zhao, X. Q., & Zhong, Y. (2021). Genetic dissection of the photosynthetic parameters of maize (*Zea mays* L.) in drought-stressed and well-watered environments. *Russian Journal of Plant Physiology*, 68(6), 1125-1134.

Zhao, X., Fang, P., Zhang, J., & Peng, Y. (2018). QTL mapping for six ear leaf architecture traits under water-stressed and well-watered conditions in maize (*Zea mays* L.). *Plant Breeding*, 137(1), 60-72.

Zhao, X., Zhang, J., Fang, P., & Peng, Y. (2019). Comparative QTL analysis for yield components and morphological traits in maize (*Zea mays* L.) under water-stressed and well-watered conditions. *Breeding Science*, 69(4), 621-632.

Zhou, L. Z., Juranić, M., & Dresselhaus, T. (2017). Germline development and fertilization mechanisms in maize. *Molecular Plant*, *10*(3), 389-401.

Zhou, T., Nijssen, B., Huffman, G. J., & Lettenmaier, D. P. (2014). Evaluation of real-time satellite precipitation data for global drought monitoring. *Journal of Hydrometeorology*, *15*(4), 1651-1660.

CHAPTER 17

FOOD PRODUCTION AMONG CONCRETE, IRON AND TRAFFIC: URBAN AGRICULTURE IS A WAY TO PROVIDE FOOD AND A HEALTHY CITY

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1. INTRODUCTION

Urban agriculture, the practice of cultivating, processing, and distributing food in urban areas, has emerged as a significant solution to a variety of challenges facing cities today. This innovative approach involves utilizing urban spaces such as rooftops, balconies, vacant lots, and even indoor spaces to grow a diverse range of crops (Sources Clinton et al., 2018).

One of the primary benefits of urban agriculture is its potential to enhance food security. By reducing reliance on long-distance transportation and promoting local food production, urban agriculture can help ensure a stable and reliable food supply. Additionally, it can contribute to improved nutrition as fresh, locally grown produce is often higher in vitamins and minerals().

From an environmental perspective, urban agriculture offers a range of benefits. It can help reduce greenhouse gas emissions associated with food transportation, conserve water, and improve air quality. Furthermore, urban agriculture can contribute to biodiversity conservation by creating green spaces within urban environments.

Beyond its environmental and nutritional benefits, urban agriculture can also have a positive impact on the social and economic fabric of cities. It can create jobs, stimulate local economies, and foster a sense of community. Urban agriculture can enhance well-being and mental health by providing opportunities for people to connect with nature and each other (Specht et al., 2019).

Here are some key dimensions of urban agriculture and its benefits :

Ensuring food security

Urban agriculture can help reduce dependence on long food supply chains and improve access to fresh, healthy produce. This is especially important in urban areas with problems such as a lack of green space and limited access to fresh produce.

Reducing environmental impacts

Cultivation in urban environments can help reduce the need to transport food from distant areas and thus reduce environmental pollutants. Also, urban agriculture can help improve air quality and reduce the effects of urban heat islands by creating green spaces.

Strengthening local communities

Urban agriculture can help strengthen social bonds and strengthen the sense of community in urban areas. Agricultural activities can provide an opportunity for social interaction, education and promotion of local skills.

Conservation of natural resources

This approach helps to preserve and manage natural resources, including water and soil The optimal use of resources in small and limited urban spaces can help reduce resource wastage and increase productivity.

Support for sustainable development

Urban agriculture can help to achieve sustainable development goals and strengthen sustainable living patterns. This type of agriculture can improve living conditions, reduce poverty and improve public health (Soga and Gaston, 2020).

2. DIFFERENT MODELS OF URBAN AGRICULTURE

Vertical farming: Using multi-story buildings and green walls to grow crops

Figure 1. Vertical farming in an urban environment with vertical structures and bright green plants with LED lighting (Designed by the authors).

- **Rooftop gardens (green roof):** Using the roofs of buildings to grow plants.
- **Hydroponic and aquaponic cultivation:** Using non-soil systems for growing plants helps reduce water consumption and increase productivity.

Figure 2. The image of a green roof in an urban environment shows a garden on the roof of a modern building (Designed by the authors).

Figure 3. A type of hydroponic agriculture that can be done in urban environments based on artificial lights (Designed by the authors).

In general, urban agriculture as an innovative solution can help improve the quality of life in cities, improve food security and achieve sustainable development goals (Poulsen et al., 2017).

Promotion of environmental awareness and education

Urban agriculture is a good opportunity to educate citizens about the importance of the environment, natural resources and preservation of biodiversity. By participating in urban agriculture projects, people can learn the principles of sustainable agriculture and gain a better understanding of the environmental impact of their daily activities. This awareness can lead to a reduction in energy consumption, better waste management and increased use of renewable resources.

Supporting the local economy

Urban agriculture can help grow the local economy and create new job opportunities Selling local products in urban markets, creating small businesses related to agriculture and even exporting specific products can help strengthen the local economy and reduce unemployment. In addition, the income from urban agriculture can improve the living conditions of low-income households in urban areas.

Promote healthy diets

Access to fresh, local produce can help promote healthy diets among urban dwellers. Urban agriculture makes it possible for people to have easy access to fruits, vegetables, and medicinal plants, and as a result, to benefit from nutrient-dense diets. This change in diet can lead to a reduction in the rate of diseases related to improper nutrition, such as diabetes and obesity.

Adaptability to climate change

Urban agriculture can play an important role in reducing the effects of climate change. Greenhouse gas emissions can be reduced by reducing the need for long transportation of food and producing local products. Also, the use of drought-resistant cultivation techniques and optimal management of water resources can help strengthen the resilience of agricultural systems against climate change.

Increasing green space and improving quality of life

Urban agriculture helps to increase green space in urban environments, which can improve air quality, reduce noise pollution, and create recreational and relaxing spaces. Also, these spaces can be used as places for social and cultural activities and help to improve the mood and mental health of the city residents (Deelstra and Girardet, 2021).

3. CHALLENGES AND SOLUTIONS

Although urban agriculture has many advantages, it also faces challenges. Among these challenges, we can mention the lack of suitable land, limited water resources, soil pollution in urban areas, and high implementation and maintenance costs. To deal with these challenges, solutions such as the use of new technologies (such as hydroponic cultivation), support for government policies for the development of urban agriculture, and the participation of local communities in the management of agricultural projects can be used.

The importance of urban agriculture in providing security

Urban agriculture, as a new and sustainable way to produce food in urban areas, plays an increasing role in providing food security. With the world's population growth and the limitation of natural resources, urban agriculture has been proposed as a promising solution to reduce dependence on agricultural products in remote areas and increase access to fresh and healthy food in cities. Planting agricultural products in urban spaces such as rooftops, balconies, parks and even inside buildings, in addition to providing part of the food needs of citizens, also brings other benefits. Among these benefits, we can mention the reduction of food transportation costs, reduction of air pollution and greenhouse gas production, improvement of air quality, creation of green spaces in cities and increase of people's awareness about the importance of healthy food production. Due to climate change and population growth, the importance of urban agriculture will become more visible in the future. This agricultural method can be considered an environmentally friendly solution to the challenges caused by water shortage, soil degradation, and climate change. Also, urban agriculture can help create sustainable and self-sufficient communities and reduce social inequalities in access to healthy food. In general, urban agriculture is an innovative and promising approach to ensure food security in the future, which can help improve the quality of life of citizens and protect the environment.

Impact of urban landscape agriculture on cities

Urban landscape agriculture, which is a combination of urban agriculture and landscape design, creates tremendous changes in the appearance of cities. This new approach, by using urban spaces such as rooftops, balconies, parks and even interior spaces of buildings, produces fresh and healthy food and at the same time, helps to improve the quality of urban life. Below are some of the most important changes that urban landscape agriculture brings to cities: Increasing green space and improving air quality: Creating gardens and small farms in urban spaces leads to an increase in green space per capita and, as a result, improves air quality. Plants provide a healthier environment for citizens by absorbing pollutants and producing oxygen. Reducing the air temperature and creating a pleasant microclimate: the presence of vegetation in cities helps to reduce the air temperature on hot days and prevents the creation of urban heat islands. Also, plants increase air humidity and strengthen the feeling of comfort in citizens. Urban aesthetics and improvement of visual quality: Creating green and colorful spaces in cities helps to improve urban aesthetics and increase the visual appeal of the landscape. This has a positive effect on the morale of citizens and their quality of life. Development of tourism: the creation of green spaces and urban agriculture can be considered a new tourist attraction for

cities. This will help economic prosperity and create job opportunities. Social connection and increased citizen interactions: Urban agriculture activities provide an opportunity for citizens to interact with each other and build local communities. Holding workshops and training courses in this field helps to increase public awareness about the importance of sustainable agriculture and healthy nutrition. Supplying part of the city's food needs and reducing dependence on agricultural products in remote areas: By producing fresh and healthy food in cities, we can help reduce transportation costs and increase food security. Reducing waste production and increasing recycling: Using compost and other organic waste management methods in urban agriculture helps to reduce waste production and increase recycling. In general, urban landscape agriculture is a multidimensional approach that helps to improve the quality of urban life, protect the environment and increase the sustainability of cities (Opitz et al; 2017).

The relationship between urban agriculture and tourism

Urban agriculture and tourism are two seemingly different fields that can greatly influence and benefit from each other. In the following, we will examine this relationship and their mutual effects:

The impact of urban agriculture on tourism

New tourist attractions: Urban gardens, vertical farms and other urban agriculture initiatives serve as new and unique tourist attractions. Tourists show interest in these spaces to get to know the process of food production in the urban environment.

Different tourism experiences: Urban agriculture can offer different tourism experiences such as agricultural tours, workshops and food-related festivals. These experiences allow tourists to connect with local culture and people's way of life.

Development of sustainable tourism: Urban agriculture contributes to the development of sustainable tourism by emphasizing local food production and waste reduction. Tourists can contribute to this type of tourism by choosing accommodations that use local agricultural products (Sanyé-Mengual et al., 2018).

The impact of tourism on urban agriculture

Economic development: Tourism can serve as a source of income for urban farmers. Selling agricultural products to tourists increases farmers' income and helps to develop this activity.

Raise public awareness: Tourism helps raise public awareness of the importance of urban agriculture, local food production, and healthy eating.

Creating employment: The development of agricultural tourism can help create new job opportunities in urban areas.

Examples of combining urban agriculture and tourism

Creating urban gardens accessible to the public: these gardens can be used as a space for rest and recreation for citizens and tourists.

Holding local food festivals: these festivals can showcase urban agricultural products and help introduce local foods.

Creating accommodations that use local agricultural products: These accommodations can provide a unique experience for tourists.

As a result, urban agriculture and tourism can complement each other and contribute to the sustainable development of cities. By combining these two areas, it is possible to create dynamic, attractive and sustainable cities (Goldstein et al., 2017).

Community Involvement in Urban Agriculture

Urban agriculture also offers an opportunity to strengthen community ties. By involving families, schools, and local organizations, children can engage in group activities that teach teamwork and collaboration. Community gardens, for instance, are excellent platforms where children can interact with peers, learn from experienced gardeners, and contribute to a shared goal. These experiences not only enhance their social skills but also instill a sense of belonging and pride in their local environment.

Role of Technology in Urban Agriculture

Incorporating technology into urban agriculture can make it even more engaging for children. Tools like mobile apps and educational software can teach children about plant care, water management, and sustainable farming techniques. Interactive technologies such as augmented reality (AR) can simulate gardening scenarios, allowing children to experiment and learn in virtual spaces before applying their knowledge in real gardens. These innovations make agriculture more appealing to tech-savvy young minds while fostering an appreciation for nature.

A Vision for the Future

Urban agriculture has the potential to nurture a generation that values sustainability, health, and community. By introducing children to gardening at an early age, we can cultivate a culture of responsibility, creativity, and environmental stewardship. This green approach to education and lifestyle not only benefits children individually but also contributes to a more sustainable and vibrant urban environment. Investing in urban agriculture for children is, therefore, an investment in a brighter, greener future for all.

Urban Agriculture and Seniors: A Path to Health and Vitality

Urban agriculture is not solely about food production. It can significantly improve the quality of life for seniors, enhancing their physical and mental health. The connection between urban agriculture and seniors brings multiple benefits to both individuals and communities, creating a meaningful and enriching experience.

Benefits of Urban Agriculture for Seniors

Physical Health: Gardening and farming activities promote physical movement among seniors, helping strengthen their muscles and bones. These activities can also improve balance and motor coordination, reducing the risk of falls and injuries.

Mental Well-Being: Spending time in nature and engaging in gardening reduces stress, anxiety, and depression among seniors. It also boosts their overall mood and life satisfaction, fostering a positive outlook.

Sense of Purpose: Caring for plants and producing fresh crops gives seniors a sense of usefulness and capability. This contributes to higher self-esteem and confidence, empowering them to stay active and engaged.

Social Interaction: Participating in group-based urban agriculture activities provides seniors with opportunities for social engagement. These interactions help combat feelings of loneliness and strengthen their sense of community and belonging.

Healthy Nutrition: Growing fresh, healthy produce at home encourages better dietary habits among seniors. Improved nutrition plays a critical role in preventing chronic illnesses and promoting longevity (Orsini et al., 2020).

How Seniors Can Benefit from Urban Agriculture

Creating Small Gardens: Seniors can create small gardens in balconies, backyards, or even indoors to enjoy agricultural activities without requiring large spaces.

Joining Group Programs: Many senior centers and local organizations offer group urban agriculture programs, allowing seniors to participate in collective gardening projects.

Using Ergonomic Tools: Lightweight and ergonomically designed gardening tools make it easier and safer for seniors to participate in agricultural activities.

Consulting Experts: Before starting any gardening activities, seniors are encouraged to consult with doctors or physiotherapists to ensure these activities align with their health conditions.

Challenges and Solutions

Physical Limitations: Some seniors may face physical challenges that make gardening difficult. In such cases, adaptive tools or simplified activities can enable them to participate comfortably.

Lack of Space: In apartments or small homes, limited space can be a constraint. Utilizing pots, vertical gardening, or container gardening can help overcome this issue.

Lack of Knowledge: Many seniors may lack the necessary knowledge about urban agriculture. Hosting educational workshops and practical sessions can help them gain the skills and confidence to engage in these activities.

Figure 4. Urban agriculture and children (Designed by the authors).

A Transformative Activity for Seniors

Urban agriculture can be a highly beneficial and enjoyable activity for seniors. With thoughtful planning and support, it can enhance their quality of life, improve their physical and mental health, and offer a fulfilling way to stay active. Embracing this green initiative not only

benefits individuals but also fosters stronger, healthier, and more connected communities (Thomaier et al., 2017).

Figure 5. Urban agriculture can affect different aspects of urban life (Designed by the authors).

4. CONCLUSION

Urban agriculture has emerged as a transformative solution to the pressing challenges of modern urbanization, offering benefits across social, economic, and environmental dimensions. It redefines the relationship between cities and food production, emphasizing sustainability, resilience, and improved quality of life for urban dwellers. By integrating agricultural practices into urban spaces like rooftops, balconies, and vacant lots, urban agriculture provides a pathway toward a healthier, greener, and more self-sufficient urban environment. At its core, urban agriculture addresses food security by enabling local food production, reducing reliance on long supply chains, and ensuring access to fresh, nutritious produce. This is especially significant in urban areas where limited access to healthy food contributes to malnutrition and diet-related illnesses. Beyond nourishment, the proximity of urban agriculture promotes environmental sustainability by decreasing transportation-related carbon emissions, conserving water through innovative farming techniques such as hydroponics, and enhancing air quality. The introduction of green spaces through urban farming also mitigates urban heat islands, creating cooler, more comfortable living conditions. Economically, urban agriculture offers diverse opportunities, ranging from job creation to supporting local markets. It stimulates local economies by fostering small-scale agricultural businesses and encouraging the sale of fresh produce within communities. Additionally, urban agriculture serves as a platform for education and community engagement. Through community gardens and cooperative farming, residents build social connections, enhance collaboration, and develop a shared sense of responsibility for their environment. These interactions strengthen social cohesion and improve mental well-being by reconnecting individuals with nature in otherwise concrete-dominated urban landscapes. Urban agriculture also supports global efforts toward sustainable development. It encourages efficient resource use, minimizes waste through practices like composting, and introduces sustainable lifestyles into urban settings. These efforts align with broader objectives such as reducing poverty, improving public health, and combating climate change. For vulnerable populations, including children and seniors, urban farming provides specific benefits. It fosters environmental awareness among children, teaching them the principles of sustainability, while offering seniors therapeutic and physically engaging activities that enhance their quality of life

(Mok and Williamson; 2019). Despite its advantages, urban agriculture faces challenges such as limited land availability, water scarcity, and soil contamination. Addressing these obstacles requires innovation, policy support, and community participation. Advanced techniques, such as vertical farming and aquaponics, optimize space and resources, making urban farming more feasible in densely populated areas. Government policies that prioritize urban agriculture and provide financial and technical support can further accelerate its adoption and success. In conclusion, urban agriculture is a promising and indispensable tool for shaping sustainable and resilient cities of the future. By combining food production with environmental conservation and community building, it offers a holistic approach to addressing the complexities of urban life. As cities worldwide continue to grow, urban agriculture provides a scalable, adaptable solution that enhances food security, reduces environmental impact, and fosters thriving, interconnected communities. Investing in urban agriculture is not only a step toward sustainable development but also a commitment to creating a better, greener, and more inclusive world for future generations (Despommier; 2018).

REFERENCES

Sources Clinton, N., Stuhlmacher, M., Miles, A., Uludere Aragon, N., Wagner, M., Georgescu, M., & Herwig, C. (2018). "A Global Geospatial Ecosystem Services Estimate of Urban Agriculture." *Earth's Future, 6(1),* 40-54.

Deelstra, T., & Girardet, H. (2021). Urban Agriculture and Sustainable Citie. United Nations University Press.

Despommier, D. (2018). The Vertical Farm: Feeding the World in the 21st Century. St. Martin's Press.

Goldstein, B., Hauschild, M., Fernandez, J., & Birkved, M. (2017). "Urban Agriculture and Ecosystem Services: A Review." *Ecosystem Services, 22,* 43-54.

Mok, HF, & Williamson, VG (2019). "The Potential of Urban Agriculture in Combating Food Insecurity: A Case Study of Melbourne, Australia." *Land Use Policy, 82,* 291-302.

Opitz, I., Berges, R., Piorr, A., & Krikser, T. (2017). "Contributing to Food Security in Urban Areas: Differences between Urban Agriculture and Peri-Urban Agriculture in the Global North." *Agriculture and Human Values, 33(2)* 341-358.

Orsini, F., Kahane, R., Nono- Womdim, R., & Gianquinto, G. (2020). "Urban Agriculture in the Developing World: A Review." *Agronomy for Sustainable Development, 33,* 695-720.

Poulsen, MN, McNab, PR, Clayton, ML, & Neff, RA (2017). "A Systematic Review of Urban Agriculture and Food Security Impacts in Low-Income Countries." *Food Policy, 55,* 131-146.

Sanyé-Mengual, E., Oliver- Solà, J., Montero, JI, & Rieradevall, J. (2018). "An Environmental Perspective on Urban Agriculture and Livestock Systems." *Journal of Cleaner Production, 171,* 56-68.

Soga, M., Gaston, KJ (2020). "The Ecology of Human–Nature Interactions: A New Research Agenda." *People and Nature, 2(2)* 248-261.

Specht, K., Siebert, R., Thomaier , S., Freisinger, UB, Sawicka, M., Dierich, A., & Henckel, D. (2019). "Perception and Acceptance of Agricultural Production in and on Urban Buildings (ZFarming): A Qualitative Study from Berlin, Germany." *Agriculture and Human Values, 31(3)*, 455-467.

Thomaier , S., Specht, K., Henckel, D., Dierich, A., Siebert, R., Freisinger, UB, & Sawicka, M. (2017). "Farming in and on Urban Buildings: Present Practice and Specific Novelties of Zero-Acreage Farming (Z.Farming)." *Renewable Agriculture and Food Systems, 30(1)*, 43-54.

CHAPTER 18

COMPARISON OF PRIORITY ORIENTED SCHEDULING ALGORITHMS USED IN HARD REAL TIME SYSTEMS

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I. INTRODUCTION

Operating systems are systems that perform the desired tasks by using hardware and software resources in the most effective way. (Canbaz, 2021: 1). Operating systems are divided into two groups according to their time dependency: general-purpose operating systems (e.g. Linux, Windows and MacOS platforms) and real-time operating systems (e.g. systems used in satellite tracking systems, radiation treatments and video conferencing applications). (Garre et al., 2014: 8). While performing the desired tasks, the concepts of start and finish times of the tasks can be of vital importance depending on whether the operating system is general purpose and real-time, and in real-time applications, which have become quite common in recent years, real-time systems are used where it is vital to complete the incoming tasks without missing the deadlines. (Canbaz, 2021: 4; MSCS & Shaheen, 2016: 396)

General-purpose operating systems prioritize tasks so that only one task can be executed at a time when two or more tasks are waiting to be executed at the same time, and execute tasks according to the higher priorities. Tasks with lower priorities are either interrupted or executed by other cores according to the processor's power. There is no concept of real time in these operating systems; the time between the start and finish of tasks is not vital. (Garre et al., 2014: 8-9). The incoming requests can be delayed for a fraction of a second, such as a percentage or a thousandth of a second, until the processor completes the task. For cases where delaying the incoming task would lead to significant issues, real-time operating systems are used.

Real-time systems, unlike general-purpose operating systems, are systems designed for critical tasks where output must be produced within a certain time frame in response to external inputs. (Kopetz & Steiner, 2022: 2). These systems, where it is vital that the output is produced at the right time and operates based on time constraints, can be examined in two categories: soft real-time and hard real-time. Although there are timing constraints in soft real-time systems, missing the deadline of a task or process does not result in major damage or death. (Salamun et al., 2023: 2). To briefly explain, soft real-time systems have a soft time limit. In these systems, delays can reduce performance, but usually do not completely affect the overall operation of the system. Examples of such systems include video conferencing applications, live sports broadcasts, sensor data monitoring, and virtual reality applications. Hard real-time systems, on the other hand, guarantee that tasks will be completed within a certain time, and the task to be executed must be completed by the specified deadline. (Shah & Shah, 2016: 1). Failure to complete a task within the specified time or missing a deadline means system failure and can have serious consequences. In other words, any delay is unacceptable in such systems. (Mahmood & Khan, 2017: 1). For example, failure of flight control systems, airbag deployment systems, and medical life support systems to respond in a timely manner may result in intolerable consequences such as loss of life, injury, or major material damage; therefore, it is imperative that hard real-time systems operate reliably and quickly.

In hard real-time systems, all tasks are periodic, task requests and running times are fixed, and the start and finish times of tasks are independent of other tasks. (Liu & Layland, 1973: 47-48). In cases where more than one task needs to be carried out on a system that includes these features, all tasks are carried out simultaneously by prioritizing the tasks in order to use resources more effectively and to complete the tasks without missing deadlines.

In general-purpose and real-time operating systems, job scheduling algorithms are used to sequence jobs. While the purpose of sequencing jobs in general-purpose operating systems is to ensure that resources are shared fairly among tasks, job scheduling algorithms used in real-time systems are used to sequence incoming tasks in a way that they do not miss their deadlines (Seçinti, 2012: 1-2). There are various job scheduling algorithms used in real-time operating systems in the literature. In this study, three different priority-oriented job scheduling algorithms, namely the fixed priority job scheduling algorithm, the Rate Monotonic (RM)

algorithm, and the dynamic priority job scheduling algorithms, Earliest Deadline First (EDF) and Least Laxity First (LLF), were considered for single-processor systems and the results obtained for the same tasks in the simulation developed using the Python language were compared.

When literature studies are examined, it is observed that the number of studies dealing with job scheduling algorithms in real-time systems is quite low. In one of the studies, Jadon et al. worked on load balancing of mixed real-time tasks in multi-core systems (Jadon et al., 2024). The aim of the study is to distribute the load equally among the processors in order to maximize the processor utilization and minimize the execution time. For this purpose, the studies in the literature were examined and the strengths and weaknesses of various load balancing algorithms, including RM, EDF and LLF algorithms, were analyzed. The study focused on factors such as scalability, fairness, response time and concluded that static and dynamic approaches should be balanced.

Yıldırım et al. wanted to rank the incoming tasks for multiprocessor real-time systems according to their priorities using job scheduling algorithms and compare the performances of the algorithms according to the results obtained (Yıldırım et al., 2020). In the study, job scheduling algorithms are considered as universal and partitioned and sample task sets are run on open-source java based Multi-Core Real-Time Scheduling Simulator (MCRTsim), Multi-Core Real-Time Scheduling Simulator (MCRTsim) application using Universal RM, Partitioned RM, Universal EDF and Partitioned EDF algorithms. In addition, in the study, First Fit Decreasing (FFD), Best Fit Decreasing (BFD) and Worst Fit Decreasing (WFD) algorithms that determine the placement order of incoming tasks on the processor in partitioned job scheduling algorithms are tried to be solved on the application. According to the 3-processor application result, when RM algorithms are compared, Universal RM algorithm continuously changes the task distributions on the processors and uses all 3 processors with high performance and produces faster responses than Partitioned RM algorithm. In the partitioned RM algorithm, when the tasks were sorted with FFD and BFD, low performance was observed because 2 processors were used. When the performances of the EDF algorithms were compared, more tasks were executed, and faster responses were produced when the Universal EDF algorithm was used. While the partitioned EDF algorithm used 3 processors when sorted with WFD, BFD and FFD executed the tasks using only 2 processors and inefficient results were obtained.

In the next study, Gönültaş et al. wanted to compare the performances of job scheduling algorithms by running RM and EDF algorithms for a sample task set via the MCRTsim application for single-processor real-time systems (Gönültaş et al., 2019). In addition, three different resource access protocols were used in the study by adding more than one resource to the task set: Priority Inheritance Protocol (PIP), Priority Ceiling Protocol (PCP) and Stack Resource Policy (SRP). When the results obtained from the application are examined, it is concluded that the RM algorithm misses the deadlines of the tasks in the task set and the EDF algorithm performs better.

In their study, Kutlu and Gençtürk aimed to compare the performances of Round Robin (RR), RM, Deadline Monotonic (DM), EDF, LLF and Advanced LLF job scheduling algorithms by working on the open source RTEMS real-time operating system for space flight embedded systems (Kutlu & Gençtürk, 2021). When the static RM algorithm, which assigns equal working hours to tasks and runs them in a cyclical order without considering their priorities, is used, it has been observed that efficiency decreases due to the cost of too many transitions between tasks in case the working time is selected small. When the tasks are sorted with the DM algorithm, if there is more than one task with the same deadline in the task set, the system performance decreases because there are too many transitions between the processes. When the LLF algorithm is used, this time, the performance decreases due to the tasks having the same slack in the task set. The situation that causes the performance decrease in the

Advanced LLF and LLF algorithms, which is a combination of the EDF and LLF algorithms, has been solved with EDF. Since the order in which the tasks in the task set will be executed for the space flight system is known in advance and the priorities are not changed is a more important factor than the performance shown by the system, the fixed priority RM and DM algorithms have been selected for this study. Among the two job sequencing algorithms, the RM job sequencing algorithm has been selected at the end of the study because the RTEMS operating system uses RM while developing open-source projects in space-related projects.

They conducted an evaluation of event-triggered RM and EDF algorithms and time-triggered job scheduling algorithms for the automotive industry, working on Saydam and Avay OSEK/VDX certified operating systems (Saydam & Ayav, 2020). It was concluded that the RM algorithm is reliable because it has a fixed priority, the performance of the EDF algorithm is more successful than the other two algorithms, and the time-triggered job scheduling algorithm provides lower resource usage compared to the event-triggered algorithms. In the study, it was observed that all three algorithms have advantages and disadvantages; the time-triggered job scheduling algorithm was selected as the most advantageous algorithm in the study because the task priorities for the automotive sector are predetermined and predictable.

In the second part of the study, general information about the scheduling algorithms is given and, in the simulation, carried out using the Python language, the tasks in the sample task sets are ranked according to their priorities with three types of job scheduling algorithms and the working logic of the algorithms is explained. In the third part, the simulation results are evaluated, and the algorithms are compared according to their performance.

2. MATERIAL AND METHOD

In all operating systems, job scheduling algorithms are used to determine the order of execution of incoming tasks. Job scheduling algorithms used in real-time systems can be examined under two headings as periodic task scheduling and aperiodic task scheduling algorithms, as given in Figure 1. Periodic tasks have regular arrival times and strict deadlines; therefore, they are much tighter in terms of scheduling. For example, a sensor that collects data every second is a periodic task. Such a sensor is based on processes that repeat at a certain interval and there is a risk of system failure if they are not completed on time. Aperiodic tasks have irregular arrival times and deadlines can be strict or soft. (Sprunt et al., 1989: 3-10). For example, a user's request to open a new page in a web browser triggers an aperiodic task.

Both periodic and aperiodic task types are divided into two types: interruptible and uninterruptible tasks. While uninterruptible tasks are executed and completed without any interruption during the working time, interruptible tasks are tasks that can be stopped and intervened when a higher priority task arrives before the working time is completed (Jadon et al., 2024: 53376; Marwedel, 2021: 208-211). In a nuclear power plant control system, a certain computational process must be completed without interruption, because any interruption can have major consequences. In a multimedia player, if an urgent system alert occurs while video playback is in progress, the video playback may be interrupted and the alert displayed, and then the video will continue where it left off. Such flexibility allows the system to complete important tasks in a timely manner and optimizes overall performance.

In this study, static and dynamic priority job scheduling algorithms are considered, which are periodic because the tasks in question are allowed to be interrupted when a priority task arrives; the tasks in question have regular arrival times and strict deadlines. Static priority job scheduling algorithms rank tasks according to their priorities at the design stage and priorities cannot be changed at runtime. This ensures that the system operates predictably and regularly, and these algorithms are used where tasks operate in a fixed order. In dynamic priority job scheduling algorithms, unlike static job scheduling algorithms, the priorities of tasks can change

at runtime. In these algorithms, the system is flexible and adaptive according to the situation, allowing critical tasks to be processed with priority. In a health monitoring system example, if an urgent health problem is detected during the execution of normal data collection processes, this task is processed by prioritizing it.

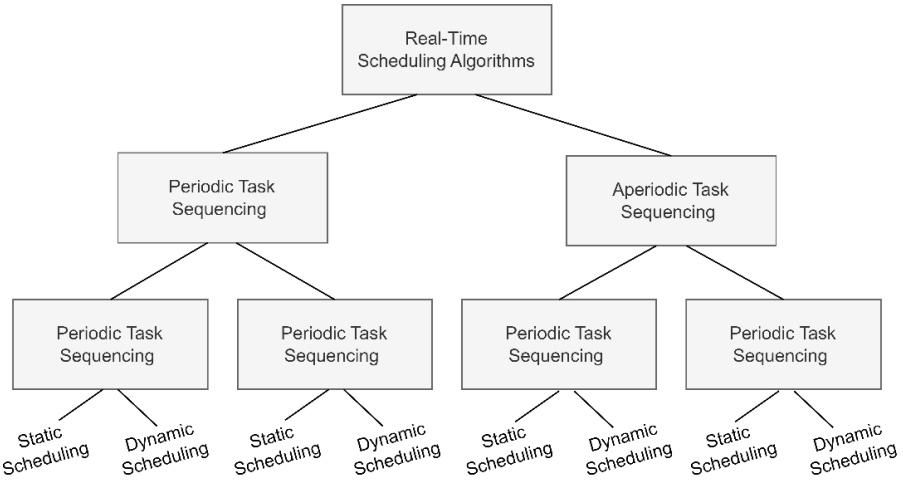

Figure 1. Classification of scheduling algorithms

Rate Monotonic (RM) Scheduling Algorithm

The RM job scheduling algorithm is a fixed, static priority algorithm used to sort periodic task sets in real-time systems (Lehoczky et al., 1989: 166). The priorities of the tasks are assigned statically according to the period values and are not changed during execution. For this algorithm, the task with a shorter period has a higher priority and can prevent the execution of the lower priority task by stopping it. In cases where the periods of two or more tasks have equal values, the algorithm gives priority to one of the tasks it randomly selects. In short, the RM algorithm provides a simple and effective solution because it offers a fixed priority order, but disadvantages may arise in cases where the periods are equal or dynamic priority is required. For example, if we give an example from sensor data, the short-period sensor data collection task has a higher priority than the other long-period tasks and therefore is run before. In this way, the system's ability to meet time constraints is increased. However, if two sensor data collection tasks with equal periods are waiting, the algorithm's random selection may cause some tasks to gain unnecessary priority and the system's timing performance may be negatively affected.

The programmability test of the RM algorithm for the given tasks is given in Equation 1 (Liu & Layland, 1973: 51-55). The tasks considered are schedulable using the RM algorithm as long as the total utilization of the task set U satisfies the inequality given in Equation 1. This condition is valid for single-processor systems. In the equation, n is the total number of tasks in the task set, c is the execution time of the tasks, and p is their periods.

$$U = \sum_{i=1}^{n} \frac{c_i}{p_i} \leq n\left(2^{1/n} - 1\right) \qquad (1)$$

In the simulation model performed using Python language, the number of tasks in the task set is given as 4 in a single-processor system. The task values entered in the written simulation are shown in Table 1. The task inputs hold the values of the variables <task id, p, c>, respectively. As seen in Table 1, the period of Task1 is entered as 10.0 and the execution time as 1.0, that is, Task1 will be executed for 1.0 duration in every 10.0 real time slots. Similarly,

Task2 should be executed for 1.0 duration in every 5.0 real time slots, Task3 for 1.0 duration in every 15.0 real time slots, and Task4 for 10.0 duration in every 30.0 real time slots.

Table 1. Task set-1

Tasks	Period (p)	Execution Time (c)
Task1	10.0	1.0
Task2	5.0	1.0
Task3	15.0	1.0
Task4	30.0	10.0

When Equation 1 is applied to the given tasks, the U value is 0.7 and the right side of the inequality is approximately 0.757 for four tasks. Since the inequality is provided, the tasks can be scheduled using the RM algorithm. The time required for the algorithm to schedule the given tasks is obtained by hyper period calculation. Hyper period is the smallest time interval in which the periodic patterns of all tasks are repeated. The hyper period value for the sample tasks is found as 30 and the real time clock is set to 30.

The results obtained by running the task set in the RM algorithm simulation are given in Table 2. As seen in Table 2, the tasks with lower periods are listed as Task2, Task1, Task3 and Task4, with higher priority. Interruption is the situation where a task is stopped when a higher priority task arrives while it is being executed. According to the simulation result given in Table 2, Task4 was interrupted three times, that is, it was stopped for a while in order to be able to run the higher priority task. When we look at the task completions of each task according to their periods, the highest priority Task2 was completed 6 times and the lowest priority Task4 was completed 1 time. There was no case of missing the deadline among the tasks.

Table 2. Simulation result for the RM algorithm

Tasks by Priority	Number of İnterrupt	Completion Count	Missed Time	Average Response Time
Task2	0	6	0	1.0
Task1	0	3	0	2.0
Task3	0	2	0	2.5
Task4	3	1	0	18.0

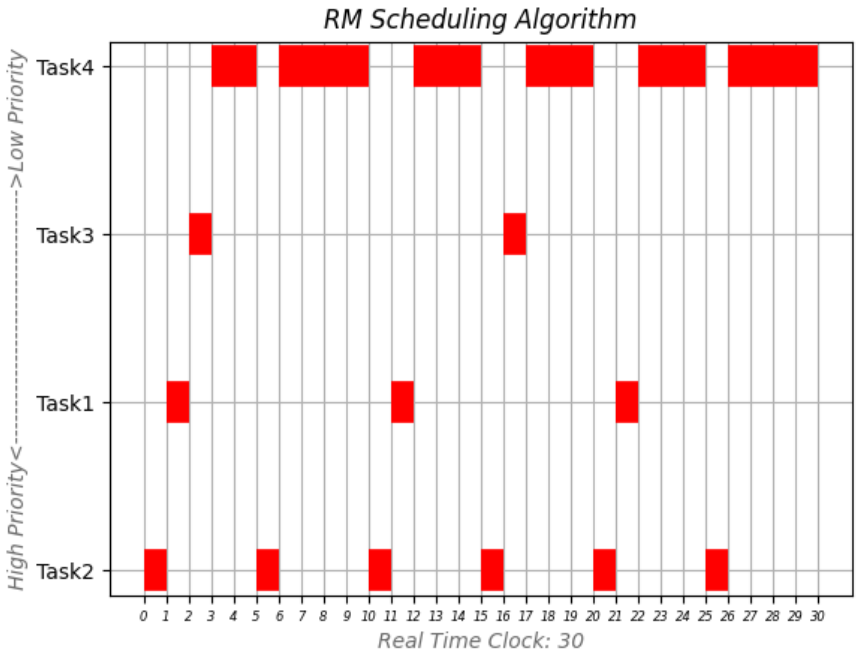

Figure 2. RM algorithm task chart

The task graph in which the tasks plotted for the RM scheduling algorithm using Python's matplotlib library are executed according to their priority order is given in Figure 2. All the tasks are waiting to be executed at time 0. As seen in the task graph in Figure 2, the highest priority Task2 was executed within the range of 0-1 for the duration of the execution and the task was completed. The next highest priority task Task1 is run and completed in 1-2 time slots and Task3 in 2-3 time slots for execution times. When the processor is empty, Task4 with the lowest priority and execution time of 10 started to execute in the 3rd time slot, but since Task2 with higher priority came at the 5th time, it was interrupted before it could complete its execution time. Task4 was run during the remaining 25 time slots when the processor was empty and was interrupted 2 more times. In other tasks, the interrupt situation was never experienced during the real time clock.

Earliest Deadline First (EDF) Scheduling Algorithm

The EDF algorithm, one of the dynamic priority algorithms used in real-time systems, takes absolute deadlines into account when assigning priorities to tasks (Cheng, 2003: 50). Among the tasks, the task with the shortest deadline is given the highest priority; the task with the longest deadline is given the lowest priority values (Short, 2010: 58). Priorities given to tasks are dynamic, priorities are reassigned at the end of each task period. If a higher priority task arrives while a task is executing, the task execution is interrupted and the higher priority task is run. The algorithm guarantees that all tasks in the task set that are expected to be executed will be executed without missing the deadlines, which is the real-time system requirement.

In the dynamic priority EDF algorithm, which is quite efficient compared to other algorithms used in the literature, priorities are constantly changing as the deadlines change during the execution of the tasks. Priority values are dynamically assigned to the tasks and are dynamically changed. In other words, while the highest priority task is being executed, a task with an approaching deadline may receive a higher priority value and cause the ongoing task to be interrupted. In this way, the algorithm, which makes an appropriate program planning

between the tasks, uses the processor very efficiently by giving almost no opportunity for the processor to remain idle.

$$U = \sum_{i=1}^{n} \frac{c_i}{p_i} \leq 1 \quad (2)$$

As given in Equation 2, each incoming task set can be scheduled using the EDF algorithm as long as the CPU utilization is not more than 100% (Liu & Layland, 1973: 51-55). If an incoming task set cannot be scheduled with the EDF algorithm, it cannot be scheduled with different real-time scheduling algorithms available in the literature.

The task set used to test the task scheduling of the EDF algorithm and measure its performance in the simulation is given in Table 3. As seen in Table 3, the period of Task1 is entered as 10.0 and the execution time as 2.0, that is, Task1 will be run for 2.0 in every 10.0 real time slot. Similarly, Task2 should be run for 1.0 in every 6.0 real time slot, and Task3 should be run for 5.0 in every 9.0 real time slot. The period values are assigned as the initial deadlines of the tasks.

Table 3. Task set-2

Tasks	Period (p)	Execution Time (c)	Deadlines
Task1	10.0	2.0	10.0
Task2	6.0	1.0	6.0
Task3	9.0	5.0	9.0

The period and execution times are obtained as the CPU utilization rate calculated to test the schedulability of the given tasks; that is, the sample task set is schedulable using the EDF algorithm with a processor utilization performance close to 100%. The results obtained when the simulation is run with the EDF algorithm for the given task set are given in Table 4.

The dynamic priority EDF algorithm initially calculates the deadlines of the tasks according to their periods and gives the highest priority to the task with the closest deadline. Accordingly, the tasks in the task set are ranked as Task2, Task3, Task1 from high priority to low priority, as in Table 4. The hyper period of the task set is found as 90 and the graphic real time clock is set to 90 units. During this period, Task2 with the highest priority was run and completed 15 times, Task3 10 times, and Task1 9 times. No interruption occurred in Task2, and the number of interruptions for Task3 and Task1 is 5 and 1, respectively. No task in the task set missed its deadline at all.

Table 4. Simulation result for the EDF algorithm

Tasks by Priority	Number of İnterrupt	Completion Count	Missed Time	Average Response Time
Task2	0	15	0	1.1333
Task3	5	10	0	6.0
Task1	1	9	0	5.3333

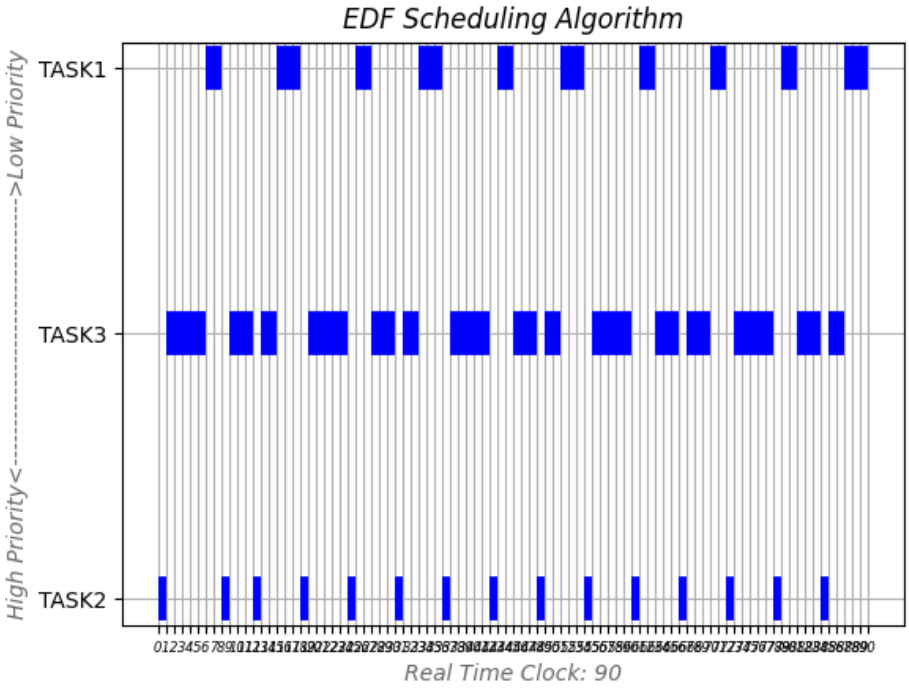

Figure 3. EDF algorithm task chart

Figure 3 shows the task graph drawn for the EDF queuing algorithm. All tasks are waiting to be executed at time 0. The highest priority Task2, 0-1 and Task3, have been executed for execution times between 1-6 and the tasks have been completed. At time 6, Task1 and Task2 are waiting to be executed. Since Task1's deadline is 10 and Task2's updated deadline is 12, priority is given to Task1. Task1 is executed in time interval 6-8 and Task2 in time interval 8-9. At time 9, Task3 is waiting to be executed. 1 unit is executed and at time 10, Task1 encounters an execution request. Since Task3's new deadline is 18 and Task1's is 20, priority belongs to Task3 and no interruption occurs. At time 12, Task2's execution request arrives, since their deadlines are the same, the algorithm will randomly choose one as the priority. It chooses Task2 and Task3 experiences its first interruption. During real time, Task2 was interrupted four more times. Additionally, Task1 was interrupted only once during the entire time, and Task2 was not interrupted at all.

Least Laxity First (LLF) Scheduling Algorithm

Another dynamic priority ranking algorithm considered in the study, LLF, was developed by Joseph and Leung in 1989 and is an algorithm that assigns priorities to tasks according to deadlines and processing times (Leung, 1989: 209). The priorities of tasks are inversely proportional to the laxity of the running time. The running time laxity expresses the urgency of the task execution and the priority order is made in such a way that the task with higher urgency is given higher priority. Since the slack of the tasks will change in each time unit, their priorities may also change. The calculation of the slack of the tasks is given in Equation 3. D used in the equation represents the deadline of the tasks, t is the time at the running moment and C represents the remaining execution time. As given in Equation 4, the remaining execution time is the difference between the running time of the task and the time it is currently executing.

$$Li = (D_i - t) - C_i \qquad (3)$$

$$C_i = (c_i - c_i^r) \qquad (4)$$

The LLF algorithm, like the EDF algorithm, is an ideal job scheduling algorithm that can schedule the incoming task set as long as the inequality given in Equation 2 is satisfied. In order to compare the EDF and LLF dynamic job scheduling algorithms, the same task set given in Table 3 was run in the LLF algorithm simulation this time and the simulation results are given in Table 5.

Table 5. Simulation result for the LLF algorithm

Tasks by Priority	Number of İnterrupt	Completion Count	Missed Time	Average Response Time
Task3	0	10	0	5.5
Task2	0	15	0	2.6666
Task1	1	9	0	5.1111

Since no task has been executed yet at the beginning, the slack of the tasks is calculated by finding the difference between their deadlines and their running times, and the tasks are ranked in such a way that the highest priority value is assigned to the lowest slack. As seen in Table 5, the tasks are initially ranked from high priority to low priority as Task3, Task2, and Task1. Task1 was interrupted only once during the real-time period; no interruption occurred in the other two tasks. Task3 was executed and completed 10 times, Task2 15 times, and Task1 9 times. As in the other algorithms, no task in the task set missed its deadline when the LLF algorithm was used.

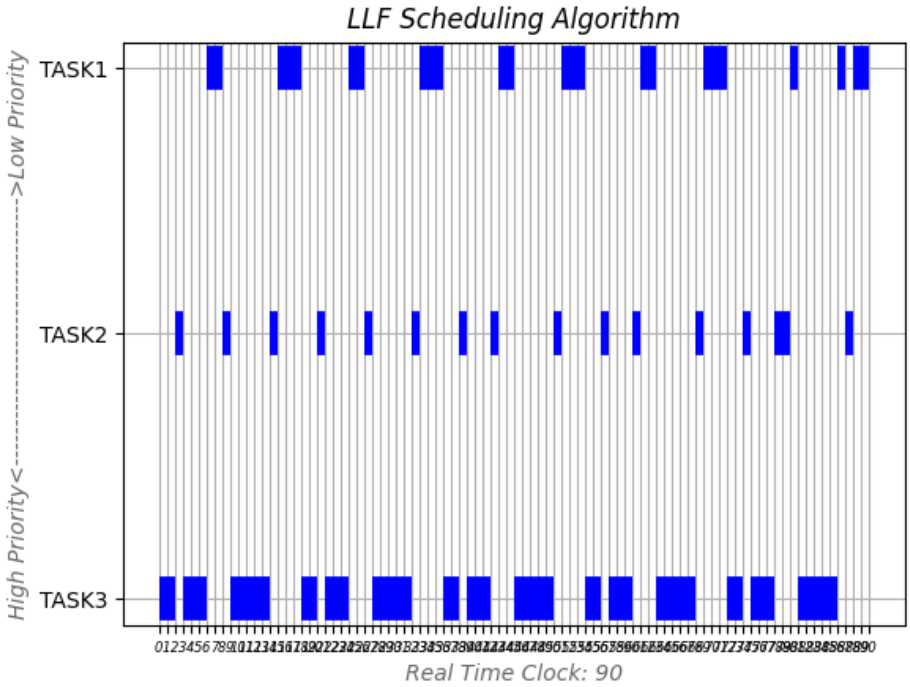

Figure 4. LLF algorithm task chart

Figure 4 shows the task graph drawn for the LLF scheduling algorithm. Among the tasks expected to be executed at time 0, Task3, which has the highest priority, was executed between

times 0-1. At time 1, the slack of the tasks was recalculated and L1=7, L2=4 and L3=4 were found. Since the slack of Task2 and Task3 was equal, the algorithm randomly selected Task3 and continued its execution. In this way, the slack of the tasks was recalculated for each unit and the algorithm continued its work during the calculated hyper period.

3. CONCLUSION AND DISCUSSION

In this study, the performances of Rate Monotonic (RM), Earliest Deadline First (EDF) and Least Laxity First (LLF) job scheduling algorithms were comparatively investigated. Simulations performed using Python language revealed how three different algorithms perform on different task sets, and provided an analysis based on critical metrics such as interruption counts, average response times and on-time task completion rates. The results clearly show how different job scheduling algorithms perform on various task sets.

When task set 1, whose input values are given in Table 1, is ranked using the RM algorithm simulation, the following results are obtained:

- When this algorithm is used, the tasks are statically prioritized and are ranked from high to low priority as Task2, Task1, Task3 and Task4, as given in Table 2.
- As a result of this ranking, Task2, which has the highest priority, and Task1 and Task3 tasks, which are handled in order of priority, were successfully completed without any interruptions, and the lowest priority Task4 task was interrupted three times.
- Although Task4 was interrupted, no task, including this task, missed its deadline and the tasks were completed on time.
- As a result of the interruption of Task4, the average completion time of this task was found to be 18.0 and it had the longest duration.
- This situation shows that the RM algorithm can cause interruptions in low priority tasks.

In order to compare the algorithms, when task set 1 is ranked with the simulation written for the dynamic job sequencing algorithms EDF and LLF, the results are listed below:

- EDF and LLF algorithms gave the same priorities to the tasks and the priority order is Task2, Task1, Task3 and Task4.
- In both algorithms, Task4 task was interrupted three times, as in the RM algorithm.
- In both job sequencing algorithms, the tasks were completed on time and no task missed the deadline.
- In the EDF algorithm, which dynamically sorts tasks according to their deadlines, the average response time of the interrupted Task4 task, as in the static sorting RM algorithm, was found to be 18.0.
- In the LLF algorithm, which dynamically sorts tasks according to their flexibility, the average response time of Task4 was 17.0.
- This result shows that the LLF algorithm reduces the number of interruptions and achieves shorter response times by sorting especially low-flexibility tasks more effectively.

In the comparison of the three algorithms considered with the 2nd task set given in Table 3, the results obtained are as follows:

- When the schedulability of the tasks with the RM ranking algorithm is measured using Equation 1, the U value is calculated as 0.9222 and the other side of the

inequality for n=3 is 0.7798; since the inequality is not provided, it is concluded that task set 2 cannot be scheduled with the RM algorithm.

- This situation shows that the RM algorithm cannot provide an efficient solution in task sets with higher processing load and complexity.
- When the EDF and LLF algorithms are compared using task set 2, the priorities of the tasks with EDF are initially ranked as Task2, Task3 and Task1, while the LLF algorithm ranked the tasks as Task3, Task2 and Task1 according to their priorities.
- The priority difference of the tasks ranked with the EDF and LLF algorithms is due to the difference in the prioritization strategies of the algorithms.
- While executing tasks with the EDF algorithm, Task1 was interrupted once, Task3 was interrupted five times, and Task2 was completed without any interruption.
- The LLF algorithm performed better than EDF, interrupting only Task1 once, and Task2 and Task3 were completed without any interruption.
- These results show that the LLF algorithm reduces the excessive workload of task switching with fewer interruptions.
- When both algorithms were used, tasks were scheduled without missing the deadline.
- When the average completion times of the tasks were compared, the maximum average completion time of Task3 was completed in 6.0 with EDF and in 5.5 with LLF due to no interruption.
- These results show that the LLF algorithm reduces the workload of task switching, resulting in shorter average response times, and thus shows better performance.

As a result;

- This study shows that EDF and LLF algorithms offer a more dynamic structure compared to RM algorithm and increase the on-time completion rate of tasks.
- The fixed priority-based structure of RM algorithm was insufficient especially in task sets requiring high processing load and resulted in the failure to schedule these tasks.
- EDF and LLF algorithms were able to successfully schedule these task sets with more flexible and dynamic scheduling strategies.
- In case the tasks can be scheduled without missing the deadlines, LLF algorithm minimized the number of interrupts to the task in progress and reduced the excessive load of task switching and showed better performance.
- It was also concluded that EDF algorithm tends to increase the number of interrupts and maximizes the minimum delay since it attaches more importance to not missing the deadlines of the tasks.
- For this reason, it is seen that the average response time of the tasks in EDF algorithm is longer than LLF algorithm which ranks the tasks according to their flexibility.

REFERENCES

Canbaz, S. (2021). *Performance analysis of RTOS and GPOS for path planning of the multi-robot systems* İstanbul Sabahattin Zaim Üniversity.

Cheng, A. M. (2003). *Real-time systems: scheduling, analysis, and verification*. John Wiley & Sons.

Garre, C., Mundo, D., Gubitosa, M., & Toso, A. (2014). *Performance comparison of real-time and general-purpose operating systems in parallel physical simulation with high computational cost* (0148-7191).

Gönültaş, T., Elewi, A., & Avaroğlu, E. (2019). *Task Scheduling Algorithms and Resource Access Protocols in Real-Time Systems.* Salih PALAMUT.

Jadon, S., Kannan, P. K., Kalaria, U., Varsha, K. R., Gupta, K., & Honnavalli, P. B. (2024). A Comprehensive Study of Load Balancing Approaches in Real-Time Multi-Core Systems for Mixed Real-Time Tasks. *Ieee Access*, *12*, 53373-53395. https://doi.org/10.1109/access.2024.3388291

Kopetz, H., & Steiner, W. (2022). *Real-time systems: design principles for distributed embedded applications*. Springer Nature.

Kutlu, E., & Gençtürk, C. (2021). UReal Time Operating Systems Scheduling Algorithms in Satellite Flight Software. *Turkish Informatics Foundation Journal of Computer Science and Engineering*, *14*(1), 1-14.

Lehoczky, J., Sha, L., & Ding, Y. (1989). The rate monotonic scheduling algorithm: Exact characterization and average case behavior. RTSS,

Leung, J. Y.-T. (1989). A new algorithm for scheduling periodic, real-time tasks. *Algorithmica*, *4*, 209-219.

Liu, C. L., & Layland, J. W. (1973). Scheduling algorithms for multiprogramming in a hard-real-time environment. *Journal of the ACM (JACM)*, *20*(1), 46-61.

Mahmood, A., & Khan, S. A. (2017). Hard Real-Time Task Scheduling in Cloud Computing Using an Adaptive Genetic Algorithm. *Computers*, *6*(2), Article 15. https://doi.org/10.3390/computers6020015

Marwedel, P. (2021). *Embedded system design: embedded systems foundations of cyber-physical systems, and the internet of things*. Springer Nature.

MSCS, & Shaheen, J. A. (2016). Architecture of Task Manager for Real Time OS Explaining Real Time Operating Systems Issues. *International Journal of Grid and Distributed Computing*, *9*(9), 395-402.

Salamun, K., Pavic, I., Dzapo, H., & Culjak, I. (2023). Weakly Hard Real-Time Model for Control Systems: A Survey. *Sensors*, *23*(10), Article 4652. https://doi.org/10.3390/s23104652

Saydam, B., & Ayav, T. (2020). Evaluation of scheduling architectures for OSEK/VDX compliant hard real-time operating systems. *2020 Turkish National Software Engineering Symposium (UYMS)*.

Seçinti, G. (2012). Virtual Negligibility Guided Job Sequencing for Multiprocessor Real-Time Systems. *Institute of Science*.

Shah, V. H., & Shah, A. (2016). An analysis and review on memory management algorithms for real time operating system. *International Journal of Computer Science and Information Security*, *14*(5), 236.

Short, M. (2010). Improved task management techniques for enforcing edf scheduling on recurring tasks. *2010 16th IEEE Real-Time and Embedded Technology and Applications Symposium*,

Sprunt, B., Sha, L., & Lehoczky, J. P. (1989). *Scheduling sporadic and aperiodic events in a hard real-time system*. Carnegie Mellon University, Software Engineering Institute.

Yıldırım, M. K., Süder, L., Abd Alkader, A., & Elewi, A. (2020). Scheduling Algorithms in Multiprocessor Real-Time Systems. *Computer Science and Technologies Journal*, *1*(2), 42-50.

CHAPTER 19

SOUND MEASUREMENT TECHNIQUES AND ACOUSTIC PROPERTIES OF NATURAL COMPOSITE FIBERS

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1.INTRODUCTION

Technological As developments increased, urbanization also accelerated. People lived in smaller spaces. to live They have started. Especially from earthquakes later on the agenda incoming light structure materials sound insulation the increase in the number of floors in buildings has created a disadvantage in terms of lighter materials in buildings. By using it, the durability of the structure increases and it is quicker structuring was targeted. As a result of this sound Concept of noise problem eyelash behind has been done.

Although insulation, especially thermal insulation, has been eliminated as a problem with laws and some regulations, sound insulation is not yet fully perceived as a problem. In this regard, work and progress acceleration slow is happening. The concept of noise unwanted and uncomfortable impressive sounds aspect is defined. In today's modern society, solutions are being sought to cope with noise. Noise pollution is an important negative factor affecting the comfort of life, especially in big cities. between place is taking. In residences and study in their places from outside incoming noises people distraction on, concentration like the lack of A lot cause of problem (Structure, 2010).

The concept of noise is one of the most disturbing and complained about issues today. In houses, there are usually noises coming from neighbors, vehicles and people coming from outside, etc. Environmental noise can become a big problem over time. When it comes to insulation, heat insulation usually comes to mind. and sound insulation is ignored. However, due to noise complaints, sound insulation is no longer great in terms of comfort importance creating and technical aspect difficulty into coming. Other On the other hand, another important issue is the wrong information about sound insulation. This information is that foam materials are ideal sound It is a misconception that it can be used as insulation material. However, the oil used in heat insulation is Materials such as foam only contribute to thermal insulation and do not provide effective results for sound insulation. cannot put it.

Synthetic porous and fibrous acoustic panels as sound absorbing panels generally used in room acoustics The use of materials is frequently seen for control applications, especially the concept of sound flow and noise. Products made from minerals such as foam, rock wool and glass wool are toxic and harmful to the environment. person to your health in damaging the one which... polluting effects with It is known (Asdrubali, F. 2006). Mineral wools, Good It is widely used for thermal and sound insulation due to its performance and low costs, however These materials into

the air directly exposed if it remains, fibers breath by when taken lung can fill the alveoli and cause skin irritation (Glé et al., 2011). The same their production at the time, natural composite from materials to those who have been made Compared to the atmosphere more carbon dioxide can release (Putra et al., 2013). However, natural composite fiber panels have the feature of being renewable, they do not harm the environment during their production and are produced with low energy costs (Bribián et al., 2011).

In general, fibers natural composite and artificial aspect are classified. Natural composite fibers based on vegetables are kenaf, hemp, wood and based on animal are wool, fur felt and based on mineral is asbestos, basalt etc. Synthetic fibers based on petroleum and mineral are glass, mineral wool, glass wool and based on polymer is termosets and thermoplastics fibers(Chandramohan and Marimuth, 2011).

Natural composite fibers moisture strength about, mushroom and interference at a loss open they are, mineral to the fibers Their biggest disadvantage is that they have negative effects such as being less resistant to fire. This next to you low intensity, Fine mechanical features, easy production, high stability, health benefits, reduced evaporation behavior, high availability, low cost and low environmental natural fibers are increasingly being used as competitive materials for acoustic applications due to their pollution properties. (Asdrubali, 2006). However, there is no information about the sound absorption behavior of natural composite materials as adequate (Arenas and Crocker, 2010).

2. NOISE CONCEPT AND SOUND INSULATION PROPERTIES.

2.1 Noise Definition

As we go crowded and spherical economy in place to take worker our cities solve the problems that need to be solved are also increasing. Transportation, unplanned construction, environmental pollution, energy problems, etc. are old problems. problems next to your importance increasing Concept of noise problem in There is (Structure, 2010). If sound wave irregular One in the spectrum place if it is taking This in case noisy from the concept of is mentioned. Noisy; pleasant non, unwanted sounds aspect expression It is done (Kuroda, 2006).

Especially when the propagation environment and the way it arises are taken into account, the

concept of noise transmitted into the space has two different aspects. in this way emerge came out understandable.

- Airborne noise: Airborne and airborne by It is the type of noise concept that reaches the affected person. The best example of this is the sound coming out of a speaker and reaching people. In addition to this, the common structure Acoustic leaks, air conduction through holes, cracks, openings etc. on the elements Concept of noise aspect is being evaluated.
- Structure -transmitted noise: The concept of noise that spreads through the structure as a result of the forces or effects affecting the structure. The most obvious type of noise is the impact noise that occurs from people's footsteps. These two types of noise concepts are summarized in Figure 1. For both types of noise concepts with different structures, different Concept of noise control measures implementation It is necessary (Hard working, 2011).

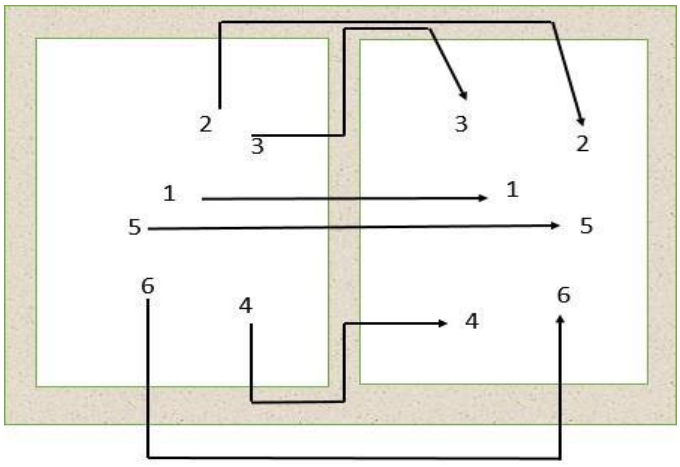

Figure 1. Weather Transmitted and Structure Transmitted noisy (Nielsen, 2011)

Physical (causes temporary or permanent hearing impairment) of noise, Physiological (Blood pressure increase, circulation disorders, in respiration acceleration, heart in your shots acceleration or slowdown), Psychological (Behavioral disorders, excessive nervousness, sudden reflexes and stress) and Work Performance (Work efficiency) falling, concentration disorder, your movements slowing down) like effects There is (Risk academy, 2017).

The noise control be able to for Generally used methods;

Active Control (Generally low frequency in their applications (used) Controlled opposite phase sound area with creation shaped is happening, Passive Control (More efficient at higher

frequencies, Absorber materials are used) is a three-stage from the system occurs;

- At the source control,
- Source-receiver between control,
- At the buyer out of control consists of (Distinguished, 2017).

Noiseless One in the environment to live, the noise no to do immediately impossible it could be. However, it is possible to control and minimize the effects of noise on the environment and human health. The most basic way to protect from noise is sound insulation applications. Sound insulation is the flooring and the sound of the walls Covering with absorbent materials is the process (Everest and arc., 2001).

2.2. Sound Insulation properties

Sound is a stimulus for the sense of hearing that can be perceived by the ear through air, water or a similar elastic medium. can be defined as the pressure change in the environment. The human ear can hear sounds between 20 Hz and 20,000 Hz. can hear. The ability to hear sound for, severity is clear to a level needs to be reached.

Essentially, there are two ways to protect against sound (Figure 2). These are sound absorption (absorption, swallowing) and sound insulation concept aspect expression is done. This two concept most times with each other mixed; Sound in absorption, weather particles, insulation material inside by rubbing your voice One part of heat to the energy they transform; like this your voice energy decreases. Sound absorption statement, sound from the source the sound of the voice What as much as source of located in the environment swallowed indicates.

In sound insulation, sound waves have a different density or flexibility than the environment in which they travel. block if encountered of energy One section is reflected, one partial in heat to the energy transforming is absorbed, the remaining part completes its transition. The insulation materials that make up the outer shell of the building also have an important role in its structure and This type of system prevents the penetration of external noise to a greater or lesser extent, depending on its design. are obstacles (Schmidt meat al., 2004).

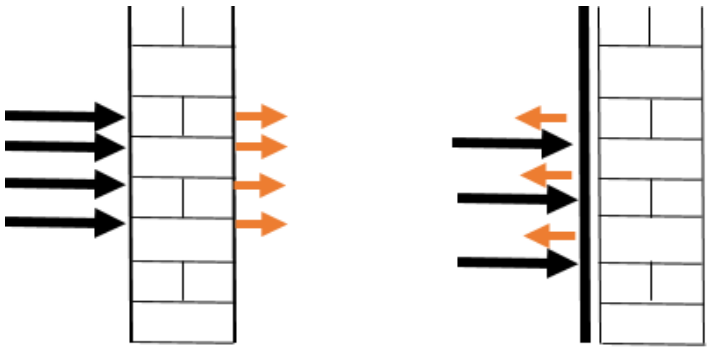

Figure 2. Sound insulation and sound absorption (Kaya, 2016)

The speed of sound propagation is related to the properties of the environment. In building acoustics, the most important environment for sound is air. Because ear sound through air The concept of sound or noise is vibration in gas, solid and liquid environments. in spreading One energy (Kaya, 2016).

Most sounds, vibrations and noise concepts encompass a variety of frequencies.

Frequency – the number of vibrations per second of sound waves is the number.

Its unit is Hertz (Hz).

The time it takes for one vibration is called a period. Its unit is seconds. The distance between two compressional or two relaxational regions shown in Figure 3 is called the wavelength (λ). Its unit is meter (m). Low frequency sounds (deep sounds) have long wavelength, high frequency sounds (Thin sounds) short wave longitudinally has.

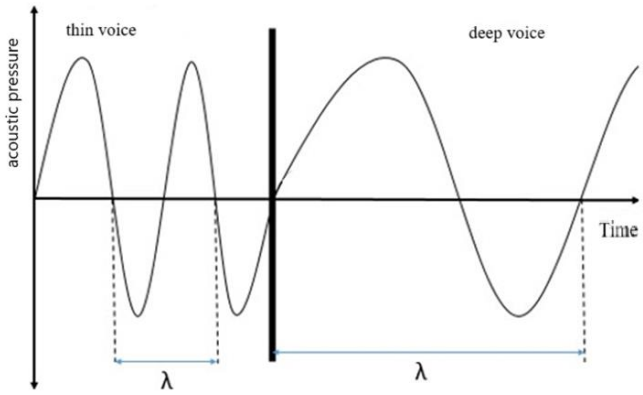

Figure 3. Wavelength stay according to and thin your voices change (DeBenedetti et al.,2007).

The material to be used for sound insulation must be fibrous or open-porous. Fibrous The

sound hitting the surfaces covered with the material, the air molecules between the fibers make the sound more or less section of heat to the energy to transform path They open. Sound swallow coefficient of size, vibration It depends on the thinness and density of the fibers, as it will positively affect their movements (DeBenedetti et al., 2007).

3. SOUND MEASUREMENT TECHNIQUES.

One of the material acoustics in your performance Only thickness and intensity like physically your features It is completely wrong to consider other factors and ignore them. The acoustic performance of a material below table 1' also stated features effective One in this way is used.

Table 1. In the material Acoustic performance determining features (Marmatek, 2015).

Feature	Explanation
The material Phase	The material thick, liquid And gas in phase be in its structure found atoms each other the one which... distance And friction coefficients acoustic feature In terms of is effective.
Intensity	Intensity as it increases sound of energy on the surface reflection rate increases. Soft materials sound energy absorbers and acoustics they contribute to performance.
Thickness	Thickness increase with together sound of energy floor he said path increases And therefore growing by friction together energy loss occurs.
Elasticity	Acoustic performance of materials that can be bent with elastic and plastic behavior to others according to more is high. This characteristic materials coup damping capabilities is high.
Diffusion-Surface geometry	Sound of energy spread surface structure with is related. The energy of transition environment density And on the surface formed by physically effect depends.
Porosity	The porous structure of the material prevents the reflection, absorption and transmission of sound energy. In terms of is important. The surface open porous, closed porous, pore depth like different in structures to be, sound of energy movement And insulation In terms of to be evaluated physically is a feature.
Mass –Spring-Mass Relationship	It is an important criterion for sound insulation, especially for composite materials to be effective. By reducing the sound energy and at the same time increasing the acoustic performance parameter by evaluating ideal One sound insulation of the material in the selection Consideration to be taken is a required feature.

Air Flow Resistance	The material pore And intensity like physically parameters with when evaluated, weather movement and surface structure Relationship sound in insulation measuring required is the criterion.

3.1. Impedance the Tube Measurement The method

This method is quite useful in terms of small sample sizes and short test times. are useful systems. Sound absorption coefficient and sound transmission coefficient are measured using the impedance tube measurement method. loss measurements with sensitivity is being done.

3.2. Sound Swallow Coefficient Measurements

The sound absorption coefficient is obtained by measuring the sound waves coming to and reflected from the sample. is calculated according to the surface impedance. In the measurement setup, the tube has an amplifier at one mouth There is a speaker that produces white noise concept together and a sample piece on the other end. Pipe Depending on their diameters, with the help of the transfer function method, all frequencies results can be obtained with a single measurement. Sound pressures produced by two microphones connected to the tube The transfer function is obtained by measuring and thus the sound absorption coefficient is calculated. Here, the pipe diameter is the upper frequency limit, The distance between the microphones limits the low frequency and the overall measurement accuracy. (Marmatek, 2015). This In the method, low frequencies (50 Hz to between 1.6 kHz) sound absorption A large tube is used to measure the property. Measurement in a large tube to be able to do 100 mm in diameter Samples is being prepared. 1.6 kHz with 6.4 kHz frequency in the range of sound swallow A small tube is used to measure the coefficient. In order to make a measurement in the small tube, 29 mm in diameter Samples is being prepared (Dias meat al.,2007). Impedance to the method according to sound swallow coefficient (α) the following formula (1,2) with expression It is done (Berardi and Lannace, 2015).

(1) In the expression R sound pressure reflection coefficient, in expression (2) Z_S surface impedance (Pa s/m), P_0 characteristic Impedance (Pa (s/m), c sound speed (m/s) ' is.

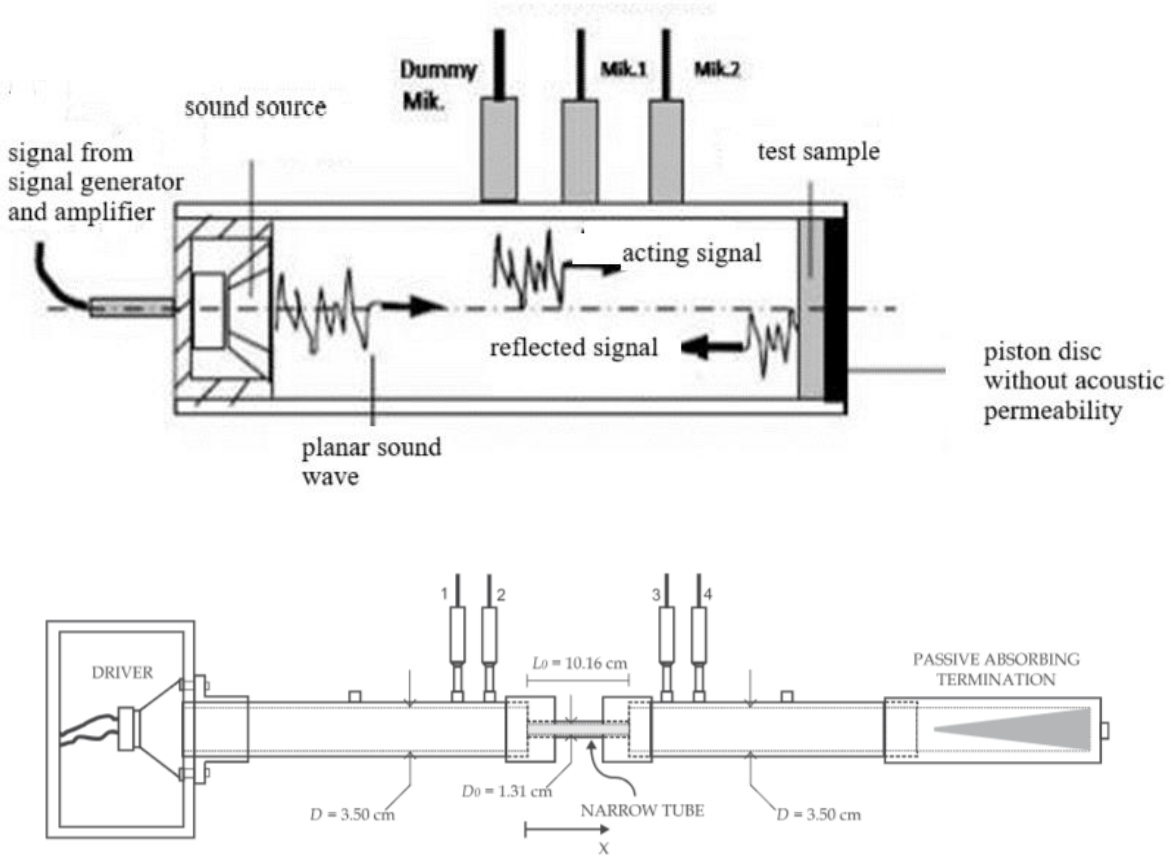

Figure 4. Impedance The tube Sound Swallow Measurement The mechanism (Bak., 2012)

3.3. Sound Transmission the Loss the value of Measurements

For sound transmission loss measurements, additional apparatus must be used in the impedance tube. As seen in Figure 5, the test specimen is placed between the tubes to create two measurement environments. In order to make the calculations, the reflected sound wave in the second measurement environment is considered from the equation for this reason, measurements should be made using a terminator and with the tube end open. times is done.

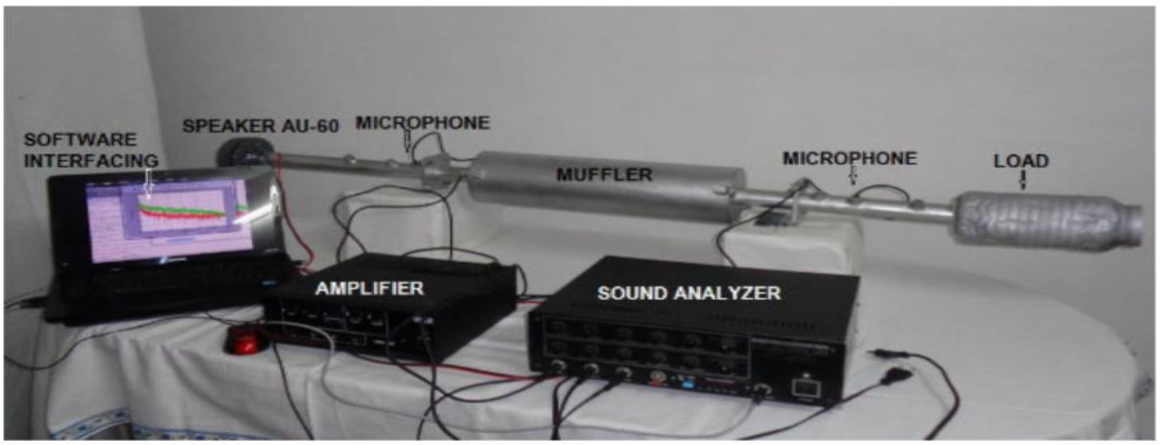

Figure 6 a) Only with Tube Impedance the Tube Kit b) Two Tube Impedance The Tube Kit

Figure 7 shows samples produced for use in the impedance tube. Different frequency in the interval's measurement can be done for 29 mm and 100 mm in diameter two separate sample is prepared.

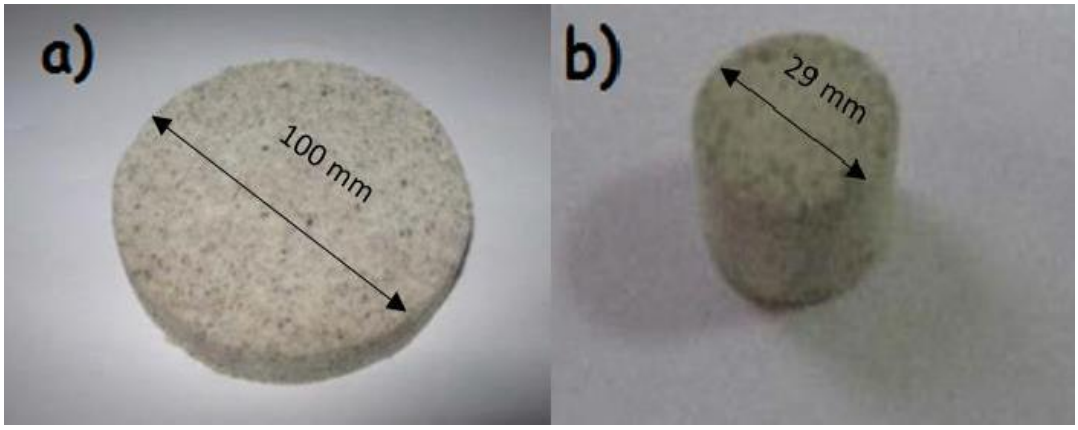

Figure 7. Impedance The tube Sample Examples a) Diameter 10mm (50 Hz-1.6 (kHz) b) Diameter 2.9mm (1.6 (kHz- 6.4 kHz) (Yunseon et al., 2009)

International standards have been set to find the sound absorption coefficient in the impedance tube. These are, ISO 10534-1 for the "Standing Wave Method" and ISO 10534-2 for the "Transfer Function Method". Also, American standards that are similar to international standards are also used (ASTM E1050). Sound transmission loss coefficient calculation for more as previously stated like There is no specific standard.

4. NATURAL COMPOSITE TO THE FIBERS AIT ACOUSTIC FEATURES

4.1. Kenaf Composite – fiber. Acoustic properties and absorption coefficient

Kenaf composite fiber (Hibiscus *Cannabinus)* is a warm climate plant obtained from plant roots. The most Its distribution is Southern Africa, Asia and India (Dempsey, 1975). Fibrous due to its structure, both plain and also Composite aspect widespread for use has. Especially paper in manufacturing, building in its materials, animal as bait has a large market. Kenaf composite fiber sound absorption When evaluated in terms of Figure As stated in 8, the density of 6 cm thickness is 50 kg/m3 and the density of 4 cm thickness is 100 kg/m^3. It is quite dense

with an average sound absorption of 0.91 in the frequency range of 1600 Hz-3600 Hz. successful to the results They have reached (Berardi and Lannace , 2015).

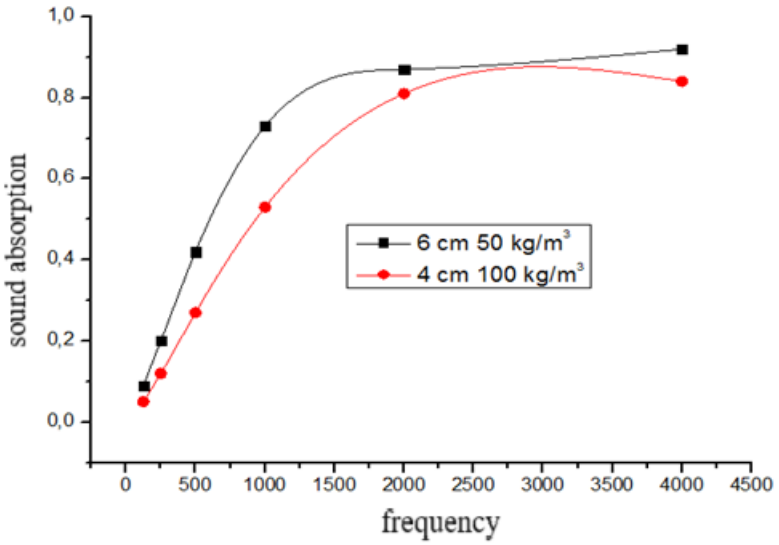

Figure 8. Kenaf Composite fiber Sound Absorption coefficient (Berardi and Lannace , 2015)

4.2. Acoustic properties and absorption coefficient of wood composite - fiber

31% of the world's land area consists of forests. The importance of wood is very in number requirement from the reception originates from (BAKA, 2012). Wood And wood based composite materials due to porous structures, They show acoustic properties by looking at their density values. The sound absorption coefficient of wood fiber is shown in Figure 9. According to the

acoustic properties of the wood fiber material (Figure 9) Sound absorption reached 0.81 with linear increase up to 1500 Hz frequency and then decreased to 2000- Continues in the 0.82 band up to 3800 Hz frequency and reached the highest value of 0.84 at 4000 Hz. It is observed that it has reached its target. Therefore, wood fiber is used in sound insulation and heat insulation in the construction sector. alternative material is in position (Rock, 2015)

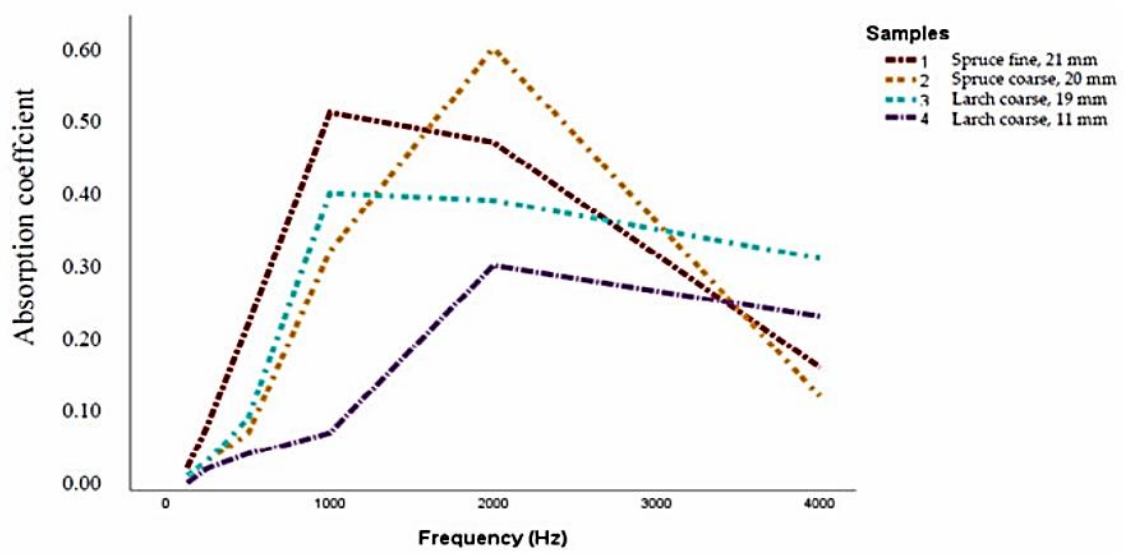

Figure 9. Wood fiber Sound Swallow coefficient (Kaya, 2015)

4.3. Acoustic properties and absorption coefficient of hemp composite - fiber

Hemp composite fiber is generally used in the textile industry. As with all natural composite fibers, combustion resistance low type and boron with the help of combustion insulation feature can be increased. With this together from hemp fibers done of the plates
person in health risk will create factor detection has not been done. Increasingly In addition to its high acoustic character, its thermal insulation feature makes it ideal for the construction sector. can be a material (Oldman et al., 2011). Hemp composite fiber with a density of 164 kg/ ^{m3}

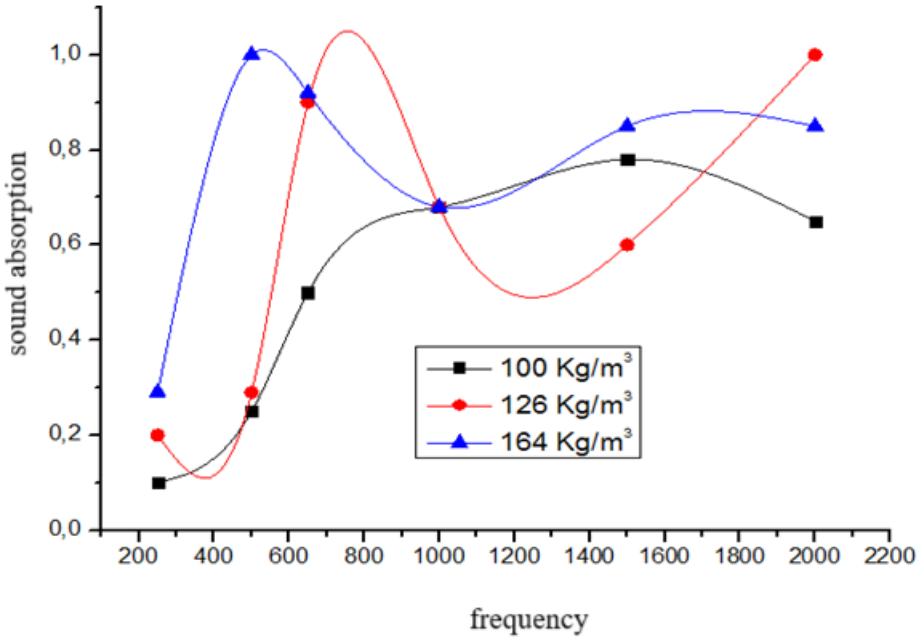

Figure 10. Hemp composite fiber Sound Swallow coefficient (Huang 2009).

Linear up to 500 Hz frequency After the increase, it decreased to 0.62 sound absorption value in the range of 600 Hz -1000 Hz and from this point on 2000Hz increasing in frequency to the highest It has been stated that it reaches a sound absorption value of 0.82. Hemp composite fiber is the highest sound absorption feature 126 kg/ ^{m3} intensity and 2000 Hz also is It is emphasized (Shape 10).

4.4 Acoustic properties and absorption coefficient of coconut composite fiber

Tropical in the areas growing palm of the tree fruit India walnut fiber of fruit external in the section the one which... and due to its very solid structure, it is used as agricultural residue in many areas. It is obtained from walnuts and after the extraction process, it is dried and either in the form of fibers or pressed. is used (Berardi and According to the data obtained from the experimental tests, low and high has good acoustic properties at high frequencies and the synthetic based commercial product is an alternative material indicates that it can be used as. This innovative sound absorbing panel is made of glass fiber and mineral based synthetic with materials compared more cheap, lighter and to the environment from his contribution because offers a brighter future than others (Rozli and (Zulkarnain, 2010). Coconut The fiber showed insufficient sound absorption at

10 mm thickness, but at 20 m thickness, especially at 2500 Hz. At later frequencies, the SEM absorption ability reached 0.98 and alternative materials were used in this area. has proven to be It is of a nature (Figure 11).

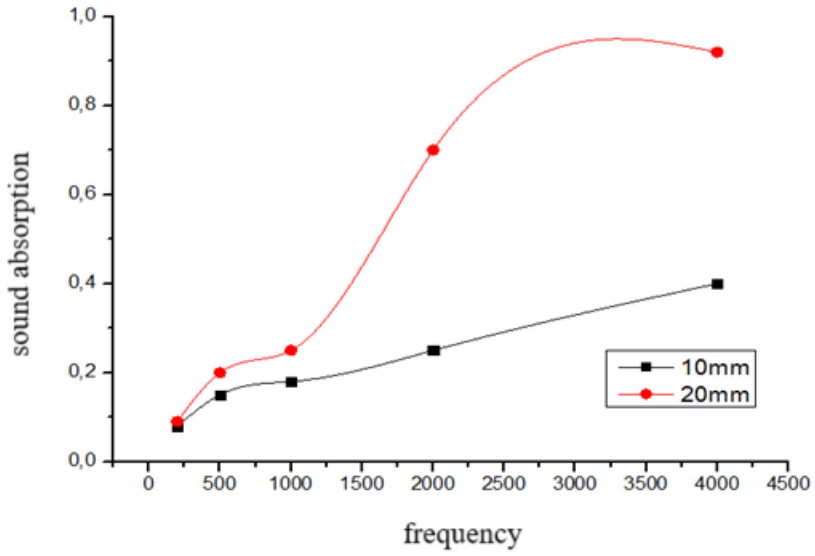

Figure 11. Coconut fiber Sound Absorption coefficient (Ersoy, 2009)

5. CONCLUSION

Natural composite fibers done measurements as a result porous materials sound in insulation showed It has been stated that they have good sound insulation properties similar to performance. Natural composite fibers acoustics, especially homogeneous distribution rate, pore structure, air flow, thickness and density are important. is a factor. The fibers thickness as it increases low frequency in the range of sound insulation value is increasing. Structure There are 6 octaves that are important in terms of acoustics and these frequencies are; 125, 250, 500, 1000, 2000, 4000 Hz. Measurements Interpretation in general This in octaves has been done. All frequency intervals When evaluated, they are valuable enough to meet the expectations of the construction sector. Especially 1000 Hz and above in frequencies coup vibrations can be prevented thickness as it increases This your feature increased It has been observed that mineral And synthetic sound insulation materials health, environment And economic from the

perspective are harmful to natural composite fibers the one which... will increase the tendency towards technological Environmental awareness has increased with developments, human health factor and sustainability use of traditional and natural composite fibers will disseminate. Thus, natural composite and traditional fibers can be used in both thermal and sound insulation. it will be possible.

REFERENCES

Arenas , JP, Crocker , MJ. (2010). Recent Trends in Porous sound-absorbing materials . *Sound & Vibration,* 44: 12- 18.

Asdrubali, F. (2006). Survey front the acoustic properties ugh new sustainable materials for noise control . *Proceedings Ugh Euronoise* , Tampere, Finland.

BAK. (2012). West Mediterrenian Development Agency. *Forest And Forest Products Sector Report*.

Berardi, U., Iannace , G. (2015). Acoustic characterization Ugh natural fibers for sound Absorption applications . *Building and Environment*, 94: 840-852.

Bribian , I. Z., Capilla , A. V., Uson , A. A. (2011). Life cycle assessment Ugh building materials: Comparative analysis of energy and environmental impacts and evaluation of the eco-efficiency Improvements potential. *Building and Environment*, 46: 1133-1140.

Bruel and Kjaer , Bruel and Kjaer Impedance Tube product data type 7758. Brochure using 4-microphones with impedance tube , Bruel and Kjaer Sound and Vibration Measurement . Denmark

Bruel&Kjaer Application Note BO 0113-11. https:/ /www.b k sv.com/en/Applications/product-noise/Acoustic-material-testing (Access date: 03.02.2017)

Chandramohan , D., Marimuthu , K., (2011). A review on natural fibres . *International Journal of Research and Reviews of Applied Sciences* , 8: 194-206.

Huang, C., Nutt, S. (2009). Sound transmission prediction by 3-D elasticity theory. *Applied Acoustics*, 70: 730-736. Hard working , M., 2011. Sound insulation . 4DuvarKnauf 41: 26-30.

DJ Oldham, C. Egan, R. Cookson. (2011). Sustainable acoustic absorbers from the biomass. *Applied Acoustics*, 72: 350-363.

DeBenedetti , B., Maffia , L., Rossi, S. (2007). From materials to eco-materials: life-cycle environmental approach for insulation products in building applications. *Proceedings of the 8th International Conference of Eco-Materials*, Brunel University, UK.

Demir, H., Top, A., Balköse , D., Ülkü , S. (2008). Dye adsorption behavior of Luffa cylindrica fibers. Journal of Hazardous Materials 153: 389-394

Dempsey, J. M. (1975). Hemp Fiber Crops. Univ. *Press of Florida*, Gainesville, Florida, USA. Dias,

T., Monaragala, R., Needham, P., Lay, E. (2007). Analysis of sound absorption of tuck spacer fabrics to reduce automotive noise. *Measurement Science and Technology*, 18: 2657-2666.

Elwaleed , AK, Nikabdullah , N., Nor, MJ, Tahir, MF, Nuawi , MZ, Abakr , YA. (2014). Experimental study on the effect of compression on the sound absorption of date palm fibers. *World Applied Sciences Journal,* 31: 40-44.

Ersoy , S., Small , H. (2009). Investigation Ugh industrial tea-leaf- fibre waste material for its sound Absorption properties. *Applied Acous*tics, 70: 215-220.

CHAPTER 20

A STUDY ON THE INTEGRATION OF PANDEMIC AND EPIDEMIC PROCESSES AND PREVENTIVE MEASURES INTO VIRTUAL REALITY ENVIRONMENTS

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1. INTRODUCTION

One of the disasters that has posed a serious threat to societies throughout recorded history is epidemics. Examples include the plague, cholera, tuberculosis, syphilis, malaria, typhus, smallpox, the Spanish flu, SARS, Ebola, and Zika. The COVID-19 pandemic, which recently left a significant mark on global history, is another notable example (Avcıoğlu Kalebek & Özdemir, 2020).

The SARS-CoV virus, which emerged in 2002–2003, spread as a severe respiratory disease. Other recent outbreaks, such as the H1N1 pandemic, the MERS-CoV outbreak, and the Ebola virus epidemic in 2014, also resulted in numerous fatalities. The COVID-19 pandemic, which began in December 2019 in China and rapidly spread across the globe, has profoundly impacted humanity. The virus, with its uncontrollable transmission rate, infected many individuals, leading to widespread mortality. The inability to halt its spread and the lack of an immediate treatment disrupted the global order. Governments were compelled to implement measures such as lockdowns and travel bans to combat the disease (Sezigen, 2020; Meydanlıoğlu, 2013). Figure 1 illustrates the World Health Organization's map representation of COVID-19 cases worldwide.

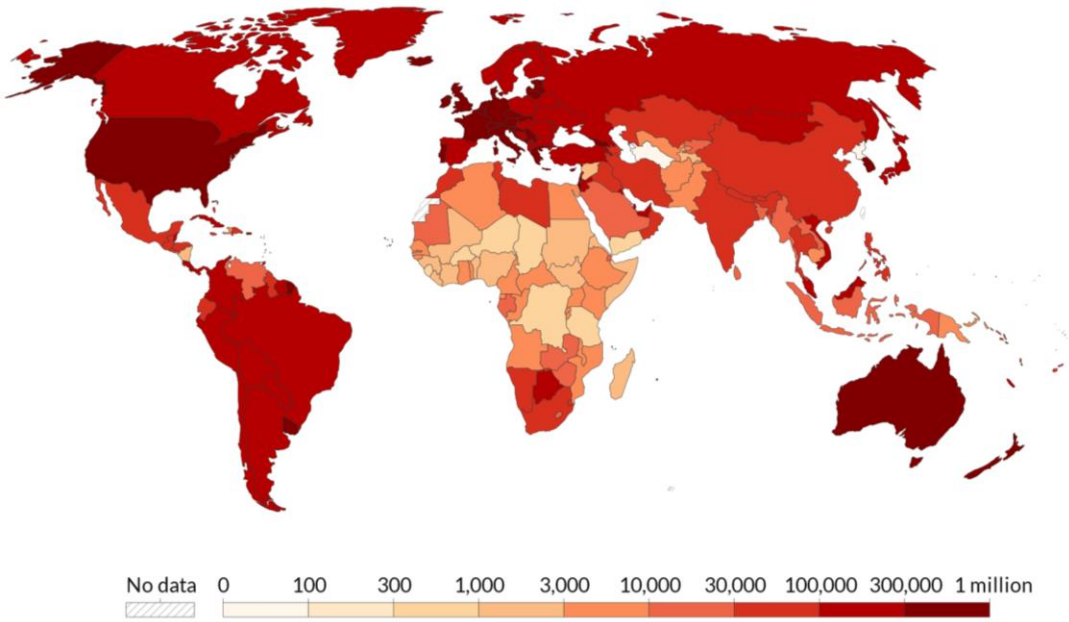

Figure 1. Map representation of COVID-19 cases worldwide (World Health Organization, 2024).

By nature, humans tend to fear the unknown. Having never experienced a pandemic like COVID-19 before, modern societies faced difficulties adapting to the process, and governments struggled to manage it effectively. Over the years, the world has confronted numerous pandemics and diseases with high transmission risks. During the recent COVID-19 pandemic, both globally and in Turkey, respiratory protective equipment emerged as one of the most frequently discussed forms of personal protective equipment (PPE). Respiratory equipment, such as masks, prevents harmful airborne substances from entering the body via the respiratory tract. Certain types also protect the eyes and face (Yüksel, 2021; Avcıoğlu Kalebek & Özdemir, 2020; Bahadır Ünal & Gökçen, 2021).

As long as life persists, diseases transmitted via the respiratory system will continue to exist. The solutions to these diseases may not always be readily available or may require significant time to develop. Consequently, individuals may need to wear masks to reduce the risk of transmission—defined as the spread of an infectious disease from an infected host to other organisms. Additionally, the increasing prevalence of autoimmune disorders and weakened immune systems has driven individuals to adopt mask-wearing as a protective measure (Bozkurt, 2020).

People who had not previously experienced such a large-scale pandemic struggled to adapt to the process and adhere to pandemic regulations. Transferring pandemic processes and regulations into virtual reality (VR) environments can provide a clearer understanding of these scenarios. During the recent COVID-19 outbreak, the significance of mask-wearing was once again emphasized. Without facing a major pandemic or being exposed to a highly contagious disease, individuals can fully experience these processes in VR environments with realistic simulations. This approach would enable societies to learn how to protect themselves and their surroundings, particularly in the case of respiratory-transmitted diseases with high pandemic potential, without suffering significant losses.

Raising awareness in society would, in turn, reduce the burden on healthcare systems, as fewer patients would require intervention, ensuring the continuity of healthcare services without disruption.

2. VIRTUAL REALITY

Virtual Reality (VR) is a technology that provides end-users with an interactive experience in a computer-generated dynamic environment that creates a perception of reality. Scientific studies have identified that learning through visual perception yields the highest retention rates. Virtual reality environments, created by practitioners, allow users to experience desired locations and feel as though they are living within events and scenarios, thereby facilitating comprehension and conceptualization. Various hardware devices can accompany VR applications to enhance this sense of reality. Examples include joysticks, gloves, headsets, and VR suits. Optimizing these devices with VR goggles can further strengthen the feeling of immersion. Additionally, it is anticipated that future developments of sensors targeting the senses of smell and touch—alongside sight and hearing—will significantly elevate the perception of virtual reality (Bayraktar & Kaleli, 2007; Aslan, 2017).

Virtual reality has begun to be utilized effectively in the field of education today. One of the major disadvantages of traditional teaching techniques has been the limitation of resources, along with constraints related to occupational safety and the lack of sufficient practice areas or opportunities to visit certain locations. Simulated virtual prototypes can overcome these drawbacks of traditional educational resources. VR has found applications in various fields, including pilot training, healthcare, tourism, entertainment, gaming, and complex scientific experiments. With continuous advancements in VR goggles and hardware, the development and widespread adoption of VR devices are expected to expand its range of applications even further (Öztürk & Sondaş, 2020; Aslan, 2017).

3. VIRTUAL REALITY APPLICATIONS IN PANDEMIC PROCESS

The use of virtual reality (VR) pandemic simulations enables users to better understand pandemic processes, the correct utilization of personal protective equipment (PPE), and the

significance of hygiene and social distancing rules, thereby facilitating quicker adaptation to such scenarios. VR-based training sessions can be incorporated into schools, allowing children to realistically experience and learn about pandemics without actually living through one. Beyond pandemic scenarios, VR can enhance understanding of the proper use and importance of PPE in all infectious disease contexts. As awareness increases, the rates of infection, hospitalizations, and mortality associated with contagious diseases are expected to decrease (Aslan, 2017; Bayraktar & Kaleli, 2007).

One of the most effective measures against highly contagious respiratory diseases is maintaining social distance, which minimizes close contact between individuals. However, achieving this in daily life is not always feasible. In such cases, using masks as personal protective equipment becomes critically important. Protective masks play a significant role in reducing the risk of transmission and slowing the spread of diseases (Bahadır Ünal & Gökçen, 2021; Bozkurt, 2020).

Advancements in health technologies contribute significantly to accelerating diagnosis, treatment, and recovery processes for patients. They also help reduce the margin of human error for healthcare professionals, enable more effective and rapid patient care, and enhance the quality and efficiency of healthcare services. It is anticipated that the ongoing development of VR technologies will lead to wider applications in healthcare in the coming years (Öztürk & Sondaş, 2020; Bozkurt, 2020).

As research continues into the development of VR technologies and equipment, the costs of these applications are expected to decrease, making them more accessible. With technological advancements, VR is projected to find even broader applications in healthcare, as indicated by recent studies (Öztürk & Sondaş, 2020; Bozkurt, 2020).

VR Headsets: Head-mounted display (HMD) systems are devices worn on the head to deliver visual content. Designed to align with the visual field of each eye, these devices consist of a pair of LCD or LED screens. By positioning the display within the user's immediate line of sight, VR headsets enhance the sense of immersion and create the perception of being inside the holographic environment. Despite their potential to limit the field of vision and introduce other natural constraints due to their design, HMD systems remain a powerful tool for interacting with virtual environments and show great promise in psychological research, education, and scientific applications (Bayraktar & Kaleli, 2007; Türker, 2005).

VR glasses leverage the relationship between the eyes and the brain to create optical illusions and more realistic perceptions of visual content. Modern VR glasses feature 360-degree imaging and sound systems, six-axis motion detection, wide-angle lenses for broader visuals, and wireless capabilities. They can also integrate with various devices seamlessly.

Leading global brands, including Google, Oculus, Apple, LG, Samsung, and Sony, manufacture VR headsets that can simulate production processes. These simulations help identify potential errors beforehand, enabling the development of new solutions with fewer resource losses. Through VR, students can virtually experience scenarios that are otherwise impossible in real life. For example, they can better understand pandemic processes, leading to more effective and lasting learning outcomes (Bozkurt, 2020; Çavaş et al., 2004). Figure 2 illustrates the Pimax 8KX PC VR headset along with its associated equipment.

Figure 2. Pimax 8kx PC VR headset and equipment.

Major pandemics are typically caused by airborne diseases that spread through coughing and sneezing. Therefore, the importance of mask usage becomes evident (Pakdemirli, 2020). In this context, the correct use of masks is crucial. Trainings regarding the proper use of masks can be effectively provided in virtual reality environments. Individuals who receive such training will learn how to protect themselves and others from contagious diseases in a lasting manner when faced with such situations (Aslan, 2017; Çavaş et al., 2004).

The studies on the virtual reality implementation of pandemic processes have been examined.

The Oxford Medical Simulation VR platform (Pottle, 2019) has developed a virtual reality platform as an educational module to help healthcare workers perform the correct intervention processes during a pandemic. The platform, which aims to create a safe working environment, includes a variety of training processes related to the healthcare sector. The platform contains simulations of experiments, where individual users can work independently to achieve self-sufficiency. Training participants can also simulate team activities with multiple users. AI-generated patient profiles allow for the development of voice-controlled skills. Additionally, the platform includes adaptations for hand control.

The Pandemic VR application (Pandemic by Prisms, 2021) is a virtual reality tool developed to manage the pandemic and assess the outcomes of decisions made during this period. Through this application, local or global decision-makers can simulate measures such as mask mandates or quarantines and analyze the spread of the disease. This allows them to take preventive actions concerning possible scenarios, such as hospital capacities.

SimX VR platform (COVID-19 Triage, 2023) is designed to help healthcare workers manage both the processes and stress during a pandemic. It simulates the entire patient reception process, from their arrival at the health cabin to the appropriate acceptance procedures, listening to patient history, and eventually discharging the patient.

The COVID-19 VR Experience (Zikas et al., 2021; Zikas et al., 2022; Stanković, 2023) is a virtual reality platform that simulates the preventive measures for users during a pandemic. It aims to gamify the explanation of processes. In scenarios like quarantine at home due to COVID-19, users are entertained while learning the benefits of staying at home and following the rules. Tasks are scored, and the user aims to increase their points in the VR game.

The PPE VR Training Platform (PPE VR Training Simulator, 2023) includes training modules for the use of personal protective equipment (PPE). It simulates processes such as

handwashing for a predefined period, the proper wearing of PPE, and safely disposing of protective equipment after use.

3.1 Virtual Reality Implementation of Pandemic Process

During the COVID-19 pandemic, there were challenges regarding proper mask usage, social distancing, and hygiene adherence, leading governments to implement control mechanisms. Societies can experience these situations in virtual reality environments, learning protection methods and adapting more quickly without encountering high-risk diseases. Virtual reality training can increase children's awareness of these issues (Taş, 2020). Figure 3 represents a visualization showing the importance of mask usage in virtual reality environments.

Figure 3. Simulation of mask usage as personal protective equipment in a virtual reality environment.

The diseases with the highest risk of transmission and the potential to evolve into regional or global pandemics are those transmitted through the respiratory route. This is because viruses and other pathogenic agents can easily spread through the air. If protective solutions, such as vaccines or medications, are not found in a short time, there is a significant risk of such infections developing into local or global pandemics. One of the preventive measures is maintaining distance and, in addition, wearing masks (Sezigen, 2020; Bahadır Ünal & Gökçen, 2021). The importance of masks as personal protective equipment and their correct usage are shown in Figure 4.

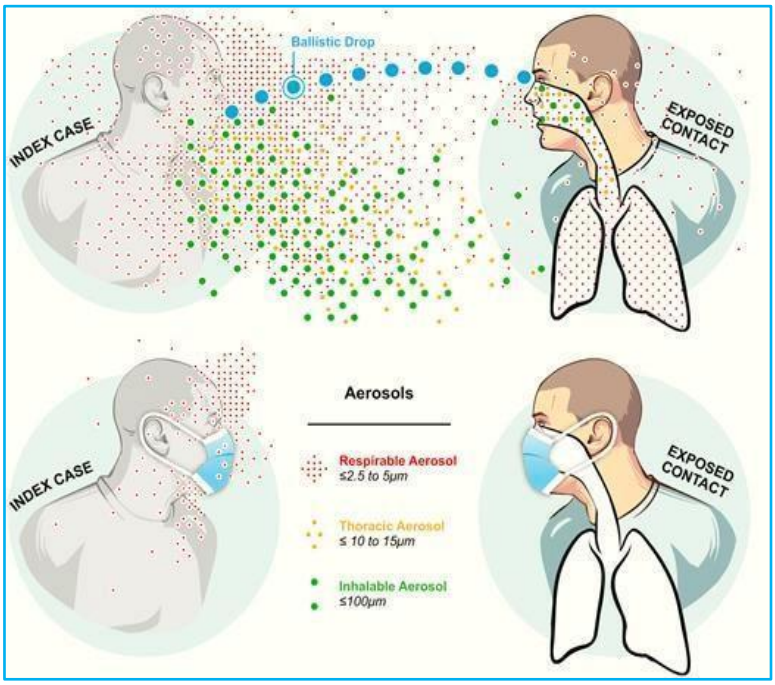

Figure 4. The Relationship Between Mask Usage and Infection Occurrence

Figure 5 illustrates the importance of correctly using a mask to protect both ourselves and those around us.

Figure 5. The role of mask usage in preventing societal transmission

Virtual reality can be used in schools and training centers to better understand pandemic processes. In this way, societies can learn how to protect themselves and others from diseases, particularly those transmitted via respiratory routes and with a high risk of becoming pandemics, without experiencing significant losses. As societal awareness increases, individuals will develop quicker reflexes against such pandemics, making it easier for them to follow rules. This approach can help minimize human and resource loss (Çavaş et al., 2004; Bahadır Ünal & Gökçen, 2021; Sezigen, 2020; Öztürk & Sondaş, 2020; Aldem et al., 2013).

3.2. Virtual Reality in Education

In recent years, virtual reality (VR) technology has gained significant attention in the education sector and is expected to find even more applications as it continues to develop. As an attractive alternative to the disadvantages of traditional education, VR is already being utilized in many educational applications.

Interactive and experiential learning plays a crucial role in ensuring lasting knowledge retention. VR technology supports education by enabling students to have concrete experiences that lead to durable learning. Virtual reality technologies allow students to engage in practical applications using virtual prototypes created through simulation models. For example, flight simulations, cadaver-free surgical procedures, and experiencing large-scale scientific experiments can all be done through virtual reality. By practicing multiple times, students can easily identify their mistakes and find solutions, thereby enhancing their expertise in the subject. One of the biggest disadvantages of traditional education is that it does not account for individual differences among students, applying the same teaching model to everyone. With virtual reality technologies, personalized teaching models can be implemented by considering students' unique learning differences and speeds. This approach enhances both the quality and efficiency of education (Çavaş et al., 2004; Türker, 2005; Bayraktar & Kaleli, 2007; Dinç, 2022).

4. HISTORY OF VIRTUAL REALITY IN HEALTHCARE

The term "virtual reality" was introduced into the literature by Jaron Lanier. Over the years, virtual reality has found applications in various fields. Initially, virtual reality was used in the military and entertainment sectors. It was first applied in healthcare in 1993, primarily for the treatment of height phobia. Over time, it began to be used for the visualization of vast medical data and for training both doctors and patients. As technology continues to evolve, it is expected to find even more areas of application, with projections indicating that its market will reach 30.4 billion dollars by 2026 (Öztürk & Sondaş, 2020).

5. HISTORY OF MEDICAL MASKS

The history of face masks dates back at least 2,000 years in recorded history. The Roman philosopher Pliny the Elder was the first to reduce harmful respiratory factors by using animal bladder skins to filter dust that was detrimental to breathing during the extraction of mineral ores. The famous explorer Marco Polo noted in his writings that during a visit to the Chinese emperor, the servants covered their mouths and noses with silk scarves. In John L. Spooner’s book The History of Surgical Face Masks, it is mentioned that masks began to be used in surgical operations in the 19th century.

The plague outbreak in China in 1910 marked a turning point in the history of masks. As a result of this epidemic, with death rates exceeding 90%, physicians of the time attempted to protect themselves by wearing masks resembling bird beaks (Pakdemirli, 2020; Yanartaş & Törün, 2020; Yüksel, 2021; Taş, 2020). Figure 6 shows an image of the bird-beak-like mask.

Figure 6. "Beak Mask" used during the plague outbreak in the 17th century.

6. DISCUSSION AND SUGGESTIONS

Human beings, by nature, fear the unknown. In the case of the COVID-19 pandemic, a process that had not been experienced before, contemporary individuals struggled to adapt, and governments faced challenges in managing the situation. Throughout history, our world has battled numerous pandemics and diseases with high transmission risks. In the recent COVID-19 pandemic, which affected both the world and our country, personal protective equipment (PPE), especially respiratory protection, became a central issue (Yüksel, 2021; Avcıoğlu Kalebek & Özdemir, 2020; Bahadır Ünal & Gökçen, 2021; Dinç, 2022).

As long as life continues, diseases transmitted through the respiratory system will persist. The solution to preventing and controlling these diseases may not always be readily available or may take time to develop. For this reason, people may need to wear masks to reduce the risk of transmission (the spread of a contagious disease from an infected host to other organisms). Additionally, with the increasing impact of autoimmune diseases and immune system weaknesses, people have been more inclined to wear masks to protect themselves (Bozkurt, 2020).

Studies related to the use of virtual reality (VR) in healthcare have been conducted, but there seems to be a gap in the literature regarding the transfer of knowledge on the correct use and importance of personal protective equipment (PPE) in pandemic processes into VR environments.

Using a computer-generated virtual pandemic simulation, individuals can better understand the pandemic process, learn the correct use of PPE, and grasp the importance of hygiene and social distancing rules. This can facilitate quicker adaptation during such processes. VR-based education can be provided in schools, allowing children to learn these processes realistically before experiencing a major pandemic. This knowledge will not only help in pandemic situations but also improve understanding of how to use personal protective equipment in all infectious diseases and their importance throughout the illness process. As

awareness increases, the rate of infections, hospitalizations, and death will decrease (Aslan, 2017; Bayraktar & Kaleli, 2007; Dinç, 2022).

REFERENCES

Aldem, M., Arslan, F. T., & Kurt, A. S. (2013). Employee Safety among Health Care Professionals. *Journal of Medical Research*, *11*(2), 60-67.

Aslan, R. (2017). New opportunities in international competition: virtual reality, augmented reality and hologram. *Journal of Ayrıntı, 5*(49), 21-26.

Avcıoğlu Kalebek, N., & Özdemir, G. (2020). Thematic reflections of the Covid-19 pandemic on clothing: Mask use. *Turkish Studies*, *15*(4), 57-68.

Bahadır Ünal, Z. & Gökçen, Ö. & (2021). Research on surgical masks and their use in children. *Review Article TJFDM, 3*(1), 11-24.

Bayraktar, E., & Kaleli, F. (2007). Virtual reality and its application areas. *IX. Academic Informatics Conference*, 253-259.

Bozkurt, A. (2020). Evaluations regarding education in the coronavirus (Covid-19) pandemic process and the post-pandemic world: New normal and new education paradigm. *Open Education Applications and Research Journal*, *6*(3), 112-142.

COVID-19 Triage. (2023). SimX. Access: 12 November 2024, https://www.simxvr.com/marketplace/covid-19-triage/

Çavaş, B., Çavaş, P., & Can, B. (2004). Virtual reality in education. *The Turkish Online Journal of Educational Technology*, *3*(4), 110-116.

Dinç, E. (2022). Using Virtual and Augmented Reality and Hologram Technique in Education. Access website ResearchGate.

Meydanlıoğlu, A. (2013). Health and safety of healthcare workers. *Balıkesir Journal of Health Sciences, 2*(3), 192-199.

Öztürk, E., & Sondaş, A. (2020). Virtual health: A look at virtual reality in health. *Kocaeli University Journal of Science*, *3*(2), 164-169.

Pakdemirli, A. (2020). Use of personal protective equipment for healthcare workers. *Journal of Obstetrics and Neonatology Medicine*, 830-837. https://doi.org/10.38136/jgon.946506

Pandemic by Prisms. (2021). Prisms. Access: 12 November 2024, https://www.prismsvr.com/

Pottle, J. (2019). Virtual reality and the transformation of medical education. *Future Healthcare Journal, 6*(3), 181-185.

PPE VR Training Simulator. (2023). SmartTek. Access: 12 November 2024, https://smarttek.solutions/portfolio/ppe-training-simulator/

Sezigen, S. (2020). Use of personal protective equipment to protect against Covid-19. *ResearchGate*, 4-49.

Stanković, S. (2023). Lecture 2—History of VR and current applications. In *Virtual Reality and Virtual Environments in 10 Lectures*. Cham: Springer International Publishing, 13-42.

Taş, F. (2020). Evaluation and recommendations on the practice and technique of using face masks among adults during the Covid-19 pandemic. *Journal of Public Health Nursing 2*(2), 52-56.

Türker, İ. H. (2005). From image to virtual reality. *Journal of Anadolu Art* (16).

VR Healthcare simulations. (2023). Oxford Medical Simulation. Access: 12 November 2024, https://oxfordmedicalsimulation.com/

Yanartaş, M., & Törün, S. (2020). Covid-19 and children. *Journal of Advanced Research in Health Sciences, 3*(1), 40-48.

Yüksel, A. (2021). The importance of using personal protective equipment (PPE) in healthcare services. *Ankara Health Sciences Services Journal, 19*(2), 44-50.

Zikas, P., Kamarianakis, M., Kartsonaki, I., Lydatakis, N., Kateros, S., Kentros, M., ... & Papagiannakis, G. (2021). Covid-19-VR strikes back: Innovative medical VR training. In *ACM SIGGRAPH 2021 Immersive Pavilion*, 1-2.

Zikas, P., Kateros, S., Lydatakis, N., Kentros, M., Geronikolakis, E., Kamarianakis, M., ... & Papapagiannakis, G. (2022). Virtual reality medical training for COVID-19 swab testing and proper handling of personal protective equipment: Development and usability. *Frontiers in Virtual Reality*, *2*, 740197.