INNOVATIVE RESEARCH IN AGRICULTURE, FOREST AND WATER ISSUES

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Assoc. Prof. Ali Beyhan UÇAK, Ph. D.
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Chapter 1

The Effects of Some Climate Parameters on Yield and Quality of Siirt Pistachio Variety (*Pistacia vera,* L) Grown in Semi-Arid Climate Conditions

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Abstract

This study was carried out to investigate the direct and indirect effects of climatic events occurred between 2012 and 2021 in the Southeastern Anatolia region which is the most important pistachio production center of Turkey, on the cultivation and production of Siirt pistachio variety. The decrease in yield of Siirt pistachio variety in some years over a 10-year period may be associated with the insufficient precipitation, high temperature and low relative humidity in the region. Significant polynomial relationships were determined between average temperature, precipitation and relative humidity in the growing season of Siirt pistachio cultivar and pistachio yield. The values of climatic parameters, which have a significant effect on morphological characteristics and yield of the Siirt pistachio cultivar, exceeded the optimum climate demand threshold of the plant, and thus, the yield and quality of Siirt pistachio cultivar were adversely affected. The yield of Siirt pistachio cultivar decreased significantly, because the fruits were not sufficiently filled or could not grow sufficiently under adverse climatic conditions. In addition, a positive linear relationship was recorded between the cultivation area and production and yield values of Siirt pistachio cultivar.

Key words: Drought, temperature, relative humidity, Siirt pistachio

Introduction

Siirt pistachio variety (Pistacia vera, L) is an important agricultural product for the Turkish economy. Pistachio is a sought-after product both as a snack and in the baklava industry, and has an important economic return in the domestic and foreign markets (Aydın and Saltuk, 2018). Ninety percent of pistachio production in the world takes place in Iran, USA, Turkey and Syria (Anonymous, 2021). Iran ranked the first with 338 thousand tons of pistachio production in 2019, and followed by USA, China, Turkey and Syria with 336, 106, 85 and 32 thousand tons. The world pistachio production in 2019 decreased by 9.6% compared to the previous season (Anonymous, 2022a). Similarly, the pistachio production in Turkey was 240 thousand tons in 2018, while decreased by 35.4% in 2019 to 85 thousand tons (TUIK, 2020). The yield of Siirt pistachio variety was 4 kg per tree in 2020, while the yield decreased by 50% in 2019 to 2 kg per tree. The average precipitation in May 2018 was 146.6 mm, and decreased to 63 mm in 2019. The maximum temperature and relative humidity in 2018 were 32.2 °C and 59.1%, in 2019 were 34.1 °C and 42.1%, and in 2020 were 33.7 °C and 47.6%. The precipitation in 2019 was not sufficient compared to the previous and next year. Therefore, climate in 2019 was the main cause of the low yield in Siirt pistachio variety (Anonymous, 2022b).

The flowering of pistachio varies according to the region and altitude. In general, the flowering starts at the end of April (earlier in low altitude, later in high altitude) and continues until mid or end of May. The flowering date varies depending on the altitude and climate of the region, thus, the main criterion to obtain an optimum yield is the matching the flowering dates of male and female varieties. In other words, male and female flowers should bloom on the same days for the maximum pollination. Pollination occurs by the pollen transport from flowers of male trees to flowers of female trees through wind or insects (Anonymous, 2022a). Generally, male pistachio varieties bloom earlier than females. The flowering period in male trees varies between 3-7 days, while it can last 10-12 days in female trees. Climatic conditions during pollination significantly affect fertilization and thus the yield of pistachio. Since pistachio has special climate demands, pistachios are mostly grown in the Southeastern Anatolia Region of Turkey. The amount of Siirt pistachio production in Siirt province has changed in years, and the production recently has exceeded 25 thousand tons. Approximately 15% of pistachio production in Turkey takes place in Siirt province (Anonymous, 2022b). Drought (insufficient rainfall), pollination or insufficient fertilization are the most important factors of yield decrease in Siirt pistachio variety. Inadequate pollination under adverse climatic conditions results in empty fruits and the yield per tree significantly decreases. Inadequate pollination can be associated with the lack of male trees (pollinator variety) or low number of male trees, the loss of male pollen vitality in a short time under high temperature and low humidity, male and female trees do not bloom at the same time (vernalization disorder), and pollinator trees are not located in the wind direction. Long-term adverse climatic events (abiotic stress) during the pollination (fertilization) period are the most important causes of the yield decrease. Abiotic stress can be defined as the increase in temperature to maximum and decrease in precipitation to minimum during pollination or fertilization period. Similar to the other crops, biotic factors such as diseases, weeds and insects, and abiotic factors such as soil, fertilizer, irrigation, tillage and climate directly and indirectly affect the pistachio growth and yield. The most important climatic parameters that are important for Siirt pistachio production are precipitation, temperature and relative humidity. Climate is one of the most important factors limiting crop production in agricultural production (Kapur et al. 2008, Ucak et al. 2010; Evans, 1969). In addition, Jones (2000) reported that atmospheric activities significantly affect the quality and yield of crops. The ideal temperature for pistachio production is between 30 and 40 °C. Excessive temperatures shortens the survival time of pollen and the pollens dry out by losing their vitality quickly under very high temperatures and pollination is adversely affected. Since summer months in semi-arid climate zones are dry, irrigation is certainly needed for optimum development of especially young pistachio trees and to increase the yield per tree in fruit bearing trees. Aydın and Saltuk (2018) conducted a study to determine the tendency of pistachio growers on irrigation, and the producers agreed that pistachio varieties (long, Siirt, red, Halabi, etc.) needed irrigation to increase yield and improve plant growth (Aydın and Saltuk, 2018). Water should not contact with the plant body during the irrigation. The temperatures over 40 °C, even under irrigation conditions, increases water loss by transpiration and water uptake by roots cannot compensate the water loss. Long term drought and high temperatures cause losing the turgor of plants, the cell structure loses the flexibility and cannot return to the former form (Öner and Sezer, 2007; Atilla, 2009). Climate is the most important abiotic stress factor affecting pistachio production. Therefore, the aim of this study was to investigate direct and indirect effects of climatic events in the growing season of Siirt pistachio variety during a 10-year period (2012-2021) on Siirt pistachio cultivation. The study area was Siirt province, which has semi-arid climate conditions and the Siirt pistachio variety is extensively grown.

Materials & Methods

The study area covers Siirt province, located in the Southeastern Anatolia region. Botan, Zarova and Çatak rivers flow within the provincial borders. The region has a typical transitional climate with hot and dry summers and mild and rainy winters. Siirt province has arid climate according to Aydeniz, semi-humid according to Erinç, semi-humid-semi-arid according to Thornthwaite and semi-arid-semi-humid according to Demartonne (FAO, 1997; Şensoy, 2007; Tümertekin and Özgüç, 1997). Although Siirt province is classified as a semi-humid climate according to Erinç, the typical transitional climate, with hot and dry summers and warm and rainy winters are dominant in the region. Severe summer droughts and high temperatures are the typical climatic events in such transitional zones. The temperature often rises above 40°C in summer and the annual precipitation is between 600 and 650 mm. The precipitation generally occurs as rain in winter and the months close to the winter (Anonymous, 2009a; Anonymous, 2009-b; Kaymaz and İkiel, 2004). Some seasonal changes are experienced due to the global warming, and the time and amount of precipitation change in time that has negative impacts on agricultural production. The superior advantages of ecology allow many horticultural crops to be grown in the Southeastern Anatolia of Turkey. Climate data between 2012 and 2021 are given in Table 1.

Table 1. Monthly Maximum and Minimum Temperature Values (°C)

Years	Temp. °C	Jan.	Feb	March	Nisan	May	June	July	August	Sept.	Oct.	Nov.	Dec.
2012	Max	12.2	13.1	17.5	27.4	31.1	38.3	42.0	40.5	37.4	34.8	23.1	16.5
	Min	-6.4	-5.8	-7.2	6.2	10.7	15.4	17.7	21.3	17.5	9.6	3.5	-0.4
2013	Max	13.1	16.3	23.8	30.5	30.7	38.2	39.5	39.5	37.5	36.2	23.8	11.7
	Min	-6.7	-1.2	-0.4	5.6	9.6	15.1	22.1	21.6	13.0	6.6	4.5	-9.8
2014	Max	19.7	20.6	21.6	28.4	34.8	38.6	41.1	41.5	39.0	29.9	19.3	17.2
	Min	-5.1	-5.4	-1.5	0.7	10.6	11.8	20.2	19.7	12.6	9.6	1.9	-1.2
2015	Max	15.0	16.3	19.6	28.6	33.0	37.2	43.2	41.9	38.4	31.1	20.4	13.0
	Min	-5.5	-1.3	-0.3	3.3	9.8	15.8	19.5	19.4	18.6	8.5	3.6	-4.7
2016	Max	12.0	20.5	21.4	26.5	30.6	38.4	41.6	41.8	36.3	31.2	22.6	12.5
	Min	-11.0	-0.9	1.0	4.2	8.0	14.8	20.6	22.4	12.4	10.2	1.5	-5.7
2017	Max	12.2	18.7	20.7	25.9	32.0	39.8	41.2	42.9	39.5	28.4	23.8	17.8
	Min	-3.3	-10.0	0.5	4.3	10.1	12.8	22.1	21.5	17.2	9.8	0.8	-1.3
2018	Max	13.4	16.1	26.0	27.1	32.2	40.0	42.9	41.1	39.3	32.6	24.3	13.4
	Min	-0.9	0.7	4.7	6.4	10.4	16.8	21.9	23.0	19.1	6.5	5.2	-0.6
2019	Max	13.7	14.3	18.2	22.9	34.1	39.7	42.0	42.1	35.5	32.9	22.4	16.4
	Min	-5.3	-0.1	0.1	2.7	7.5	20.9	20.8	21.0	15.3	9.1	4.6	2.4
2020	Max	11.6	16.9	22.8	23.8	33.7	37.0	41.0	39.9	40.0	31.0	25.1	17.1
	Min	-3.6	-9.0	2.5	5.0	10.0	16.3	19.2	20.4	19.1	13.2	3.2	-2.8
2021	Max	15.3	18.7	21.3	31.8	36.8	39.7	43.0	41.2	37.9	33.7	24.5	16.6
	Min	-4.4	-2.0	-0.1	4.4	13.0	17.4	23.0	22.9	13.8	10.5	6.4	-3.5

The region is under continental climate which is characterized by cold and rainy and snowy winters, and hot and dry summers. Long term average air temperature of the region in summer is 26 ºC and 2.7 ºC in winter. The maximum and minimum relative humidity are 70.2% and 26.9% in in January and August, while the long-term annual average relative humidity is 50.4%. Long term annual precipitation is 669.2 mm, and monthly precipitation ranges from 103.6 mm to 1.3 mm. Mean Monthly Temperature (°C), Relative Humidity (%) and Precipitation (mm), values were shown in Table 2. Undisturbed soil samples were taken using a steel core sampler of 100 cm3 volume. The undisturbed soil samples were capillary saturated and equilibrated to -1/3 bar matric potential for field capacity moisture content (Klute, 1986). Bulk density was determined in undisturbed samples using the core method of Blake and Hartge (1986). Organic matter content, particle size distribution and permanent wilting point were determined using the disturbed soil samples. Walkley-Black dichromate oxidation method was used to determine soil organic matter content (Tuzuner ,1990), and water content at permanent wilting point -15 bar was determined according to Klute (1986). Particle size distribution of soils was determined using the hydrometer method (Tuzuner ,1990).

Table 2. Mean Monthly Temperature (°C), Relative Humidity (%) and Precipitation (mm) Values

Year	Parameters	Jan.	Feb.	March	Apr.	May	June	July	August	Sept.	Oct.	Nov.	Dec.
	Temp.	**3.2**	**2.8**	**5.2**	**16.1**	**20.4**	**28.0**	**31.1**	**31.3**	**26.7**	**19.4**	**12.8**	**5.9**
2012	Rel. Hum.	**80.8**	**68.7**	**62.6**	**51.4**	**46.2**	**24.7**	**21.2**	**18.5**	**22.3**	**48.5**	**67.0**	**76.0**
	Prec.	**65.2**	**164.0**	**85.6**	**60.6**	**59.2**	**2.8**	**6.6**	**0.0**	**0.8**	**67.6**	**31.2**	**110.4**
	Temp.	**3.2**	**6.7**	**10.1**	**15.7**	**19.8**	**26.7**	**31.0**	**30.5**	**24.8**	**17.9**	**12.5**	**0.8**
2013	Rel. Hum.	**73.3**	**70.2**	**56.9**	**52.6**	**50.8**	**25.5**	**19.2**	**18.5**	**24.4**	**32.8**	**63.0**	**75.6**
	Prec.	**153.6**	**72.6**	**98.0**	**51.6**	**85.2**	**5.0**	**0.0**	**0.0**	**1.6**	**11.2**	**61.6**	**42.6**
	Temp.	**4.8**	**7.2**	**11.5**	**15.8**	**20.8**	**26.6**	**31.4**	**31.7**	**25.3**	**18.2**	**9.6**	**6.7**
2014	Rel. Hum.	**69.6**	**45.0**	**57.5**	**49.9**	**42.1**	**26.3**	**19.2**	**17.4**	**29.9**	**52.3**	**61.8**	**81.0**
	Prec.	**82.0**	**39.2**	**123.6**	**93.2**	**18.0**	**15.0**	**0.0**	**5.0**	**37.4**	**51.6**	**95.5**	**105.8**
	Temp.	**3.9**	**6.0**	**9.1**	**13.7**	**20.4**	**26.8**	**32.0**	**31.4**	**28.2**	**18.6**	**10.6**	**5.1**
2015	Rel. Hum.	**73.9**	**70.8**	**63.1**	**55.8**	**43.0**	**27.8**	**19.6**	**22.5**	**22.9**	**59.1**	**64.7**	**61.5**
	Prec.	**60.8**	**92.0**	**125.0**	**53.2**	**29.2**	**3.6**	**0.0**	**2.4**	**0.0**	**189.6**	**40.8**	**64.8**
	Temp.	**1.7**	**8.2**	**10.1**	**16.6**	**19.9**	**26.5**	**31.4**	**32.3**	**25.0**	**19.5**	**10.4**	**3.3**
2016	Rel. Hum.	**76.2**	**68.1**	**62.3**	**47.5**	**48.9**	**32.7**	**24.5**	**20.5**	**29.8**	**36.8**	**49.7**	**73.1**
	Prec.	**167.4**	**63.8**	**135.6**	**66.8**	**64.4**	**20.6**	**2.4**	**0.2**	**19.0**	**23.2**	**55.4**	**116.2**
	Temp.	**3.0**	**2.7**	**9.6**	**14.0**	**19.5**	**26.9**	**32.3**	**32.0**	**28.4**	**18.4**	**11.2**	**8.0**
2017	Rel. Hum.	**65.9**	**64.9**	**63.9**	**59.5**	**51.7**	**29.5**	**19.0**	**19.0**	**19.1**	**34.6**	**64.4**	**65.2**
	Prec.	**46.4**	**29.0**	**118.4**	**132.8**	**74.6**	**0.0**	**0.0**	**0.4**	**0.0**	**5.Şub**	**85.6**	**47.4**
	Temp.	**5.7**	**8.2**	**13.7**	**16.8**	**19.8**	**27.4**	**32.3**	**32.1**	**27.9**	**20.2**	**11.0**	**6.6**
2018	Rel. Hum.	**70.5**	**67.7**	**55.9**	**47.6**	**59.1**	**31.7**	**20.1**	**21.4**	**23.0**	**47.8**	**76.2**	**82.4**
	Prec.	**56.4**	**75.6**	**47.2**	**60.8**	**146.6**	**2.8**	**0.6**	**1.6**	**0.0**	**100.6**	**93.8**	**182.8**
	Temp.	**4.0**	**5.8**	**8.3**	**11.9**	**21.9**	**29.1**	**30.5**	**31.8**	**26.4**	**20.9**	**11.9**	**7.5**
2019	Rel. Hum.	**72.5**	**66.9**	**67.4**	**66.8**	**42.1**	**26.9**	**23.7**	**22.3**	**25.9**	**41.1**	**50.2**	**75.0**
	Prec.	**94.0**	**110.4**	**185.2**	**166.6**	**63.0**	**1.2**	**0.0**	**2.6**	**0.0**	**40.4**	**51.4**	**75.8**
	Temp.	**3.5**	**3.8**	**11.1**	**14.1**	**20.6**	**27.2**	**31.6**	**30.6**	**29.0**	**21.7**	**11.9**	**6.5**
2020	Rel. Hum.	**72.7**	**72.8**	**63.4**	**60.2**	**47.6**	**26.6**	**25.2**	**23.5**	**22.1**	**22.1**	**65.3**	**69.6**
	Prec.	**63.8**	**137.2**	**229.6**	**158.6**	**40.4**	**0.2**	**5.2**	**3.8**	**0.0**	**0.0**	**57.8**	**38.6**
	Temp.	**5.7**	**7.9**	**9.3**	**17.9**	**24.3**	**28.5**	**32.7**	**31.7**	**26.0**	**19.5**	**12.8**	**5.5**
2021	Rel. Hum.	**58.6**	**58.0**	**60.5**	**40.2**	**29.4**	**20.6**	**21.3**	**21.6**	**26.2**	**35.7**	**60.3**	**71.6**
	Prec.	**92.0**	**54.0**	**112.6**	**8.6**	**13.2**	**0.0**	**0.0**	**7.0**	**3.0**	**17.8**	**25.4**	**68.8**

Siirt pistachio cultivation, which commercially started in the 1980s, has gradually increased in the Southeast Anatolia and has become an indispensable crop of the farmers in the region. The Southeast Anatolia region of Turkey ranks the first in pistachio (Siirt, Uzun, red, Halebi, etc.) production. Abiotic factors are as important as biotic factors in pistachio cultivation. Drought, one of the most important abiotic factors, significantly affects the agricultural production (Öztürk, 2007; ; Ekberli et al. 2005; Onen et al., 2017; Fahad et al. 2017). The research yearbooks of the Ministry of Agriculture and Forestry Siirt Provincial Directorate of Agriculture on Siirt pistachio variety, literature reviews, field observations, farmer interviews, agricultural production reports between 2012 and 2021, meteorological data and various sources were used as the materials of the study. The regression analysis between yield values and the climate data were carried out, and the relationships were interpreted based on the correlation coefficients between the parameters.

Results

3.1. The Effects of Temperature and Relative Humidity on Pistachio Growth

The Siirt pistachio cultivation area, production and yield values between 2012 and 2021 growing seasons are given in Table 3. The pistachio yield per fruit bearing tree ranged between 2 (2016, 2018 and 2019) to 7 kg (2013) with a mean value of 3.90 kg. The images of male flowers and female flowers with fruits of Siirt pistachio are shown in Figure 1 and 2

Figure 1. Male flowers of Siirt pistachio

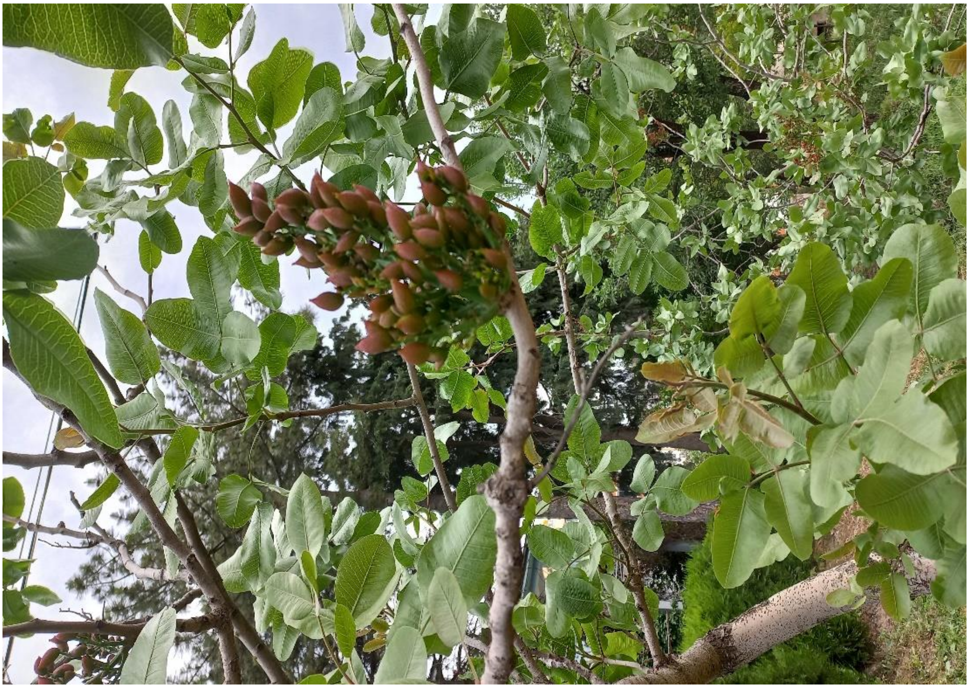

Figure 2. Female flowers of Siirt pistachio.docx

Table 3. Siirt Pistachio Cultivation Area and Production Values (2012- 2021)

	Siirt Pistachio		
Years	Coverage Area (ha)	Production (ton)	Pistachio Yield (kg/ fruit-bearing tree)
2012	23838.60	17478.00	6.00
2013	18957.50	18831.00	7.00
2014	19066.30	15228.00	5.00
2015	19066.30	11221.00	4.00
2016	19895.00	6713.00	2.00
2017	18807.30	7944.00	3.00
2018	28207.10	11301.00	2.00
2019	28520.60	12208.00	2.00
2020	32060.00	25824.00	4.00
2021	33492.00	26371.00	4.00
Mean	23838.60	17478.00	3.90
CV (%)	24.29	44.64	44.33
Std. Dev.	5876.35	6835.98	1.73
Correlation (%)	64.96		

$p \leq 0.05$; $^{**}p \leq 0.01$ It is important within the error limits. ns:not significant Similar letter in the same column are not significantly different from each other.

WUE; Water use efficiencies. CWSI; Crop water stress index. Eta; Evapotranspiration

High temperatures and low relative humidity during the fertilization period caused significant decreases in pistachio yield (Table 3, Table 4a and 4b). The temperature and relative humidity in the study area during the fertilization period of Siirt pistachio in 2019 (13,14,15 and 16 May) were around 43.1˚C and 32.5%, respectively. The trees could not meet the water demands and could not grow sufficiently during the flowering period and the yield remained at the same level (2 kg per tree) as in 2018, due to the low fertilization rate. In addition, the yield per tree decreased from 4 kg to 2 kg in 2016 and 2018.

Table 4-a. Climate data during fertilization of Siirt pistachio variety in May between 2012-2022

Year	Parameters	20	21	22	23	24	25	Year	20	21	22	23	24	25
2012	Max. Tem. (°C)	30.7	25.5	25.3	26.5	29.9	23.8	2015	31.6	33.0	27.6	27.1	28.8	29.9
	Min. Temp. (°C)	19.5	16.7	14.1	12.4	12.9	15.5		14.3	15.8	9.6	17.5	15.2	11.9
	Daily Ave. Temp. (°C)	23.9	21.7	18.4	18.8	19.0	20.5		24.5	26.7	22.8	23.6	21.5	22.9
	Daily Rel. Hum. (%)	36.5	38.7	44.6	47.7	56.1	41.5		30.8	32.0	39.5	35.7	42.8	43.2
	Precip. (mm)	0.0.	0.0	0.0	1.0	2.8	0.0		0.0	0.0	0.0	0.0	0.0	0.0
2013	Max. Tem. (°C)	25.0	19.3	26.8	29.3	30.7	29.8	2016	26.1	28.5	29.3	32.6	33.6	30.0
	Min. Temp. (°C)	18.5	17.6	15.1	19.4	11.4	11.1		19.8	20.4	17.4	19.3	20.7	21.0
	Daily Ave. Temp. (°C)	19.5	17.0	19.0	22.8	24.0	23.7		19.5	21.7	23.0	24.5	21.7	20.7
	Daily Rel. Hum. (%)	49.3	67.5	59.9	45.2	38.6	43.2		39.7	38.2	33.6	28.8	42.9	41.8
	Precip. (mm)	0.0	0.0	2.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
2014	Max. Tem. (°C)	24.6	25.7	24.8	28.2	23.9	27.7	2017	26.7	19.3	23.2	20.0	22.1	24.1
	Min. Temp. (°C)	17.5	11.6	16.8	14.8	10.0	18.9		18.6	19.1	14.5	12.9	11.5	17.0
	Daily Ave. Temp. (°C)	17.2	19.7	18.5	20.8	19.7	20.8		22.2	15.9	17.8	15.9	15.6	18.3
	Daily Rel. Hum. (%)	48.4	35.3	47.4	46.9	50.3	45.5		39.6	70.8	55.6	66.9	72.0	50.0
	Precip. (mm)	3.0	0.0	0.0	1.2	2.0	0.8		0.6	17.8	0.0	0.2	9.0	0.0

Most growers believe that the pistachio plants grow well on warm nights. On the contrary, the pistachio plants do not grow well on hot and humid nights. The respiration increases in hot and humid nights, and more energy is consumed. Therefore, high temperature is not suitable for pistachio growth. Pollen quickly loss their vitality at high temperatures, and pollination decreases. The most ideal conditions for pistachio are cool nights, sunny days and moderate temperatures (Anonymous, 2020). The pistachio plants are adversely affected by low air humidity, especially during the pollination period, hinders pollination and increases water losses by transpiration. Moisture stress (at 50% or less humidity) during the fertilization period causes 3% yield loss per day when 6% of trees have female flowers, and 7% yield loss per day when 75% of trees have female flowers. The yield decrease per day was reported 4.1% due to moisture stress during the grain filling period (Kırtok, 1998).

Table 4-b. Climate data during fertilization in Siirt pistachio variety in July between 2012 and 2021

Year	Parameters	20	21	22	23	24	25	Year	20	21	22	23	24	25
2018	Max. Temp. (°C)	**30.8**	**31.9**	**29.7**	**29.2**	**25.9**	**30.0**	**2021**	**33.9**	**36.8**	**34.8**	**28.4**	**28.9**	**34.1**
	Min. Temp. (°C)	**19.4**	**20.5**	**19.8**	**18.1**	**15.5**	**15.9**		**19.8**	**21.7**	**24.8**	**18.8**	**17.3**	**17.0**
	Daily Ave. Temp. (°C)	**25.1**	**26.0**	**24.8**	**23.8**	**19.7**	**22.0**		**27.3**	**29.3**	**30.1**	**23.6**	**23.3**	**23.7**
	Daily Rel. Hum. (%)	**39.0**	**36.8**	**43.8**	**48.5**	**68.8**	**52.7**		**23.1**	**19.9**	**21.0**	**20.7**	**26.0**	**34.0**
	Precip. (mm)	**0.0**	**0.0**	**0.0**	**2.4**	**4.4**	**0.0**		**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**
2019	Max. Tem. (°C)	**27.3**	**28.0**	**29.0**	**28.6**	**32.5**	**33.4**							
	Min. Temp. (°C)	**15.8**	**14.7**	**17.0**	**18.5**	**20.5**	**22.3**							
	Daily Ave. Temp. (°C)	**22.1**	**21.8**	**23.5**	**23.7**	**26.3**	**26.7**							
	Daily Rel. Hum. (%)	**36.8**	**41.8**	**38.1**	**43.1**	**35.9**	**33.1**							
	Precip. (mm)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**							
2020	Max. Tem. (°C)	**32.2**	**33.7**	**33.6**	**27.4**	**27.1**	**18.5**							
	Min. Temp. (°C)	**11.3**	**9.6**	**10.4**	**12.4**	**12.9**	**15.9**							
	Daily Ave. Temp. (°C)	**25.6**	**26.7**	**27.6**	**23.4**	**19.9**	**18,5**							
	Daily Rel. Hum. (%)	**24.1**	**30.5**	**34.4**	**35.8**	**63.6**	**75.2**							
	Precip. (mm)	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**3.2**							

Significant polynomial relationships p<0.01) were obtained between 5-month average maximum temperature of the growing period and yield (Figure 3). Significant polynomial relationships obtained show that insufficient precipitation (drought), high temperature and very low relative humidity between 2012-2021 had negative impacts on pistachio yield (Figures 3-6). The development of pistachio fresh shoots accelerates when the temperature in 5-10 cm soil depth reaches 15 °C. The amount of root and stem growth and temperatures between 10-30 °C during the shoot elongation period had a linear relationship. Root and stem elongation suddenly decrease when the temperature reaches 36 and 40°C. On the other hand, root elongation of plants stops at temperatures below 9 °C (Kırtok, 1998).

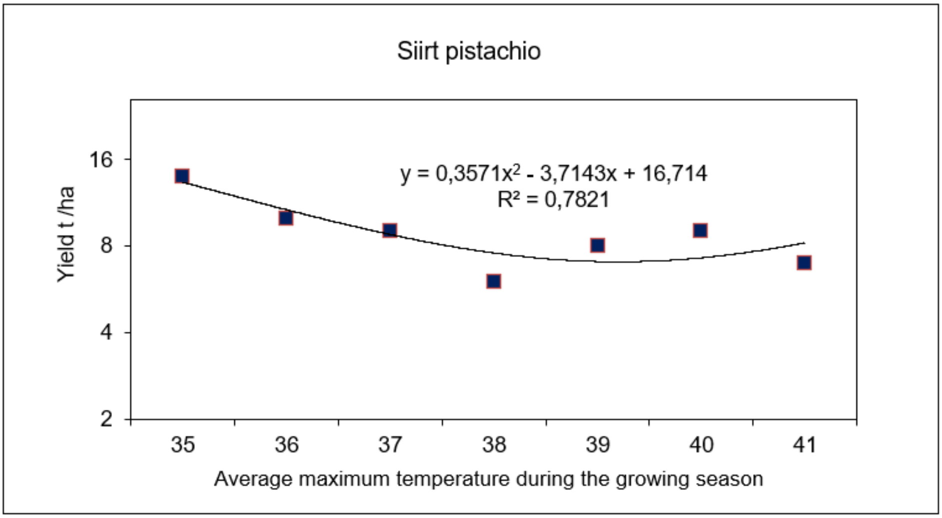

Figure 3. The relationship between average maximum temperature and pistachio yield

A significant ($p<0.01$) polynomial relationship was determined between the average temperature and relative humidity values of the pistachio growing period and the yield (Figure 4). The results showed that the effect of temperature and humidity on pistachio yield was similar. In addition, a similar relationship was recorded between the average maximum temperature and average relative humidity in the first three months of the growing period and the pistachio yield. The results revealed that the effect of relative humidity on peanut yield is higher than the temperature (Figure 6). In addition, high relative humidity as well as high temperature during pistachio growth period have a significant effect on pistachio yield.

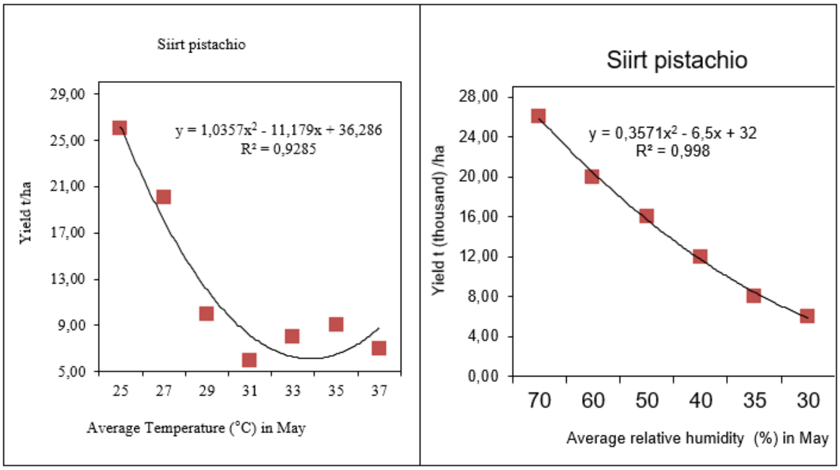

Figure 4. The relationship between average temperature and relative humidity in May and pistachio yield

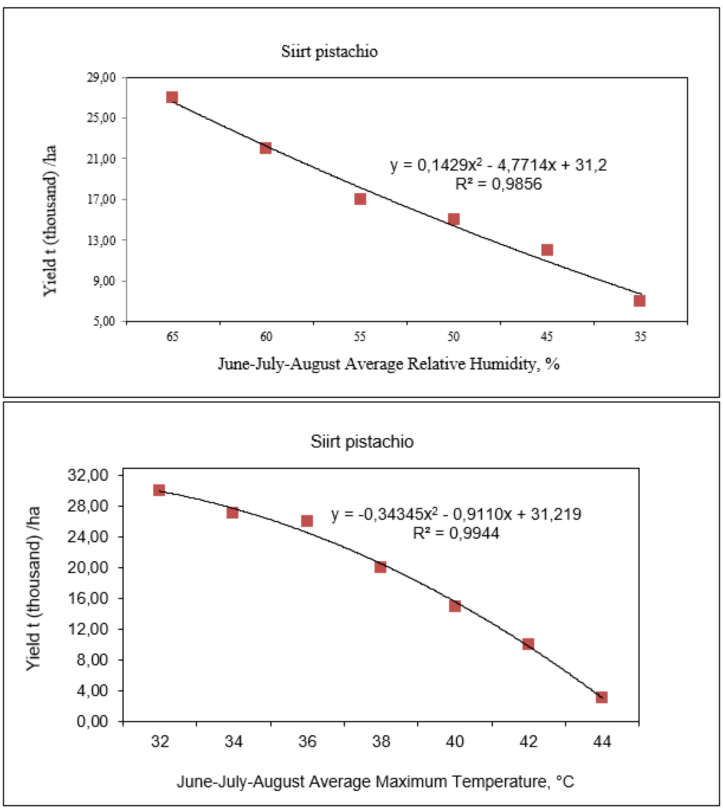

Figure 5. The relationship between average relative humidity in June-July and August and pistachio yield

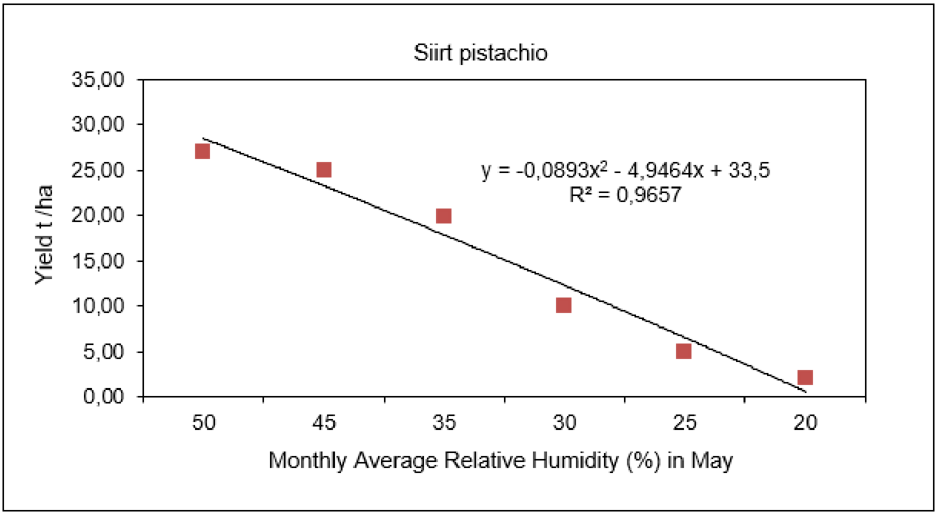

Figure 6. Average relative humidity-yield relationship in May

3.2. The Effects of Precipitation on Pistachio Growth

A significant relationship was determined between total amount of precipitation during the growing period and the pistachio yield. The correlation coefficient between precipitation and yield was also very high (Figure 7).

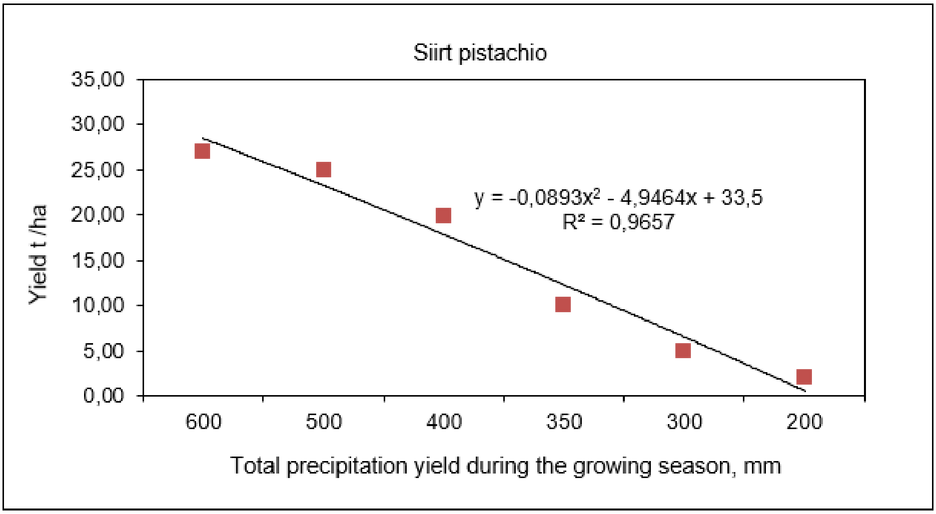

Figure 7. Total precipitation-yield relationship during pistachio growth period

Discussion

Siirt pistachio variety can grow even on sloping lands in almost any type of soil, therefore, soil is not a limiting factor. The most important factors constraining the pistachio cultivation are high temperature, insufficient precipitation and very low humidity. Dry climatic conditions prevail in summer, the planting of pistachio seedlings (orchard establishment plant) in the region is carried out in autumn or spring. In general, planting in autumn is preferred. The male pistachio trees begin to bloom on average in May depending on the temperature and humidity, and the female pistachio trees bloom in the following 2-3 days. Fertilization of Siirt pistachio takes place in the second week of May on average, the fertilization is highly affected by drought, extreme temperature and very low humidity. Therefore, the relationship between the climate data belonging to the fertilization period and the yield between the 2012-2021 was investigated. The results showed that climatic values have a negative impact on the yield of Siirt pistachio cultivar.

In semi-arid climate conditions, the Siirt pistachio variety begins to pollinate in the second week of May on average. Therefore, the pollination days of May should be examined to assess the effects of climate on pistachio yield. Insufficient precipitation, very low relative humidity and high temperatures in the second week of May 2019 are the main causes of pistachio yield decrease. High temperatures (up to 43.1˚C) and low relative humidity (30-40%) negatively affected pollination, adequate fertilization could not be achieved, the fruits were not filled adequately, and the yield significant decreased (Table 4a). In addition, the yields of other products decreased in the same period compared to previous years. The ratio of pollination is decreased by insufficient precipitation, extreme temperatures and low or high relative humidity conditions. Therefore, the main cause, except for the lack of periodicity and male pollinator trees, of yield decrease in drought years under semi-arid climate conditions is climatic events or insufficient precipitation. In dry years, the water needs of plants reach the maximum level, the relative humidity in the air decreases and extreme temperatures occur, which all negatively affect the pollination.

The main causes of low yield in 2016 are the periodicity and the lack of insufficient fertilization due to excessive rain and wind during the flowering period. Therefore, the yield in 2016 was half of the previous year. The low yield in 2018 can be attributed to the insufficient winter chilling (vernalization) of pistachio trees in the region. In addition, the Septoria pistaciae epidemic, disease and pests also cause a significant yield decreased in 2018 compared to the previous year.

The most critical period in pistachio growth are the months of April and May. In general, climatic stress in pistachio growth is not expected during April and May, however, a severe drought in this period adversely affects the entire vegetation period of the pistachio trees. Because the pistachio flowers are pollinated and the fruits are filled in these months (Anonymous, 2001). Therefore, drought risk models have been developed in regions where precipitation is irregular or insufficient (Wu, 2004). Precipitation, which positively affects yield and fertilization of pistachio trees, occurs low in May in the study area for some years. In semi-arid climate conditions, planting of pistachio seedlings should be completed in the early fall or spring. Late plantings may be risky as the vegetation period will not be sufficient. The harvest of pistachio starts in September depending on the variety, altitude, temperature, humidity and precipitation of the region. In the semi-arid climate zone, precipitation does not occur in summer months or may occur very small amount. The rainfall falling during the pollination period creates a cool air and makes a positive contribution to the prolongation of the fertilization period. In addition, the precipitation in winter months positively contributes to the yield and development of pistachio trees.

The precipitation is an important factor in pistachio cultivation. The amount of water required for fresh shoots is higher especially at the beginning of growing period of young pistachio seedlings, than other seedlings. Therefore, the irrigation of pistachio trees in summer is needed due to the lack of adequate rain in summer months (Aydın and Saltuk, 2018). Since the vegetation period of the pistachio trees is the summer months, the water demand of plants is very high due to the high temperature and evaporation during the growing season. Three or four times of irrigation during the vegetation period positively affect the growth of young pistachio seedlings (Anonymous, 2020). However, the number of irrigation may vary from region to region**.**

Conclusions

Data of 2018 were not evaluated due to the Septoria pistaciae epidemic in 2018. The peanut yield per tree was 3 kg in 2017, while the yield decreased to 2 kg in 2019 due to drought. Pistachio yield per tree in 2020 was increased to 4 kg. The pistachio yield per tree was 3 kg in 2018, while the yield per tree decreased by 37.5% in 2019 to 2 kg. The pistachio yield loss in 2019 was 50% compared to the average yield in 2020. Average yield loss in 2019 due to climate changes was 43.75%. The main cause of yield decrease is the low precipitation (drought), high temperature and very low relative humidity related to the climate change. The results revealed that extreme values of temperature and relative humidity had a negative effect on the pistachio yield. The fruits do not fill enough or the survival time of pollens is shortened under unsuitable climatic conditions. The change in pistachio plantation area and amount of production had a similar tendency, whereas the yield had a different tendency and decreased due to the climatic conditions. Insufficient rainfall during the development period of the pistachio plants adversely affected the pistachio production and productivity in 2019 compared to previous years. Therefore, pistachio plants should be irrigated frequently before 50% of the available soil moisture depleted, especially during the pollination period under insufficient precipitation, and the irrigation system should be converted to the pressurized (drip) irrigation. The moisture content in the root zone can be kept close to the field capacity in the drip irrigation system, therefore, the plants do not expose to moisture stress, can reach the moisture in the plant root zone when needed, and pollination and yield of pistachio plants increase.

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Chapter 2

Pea Production Statistics in the World and in Turkey

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ABSTRACT

INTRODUCTION

Grains take the first place in the fields where field crops are produced in the world and in Turkey, followed by edible legumes. Of the 1.5 billion hectares of agricultural land in the world, 66.8 million hectares of legumes are cultivated and 61.2 million tons are produced. While the most cultivated legumes in the world were beans, chickpeas, black-eyed peas, peas, lentils and broad beans, the most produced ones were beans, chickpeas, peas, black-eyed peas, lentils and broad beans. Legumes are cultivated in 735 thousand hectares of the total agricultural area of 24.3 million hectares in our country, and approximately 1 million tons of production is made. While the most cultivated legumes in our country were chickpeas, lentils, beans, broad beans, black-eyed peas and peas, the most produced ones were chickpeas, lentils, beans, broad beans, peas and black-eyed peas. Edible legumes have held a very important place in the world and our country as the main source of vegetable protein in human nutrition for thousands of years. Edible legumes are a source of protein for more than 2 billion people in the world. It is low in fat, high in carbohydrates and nutritious. 22% of vegetable proteins and 7% of carbohydrates in human nutrition in the world; 38% of protein in animal nutrition and 5% of carbohydrates are provided from legumes. Turkey is the most important part of the Fertile Crescent, which is considered the gene center of legumes. Apart from this, it has an important place in the world in terms of consumption rates and has historically been a net exporter. Edible legumes grown in almost every region of our country constitute the protein source of Turkish cuisine and especially for low-income families (Adak et al. 2010).

Pea plant, which is one of the edible legumes, comes to the fore in human nutrition due to the high protein content in it. It is an alternative vegetable protein source to fill the protein deficit in our country where access to animal protein is difficult. It is grown in temperate regions in the world, and especially in the Mediterranean, Aegean, Black Sea and Marmara regions in our country. It grows quite well in cool and humid areas. Peas are produced in the world and in Turkey as dry and wet peas.

PEA PRODUCTION IN THE WORLD

The pea is one of the oldest plants to enter Europe, which became a suitable place to live again after the end of the ice age (Ljuština & Mikić 2010). With the start of the agricultural revolution, pea has become an important plant in the world (Erskine 1998). With the available evidence, it is known that the pea entered Europe from the southeastern regions and proceeded inland via the Danube River (Mikić et al 2009). In the world and Europe, especially in the last ten years, there has been an increase of 34% and 44% in legume production, including pea production.

Dry Pea Cultivation, Production and Yield Values in the World

According to FAO data, dry pea cultivation area was recorded as 7,043,605 hectares worldwide in 2021. When the cultivation area statistics of the last ten years are examined, it is observed that there has been an increase in the dry pea cultivation area in the world in the last ten years. Total dry pea production in the world in 2021 reached 12,403,521 tons, and the yield was determined as 17,610 hg/ha. An increase has been observed in the yield and production values of dried peas in the last ten years (Table 1).

Table 1. Dry pea cultivation area, production and yield values in the world

Years	Cultivation area (ha)	Yield (hg/ha)	Production (ton)
2011	6178118	16637	10278737,75
2012	6712406	15848	10638145,19
2013	6413637	17583	11276816,88
2014	6807590	17201	11709552,01
2015	6900983	17288	11930104,34
2016	7450581	20021	14916778,28
2017	8053776	20252	16310356,10
2018	7511375	17888	13436002,15
2019	7174402	19562	14034340,63
2020	7219781	20420	14742987,25
2021	7043605	17610	12403521,85

Source: FAO 2023

Pea, which is a plant rich in protein content, is resistant to frost and cold. It is an important legume plant that grows easily in the world and Europe as it is grown in cold climates. There are two types of peas that are widely commercialized in the world and Europe. These are *Pisum sativum* L., which is marketed as fresh or canned, and *Pisum sativum* L. var. macrocarpon., known as yellow pea, which is marketed as dry . Yellow peas, which are widely sold, dominate the world market (Tassoni et.al.,2020).

Fresh Pea Cultivation, Production and Yield Values in the World

When the fresh pea cultivation area data of the last ten years around the world are examined (Table 2), it is seen that wet peas were planted in an area of 2.590,367 ha in 2021. Worldwide cultivation areas of fresh peas have increased in the last ten years. If we examine the yield and production values, an increase has been observed in the yield and production amount of fresh peas in the last ten years. While the fresh pea yield in 2021 was 79.254 hg ha^{-1}, the fresh pea production was 20,529,759 tons (Table 2).

Table 2. Fresh pea cultivation area, production and yield values in the world

Years	**Cultivation area (ha)**	**Yield (hg ha^{-1})**	**Production(ton)**
2011	2212922	76445	16916713,58
2012	2256533	75350	17002871,78
2013	2258671	76881	17364795,15
2014	2315769	74995	17367106,82
2015	2485870	77838	19349439,76
2016	2401251	77560	18624179,25
2017	2511572	78392	19688699,92
2018	2516986	77892	19605271,77
2019	2519667	78336	19738011,47
2020	2572585	78706	20247758,69
2021	2590367	79254	20529759,32

Source: FAO 2023

Pea cultivation area in the world by continents

When the cultivation area, production and yield values of the pea plant, which is cultivated in a wide area in the world, are examined on the basis of continents, Europe and America come to the fore (Table 3). According to the years, the continent with the highest cultivation area is Europe, followed by the Americas, followed by Asia, Africa and Oceania, respectively. In the European continent, peas were produced in a total area of 2,541,703 ha in 2021. The European continent has the highest share of cultivation area in the production of peas in the world. The European continent is followed by the American continent with a pea-pea cultivation area of 2.006,155 ha. While the Asian continent ranks 3rd with a pea cultivation area of 1,758,424 ha, Africa and Oceania continents follow the Asian continent.

Table 3. Pea cultivation area in the world by continents

Years	EUROPE	AMERİCA	ASIA	AFRICA	OCEANIA
2011	2.077,457	1.286,723	1854866,00	698985,00	260086,00
2012	1.936,762	1.931,499	1813630,00	743615,00	286899,00
2013	1.646,608	1.820,231	1915790,00	779586,00	251423,00
2014	1.632,277	2.156,736	2102636,00	663864,00	252078,00
2015	1.889,067	2.163,693	2015313,00	589338,00	243572,00
2016	2.250,333	2.407,976	2031434,00	515714,00	245124,00
2017	2.808,087	2.236,455	2262834,00	509173,00	237228,00
2018	2.744,277	1.906,120	2064848,00	497757,00	298374,00
2019	2.348,946	2.292,734	1789652,00	506568,00	236501,00
2020	2.441,096	2.249,749	1762646,00	511697,00	254593,00
2021	2.541,703	2.006,155	1.758,424	478663,00	258660,00

Source: FAO 2023

Pea yield in the world by continents

When we compare pea yields by continent, the highest pea yield at the end of 2021 was 37.165 hg ha^{-1} in the America. The American continent was followed by the European continent, and the pea yield was recorded as 23.220 hg ha $^{-1}$. The European continent was followed by Oceania, Asia and Africa, respectively (Table 4). Average seed yield worldwide is 1.5 t ha^{-1} while yields as high as 4 to 5 t ha^{-1} have been recorded in some developed countries.

Table 4. Pea yield in the world by continents

Years	AFRİCA	AMERİCA	ASIA	EUROPE	OCEANIA
2011	8365,00	39745,00	12076,00	19653,00	14415,00
2012	8716,00	40208,00	12037,00	17187,00	11845,00
2013	9506,00	39257,00	11974,00	18169,00	14582,00
2014	9426,00	38232,00	11672,00	20803,00	14685,00
2015	10067,00	50557,00	11647,00	22803,00	12830,00
2016	10915,00	39874,00	11505,00	24060,00	9359,00
2017	11335,00	40437,00	12429,00	26170,00	18557,00
2018	11418,00	38612,00	13568,00	18949,00	11436,00
2019	11560,00	38682,00	14032,00	22337,00	7789,00
2020	11269,00	39668,00	14458,00	22504,00	9233,00
2021	11978,00	37165,00	14515,00	23220,00	16380,00

Source: FAO 2023

Primary regions of production include Canada, China, France, and the Russian Federation followed by India, Germany, Australia, Ukraine, UK, and the USA.

Pea production amount by continent

When the production of peas by continents is examined, the highest production was obtained from the European continent with 5901880 tons. The European continent is followed by the Americas with a production amount of 584404,62 tons, and the continents of Africa, Oceania and Asia follow the production of peas by continent, respectively (Table 5).

France, England, Italy, Germany and Spain are important legume producing countries in Europe. While countries such as Spain and Italy, which have a mediterranean climate, grow more temperate varieties in terms of climate demand, France, Germany and the United Kingdom, which have a cold and continental climate, specialize in pea cultivation due to their cold climate. Having 61% of global production, China is the country with the largest *green pea* production in the world. China is followed by India and the USA. The main pea producing countries in Europe are France, Spain and England (Tassoni et.al.,2020).

Table.5.Pea production amount by continent (tons)

Years	AFRİCA	AMERİCA	ASIA	EUROPE	OCEANIA
2011	584733,25	636059,80	2239863,22	4082866,53	374901,00
2012	648166,07	722581,85	2182998,36	3328711,78	339828,00
2013	741055,32	678050,13	2294005,54	2991678,73	366632,00
2014	625740,23	688580,48	2454218,31	3395620,97	370170,00
2015	593297,24	733201,36	2347255,05	4307558,02	312509,35
2016	562898,05	632594,67	2337194,12	5414360,13	229403,78
2017	577123,93	593093,10	2812415,00	7348719,83	440213,71
2018	568319,37	596038,76	2801562,68	5200213,25	341222,61
2019	585574,55	585333,13	2511268,08	5246774,85	184204,37
2020	576615,39	622138,71	2548401,97	5493487,74	235063,23
2021	573350,96	584404,62	2552431,97	5901880,82	423688,40

Source: FAO 2023

Dry pea is adapted to different ecological conditions, grows on marginal land, plays an important role in crop rotation and provides an important source of vegetable protein. After beans and lentil, pea is the third most important legume produced for poorer consumers, particularly in developing countries, similar to chickpeas and cowpeas. Important production areas include France, Russia, Ukraine, Denmark and the United Kingdom in Europe; China and India in Asia; Canada and the USA in North America; Chile in South America; Ethiopia in Africa and Australia. World total dry pea production rose from 8-9 million tonnes in the 1970's to 16,7 million tonnes in 1990. Pea consumption in the world was 2.2 kg/capita at the beginning of the 1960s, while this rate was 0.5 kg/capita at the end of the 1990s. The level of peas for human consumption has decreased, but the increase has shifted towards animal nutrition. (Kralovánszky, 1975).

Canadian pea production has increased by 450% in the last decade. In Canada and Australia, exports are likely to grow more slowly than in the past, partly due to weakening demand for imports of feed. (Lazányi, 2002). As regards dry yellow peas, in 2017 Canada was the largest producer followed by the Russian Federation and China. Different from green peas, dry yellow peas are mainly produced in Europe (43.7%), North and South America (33.7%) and Asia (15.9%) (Tassoni et.al.,2020).

PEA PRODUCTION IN TURKEY

Approximately 3.2% of agricultural land processed each year.Legumes are grown in our country. Legumes occupy the most important place after cereals in terms of cultivation area. The most cultivated legumes in our country are chickpeas, lentils, beans, broad beans, cowpea and peas, while chickpeas, lentils, beans, broad beans, peas and black-eyed peas produced the most.There is a continuous decrease in the cultivation, production and yield values of legumes in Turkey over the years. The most important reason for this is that TMO reduced legume purchases after 1990 and stopped it completely in 1994, and the producer of leguminous crops left behind has shifted its fields to other products that have price guarantees and are easier to produce (Akova 2009). Edible legumes are a source of protein for more than 2 billion people in the world. It is low in fat, high in carbohydrates and nutritious. 22% of vegetable proteins and 7% of carbohydrates in human nutrition in the world; 38% of protein in animal nutrition 5% of carbohydrates are provided from legumes. Turkey is the most important part of the 'fertile crescent', which is accepted as the gene center of legumes. In addition, in terms of consumption rates in the World. It has historically been a net exporter as well as having an important place. grown in almost every region of our country. Edible legumes constitute the protein source of Turkish cuisine and especially for low-income families. The legumes we produce are important Some of it is consumed domestically. Considering the annual average consumption of 3-4 kg of beans, 4-5 kg of lentils and 5-6 kg of chickpeas per capita in our country, edible legumes are of great importance for the people of our country (Adak et al. 2010).

In terms of pea planting and production in our country, Aegean, Marmara and Central Anatolia Regions come to the fore. According to the 2023 TUIK data in our country, peas were planted in a total area of 8,873 decares, a yield of 270 kg/da was obtained and a production of 2,392 tons was achieved (Table 6).

Table 6. Pea cultivation area, yield and production amount in Turkey

Years	Cultivation area (da)	Yield (kg da^{-1})	Production (ton)
2012	12083	222	2686
2013	12618	256	3235
2014	11490	260	2987
2015	11118	281	3125
2016	10882	268	2919
2017	9415	284	2673
2018	9065	287	2603
2019	7813	281	2193
2020	5517	279	1538
2021	6786	266	1805
2022	8873	270	2392

Source: TUİK 2023

In our country, pea cultivation is carried out at a considerable level, especially in the Mediterranean and Aegean regions. Especially Antalya, Balıkesir, Bursa, Çanakkale, Hatay, Konya, İzmir, Adana, Afyonkarahisar, Amasya, Aydın, Bartın, Kilis, Kütahya, Manisa, Ordu, Samsun, Sinop and Zonguldak are the provinces where pea production is made intensively. According to the provinces, the highest cultivation area is in Konya with an area of 2860 decares. Bursa, Çanakkale and İzmir provinces follow Konya (Table 7).

Table 7. Pea cultivation areas by provinces in Turkey

Years	Antalya	Balıkesir	Bursa	Çanakkale	Hatay	Konya	İzmir
2012	460	1364	2529	327	466	1973	2829
2013	366	842	2113	285	398	2050	2870
2014	356	760	1940	270	510	2550	2820
2015	306	760	1460	273	490	2510	3320
2016	292	700	1350	270	385	2533	3370
2017	257	735	1245	220	50	2460	2820
2018	237	725	980	218	39	2271	2920
2019	220	757	925	467	40	950	2920
2020	150	680	918	515	34	1250	759
2021	200	715	1743	498	50	2380	244
2022	50	845	2442	488	45	2860	282

Source: TUİK 2023

When the pea yield statistics by provinces are examined, Konya province had the highest yield with 931 kg da^{-1} , followed by Bursa with 563 kg da $^{-1}$ and Balıkesir with 249 kg da $^{-1}$ (Table 8).

Table 8. Pea yield (kg da^{-1}) by provinces in Turkey

Years	Antalya	Balıkesir	Bursa	Çanakkale	Hatay	Konya	İzmir
2012	77	200	618	75	69	592	764
2013	73	155	524	67	71	695	968
2014	71	145	517	66	106	832	955
2015	73	186	385	66	100	817	1155
2016	69	161	353	64	72	718	1175
2017	61	173	335	52	15	746	955
2018	56	172	250	54	12	795	915
2019	51	179	225	113	12	378	911
2020	30	159	216	126	10	425	322
2021	46	203	327	121	15	772	94
2022	11	249	563	119	14	931	71

Source: TUİK 2023

When we examine the production of peas by provinces, Konya ranks first with 326 tons of wool, and Hatay ranks second with 311 tons. Balıkesir ranked third with 295 tons, İzmir fourth with 252 tons, Çanakkale fifth with 244 tons, while Bursa ranked sixth with 231 tons (Table 9).

In Turkey, the temperature varies depending on the latitude difference on the coasts, and the distance from the sea, altitude, and landforms in the interior. The daily and annual temperature differences are less in the coastal regions and more in the interior regions. The least annual difference is seen in the Eastern Black Sea coast (15 - 16°C). The biggest annual difference is in Northeast Anatolia. Turkey, in general, is under the influence of the Mediterranean climate. In this context, throughout Turkey, summers are dry and winters are rainy. However, there are three main climate types that can be distinguished from each other with clear differences. These are the Black Sea and Mediterranean climates and the continental climate. Due to the diversity in its climate, peas are suitable for growing in almost every region of our country.

Table 9. Pea production by provinces in Turkey (tons)

Years	Antalya	Balıkesir	Bursa	Çanakkale	Hatay	Konya	İzmir
2012	167	147	244	229	148	300	270
2013	199	184	248	235	178	339	337
2014	199	191	266	244	208	326	339
2015	239	245	264	242	204	325	348
2016	236	230	261	237	187	283	349
2017	237	235	269	236	300	303	339
2018	236	237	255	248	308	350	313
2019	232	236	243	242	300	398	312
2020	200	234	235	245	294	340	424
2021	230	284	188	243	300	324	385
2022	220	295	231	244	311	326	252

Source: TUİK 2023

To increase the production of peas in our country,

- Input prices should be lowered
- Resistant to diseases and pests, high yielding varieties should be bred
- Use of certified seeds and seed support should be given to spread it
- Land consolidation processes should be accelerated and legume production, which is carried out as subsistence agriculture in small family businesses, should be made for the market
- Producer associations should be established and established should be supported by the state,
- During the crop harvest period of the producer pea imports should be strictly avoided
- Pea in fallow fields should be put into crop rotation.

CONCLUSION

Peas are planted in 8,873 hectares of the total agricultural area of 24.3 million hectares in our country, and 2,392 tons of peas are produced. Although peas are the most consumed legume throughout the year in many countries of the world, the habit of consuming peas is not common in our country. Although it is the most consumed legume plant in the world, especially in the canning industry, pea consumption is not yet at the desired level in our country. However, especially in the last ten years, due to the rapid development of the canned and frozen food industry, significant increases have been achieved in the cultivation and production of peas. Peas have a great importance in human nutrition. It is rich in protein, carbohydrates and especially vitamins A, B and D. Pea grains contain 18-20% dry matter. 10-12% of this is in the form of carbohydrates and 20-30% of it is in the form of protein. It is among the richest legumes in terms of protein. Stubble residues, straw and straw residues after harvest are used in animal nutrition. It is a good alternation plant because it enriches the soil with nitrogen with the Rhizobium bacteria in its roots and leaves a good soil for the next plant. In parallel with the scarcity of cultivation area, pea is the poorest in terms of the number of locally registered varieties among the food legumes cultivated in our country. In our country, 11 varieties for fresh consumption have taken place on the market, either registered or with production permission. However, Akçin (1988) reported from Trabut (1911) and Vavilov (1950) that the Near Asian and Mediterranean gene centers in our country are the gene centers for peas as well as for many plants, and the transfer of these materials and plant diversity from the present to the future is one of them. Conservation, preservation and utilization are the most important resources for the sustainability of agriculture. Considering the diversity in the field of use, the benefits it provides to the soil, animals and people, and the benefits it provides to sustainable and organic agriculture, it is necessary to accelerate the efforts to increase the pea cultivation areas in our country. The development of varieties for dry and fresh use through breeding studies should be given due importance to the pea plant and studies should be carried out to increase its production, due to its contribution to the country's economy and the benefits it will provide for human, soil and animal nutrition.

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Chapter 3

Rural Migration and Woman: Case Study of Adana, Turkey

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ABSTRACT

Migration can be defined as the movement of individual from one place to another generally for economic, social or political reasons. This study examines how women, who migrated to urban Adana and settled in the city, were affected by this process. 115 women were interviewed using the Simple Random Sampling method. According to the findings, almost all women migrated with their spouses and children. Women were not free in their decision to migrate. The main reasons for migration are marriage, employment and the education of children. Another important reason is the lack of agricultural land in the village. Men are influential when it comes to women's decision to migrate. The choice of neighbourhood is affected by the following factors: having acquaintances, the husband’s opinion, and lower costs of living. Rather than financial support, women have received high levels of moral support after migrating to new places. They stated that following the decision to migrate, they experienced many emotions such as excitement, fear, joy and sadness. After migration, adaptation to urban life, alienation, loneliness, regret and unemployment were the most important problems. Despite these problems, women do not want to leave the city's opportunities and go back to rural areas. Consequently, increased support should be sought for women in both rural and urban setting, as they have numerous responsibilities. Fostering future generations requires the development of women who are both physically and mentally healthy and attentive.

Keywords: migration, women, health, rural, Adana

INTRODUCTION

Migration is the process of moving, either across an international border or within a country, encompassing any kind of movement of people regardless of the causes (Anonysmus, 2011). The International Organisation for Migration (IOM) defines migrant as a term "to cover all cases where the decision to migrate is taken freely by the individual concerned, for reasons of ‘personal convenience' and without intervention of an external compelling factor" (Anonysmus, 2012).

A large part of the migrant population migrates with the hope of better living conditions or in order to save their lives from war, civil war, ethnic or religious conflicts, or due to political oppression or poverty reaching an intolerable rate (Hall, 2016). As with all social occurrences, migration is affected by many factors such as social events (FAO, 2009).

Furthermore, Oliver-Smith (1991) points out that decisions to migrate out of rural areas are often based on perceptions of land fertility and the availability of resources. If rural populations feel they are unable to engage in subsistence livelihoods, community members may migrate to urban centres in search of employment opportunities that would better enable them to provide for their families. Such patterns of out-migration are often gendered, with young men leaving rural areas in search of livelihood (Tiwari and Joshi, 2016; Pedraza, 1991). While this is often framed as voluntary labour migration, it could also be considered a pattern of migration that emerges out of necessity, as food insecurity is a direct threat to life (White et al., 2013). Migration has an important secondary effect on the labour market in migrant-sending areas, as the rapid outflow of young people reduces the number of workers available for agricultural labour and other work (Wiggins and Keats, 2014). Rural shrinkage brings about depopulation, population ageing, brain drain, abandonment of land, vacancy and similar issues (Carney, 1998; Liu and Li, 2017).

The industrialisation and mechanisation of agriculture in Turkey, which started in the 1950s, led to significant improvements in the socio-economic structure resulting in the process of internal migration and outside migration since the mid-1960s (ILO, 1997). In the 1950s, Turkish society was engaged in a rapid process of capitalisation and agricultural mechanisation; as a result, the amount of land in rural areas and the size of populations became unbalanced. The labour force was left out of the manufacturing process and began to migrate to large cities (Efe and Uluoglu, 2015). The advent of urbanisation has increased the proportion of the population living in cities significantly. The rapid migration that occurred in Turkey has created a striking imbalance in the rate of rural vs. urban population. Of course, rapid industrialisation is not the only reason for migration.

Broadly speaking, family reasons seem to be the most significant cause for various types of migration all across Turkey. Migration undertaken for individual or financial reasons are the second and third biggest motivators. When viewed across different time periods, migration due to individual reasons has a tendency to increase and migration due to economic reasons has a tendency to decrease (ILO, 1993). Better educational opportunities also lead rural people to migrate.

Our focus on patterns of female migration is critical, since the motivation for migration could differ significantly based on gender. When it comes to women's migration, the decision to exist as an independent individual rather than a part of the family unit necessitates the move to a new location. Another reason for female-specific migration is referred to as "marriage migration." Marriage and moving in with one's children are among the biggest motivators for women's migration. The extremely low marriage age of women in rural areas, and the frequent occurrence of oppression at the hands of male family figures make women desperate to get away and complicate this social problem further. Economic and social factors, access to better healthcare, and willingness to leave villages in favour of cities are other reasons. Agriculture and poverty are very closely related, and women in rural areas suffer from poverty in much greater percentages than men. Currently more than one billion people in the world are estimated to live in poverty; the majority being women who live in developing countries. So the hope of finding a higher standard of living is another reason for women to migrate from rural areas to urban areas. A less commonly encountered reason is women migrating as a matter of preference; whether the migration occurs due to economic reasons to find jobs.

Most of the migrant population in the cities live in slums similar to the villages they hail from (Erman, 2001). Financial and social problems are exacerbated by the poverty and destitution in these areas; case studies have revealed that these risk factors affect women more (Gökbayrak, 2002). However, when migrants arrive at cities they have little choice but to live in rundown locations in unhealthy conditions. Migrant rural women are generally employed in labour-intensive and low-wage jobs such as in the textile manufacturing sector, handiwork, and cleaning.

Studies show that women cannot adequately benefit from prenatal care in areas with large migrant populations due to socio-cultural and psychological factors such as financial status, the environment in which one lives, fear, and other similar emotions (İpekyüz, 1996; Ozen 1996). When primary healthcare services, such as mother and children's health and family planning, is surveyed in terms of access by migrant individuals, they do not seem to derive much benefit from them. For most migrant women from rural areas, having children is highly important due to their traditional culture which places great importance on the continuation of the bloodline, which leads to low rates of utilisation of family planning services. (Ozen, 1996). It is a known fact that obstacles preventing migrant individuals from accessing healthcare include financial reasons, lack of local healthcare providers, lack of health insurance, being a foreigner, legal reasons, lack of access to transport, lack of childcare services for working women, unsuitable working hours, and language limitations (Ertem 1999; Ozen, 1996; Sohng et al., 2002).

When it comes to the dietary habits of migrants, it is observed that they encounter problems providing themselves with adequate and balanced nutrition, and their diet mostly consists of fat and carbohydrates depending on their individual financial circumstances and habits. Physical activity is rare, and women's body mass index is generally higher than men's (Choudry, 1998; Ozen, 1996). Another health problem is the malnutrition encountered in children, which can have serious and even fatal consequences. Studies have shown that the height-weight ratio of migrants' children are negatively affected and are in the lower percentiles (Ertem, 1999; İpekyüz, 1996).

Migration can cause psychological distress as well as physical problems. Mental health issues affect women and children the most. Mental illnesses such as post-traumatic stress disorder can occur in women due to cultural conflicts, changes in family roles, and events such as domestic violence. In children, fear and introversion as a trait of autism are common complaints (Tuzcu and Ilgaz, 2015, İpekyüz 1996).

This study examines how women who migrated to urban Adana province, Turkey, and settled in the city were affected by this process.

MATERIAL AND METHODS

Main material of this study were collected from structured questionnaire which conducted by face to face interviews with women who migrates from rural to Adana province. Also researchers' observations and secondary data were used. Neighborhoods with a high concentration of immigrations are not officially registered in Adana province. However, since it is known by the community which neighborhoods they are concentrated in, these neighborhoods were chosen purposively. From these purposively selected neighborhoods, sample size were determined using Simple Random Sampling Method and to formula to be used in the case of a finite set (N<10000) as follows (Arıkan, 2017).

N:Accessible population

n:Sample size

z:2,58 (99% z-value from the accepted confidence level)

p:The probabality of being able to present population (p=0,80)

q:(1-p) Proportion of the population who doe not have the relevant attribute

d:Accepted sample error (±10% accepted)

The sample size for this study was calculated as 105. But in case of unsuable questionnaires 10 more questionnaires conducted and 115 usable questionnares used in data analysis. Before data collection pre-test was conducted with 20 migrant women and questionnare was revized according the pre-test results. Migrant women selected randomly but neighbourhoods selected purposively.

Data were collected in the late 2018 and early 2019. The survey questionnaire consisted of 46 questions in three parts: The first part contained items to measure the socio-demographic and economic characteristics of the women such as age, family income; family size, living places and etc. In the second part, women were asked to indicate to what extent they participated in the statements about feeling about migration and faced problems on a 3 point Likert type scale (1=None, 2= Some, 3= A lot; 1= Disagree, 2= Some, 3= Agree). The third part included health problems and health service. SPSS 23.00 package was used to analyse the data. The Independent Sample T-test and the One-way ANOVA were performed to reveal the relationships between the variables. The Cronbach Alpha reliability coefficient of the survey was found to be $\alpha = 0.734$.

RESULTS

The average household size was 3,77 person. It is similar to Turkey's avearage household family size which was 3,4 person in 2019 (TUIK, 2019). It is observed that there is a shift from big families to nuclear family. The mean age of women was 39,54 years and 36,50% had a high school diploma. The average household income was 3.676,95TL. More than half of the women (61,7%) migrated from villages and others from districts. They have been living in Adana 15,26 years and 95,7% migrated with their spouses and children. Women choosed their husband with arrangement of their families (87,8%). The majority of women stated that they went to help homes or look after children. Due to their level of education, they find it difficult to find more qualified jobs and often work in unregulated sectors of the economy, such as low paid, low status and service jobs. As UNFPA (2014) declared that migrant women works generally low paid and low status job such as service or house jobs. Almost all of them (98,3%) had a hard time to make this decision but they pointed out that they had no other option but work. They emphasized that it is more difficult for their spouses to find a job and sometimes the family earns a living just by their own income. The majority of women give the income to their husbands, while the remaining few say they spend on family needs. Although the income they receive is neglected at home, women consult their husbands before spending. They stated that they were forced but felt more free and valuable while working. When they moved to Adana, first few days they had to stay with their relatives or friends then found a place to live which is cheap (31,3%), near to their relatives/fellows (34,8%) and their husband preferences (33,9%). They pointed out that not only get help to find a house but also find a job and moral support from relatives/fellows.

Many reasons cause migration. For women, migration means rather than being an independent decision, it is an obligation to move a new place to be with her family. Another migration reason for women is "marriage migration". As seen from Table 1, lack of agricultural land, marriage, find a job and better education for the children were the main factors of migration. It was also found out that 84,3% of women declared that they tried to change their husband decision about migration but they could not changed the result. Women were not independent in their decision to about migration. Men are influential in their decision to migrate.

Table 1. Migration reasons

Factors	None		Some		A lot		Mean	St.d.
	n	%	n	%	n	%		
Lack of agricultural land	0	0,0	74	64,3	41	35,7	2,35	0,48
Marriage	9	7,8	67	58,3	39	33,9	2,26	0,59
Job	0	0,0	85	73,9	30	26,1	2,26	0,44
Education of children	0	0,0	96	83,5	19	16,5	2,16	0,37
Health problems	23	20,0	91	79,1	1	0,9	1,80	0,42
Safety	36	31,3	79	68,7	0	0,0	1,68	0,46
Evacuation of village	94	81,7	21	18,3	0	0,0	1,18	0,39
Plateau ban	104	90,4	11	9,6	0	0,0	1,10	0,29
Vendetta/conflict	105	91,3	10	8,7	0	0,0	1,08	0,28
Natural diasters	105	91,3	10	8,7	0	0,0	1,08	0,28

After the migration decision, women stated that they experienced all emotions such as excitement, fear, joy, sadness. They also faced economic and psychological problems during migration. Migration comes with difficulties that must be dealed with it, such as adaption of city life, strangeness, loneliness, regrets, unemployment, shelter and so on. Table 2 shows that migrant women had to face a lot of difficulties and different feelings. Psychological issues are very important and listed at the top of the list.

Table 2. Difficulties faced and feelings after migration

Difficulties and feelings	None		Some		A lot		Mean	St.d.
		%	n	%	n	%		
Adoption of city life	0	0,0	31	27,0	84	73,0	2,73	0,46
Strangeness	0	0,0	30	26,1	85	73,9	2,73	0,44
Loneliness	13	11,3	29	25,2	73	63,5	2,52	0,69
Regrets	20	17,4	25	21,7	70	60,9	2,43	0,77
Unemployment	0	0,0	78	67,8	37	32,2	2,32	0,47
Shelter	0	0,0	83	72,2	32	27,8	2,28	0,45
Social Isolation	2	1,7	81	70,4	32	27,8	2,26	0,48
Nutrition	0	0,0	87	75,7	28	24,3	2,24	0,43
Longing	7	6,1	75	65,2	33	28,7	2,22	0,55
See herself worthless	10	8,7	70	60,9	35	30,4	2,21	0,59
Fear	17	14,8	80	69,6	18	15,7	2,01	0,55
Safety	23	20,0	75	65,2	17	14,8	1,94	0,59
Education	22	19,1	81	70,4	12	10,4	1,91	0,54
Health	30	26,1	82	71,3	3	2,6	1,76	0,48

Although they have experienced some problems with migration, most of the women do not want to leave the city's opportunities and return. As mentioned before one of the migration reason was the better education opportunities for their kids. Even if women say that the children who grow up in the village are more dependent on their families, they want their children to live in the city for better education and job.Women were asked by whom the decisions on economic, social and family matters are made within the family. As seen from Table 3., 85.2 of the women stated that their husbands usually decide on economic issues, they decide on social issues (48.7%) and decide on family issues together (39.1%).

Table 3. Decision of economic, social and family matters

Person	Economic		Social		Family matters	
	n	%	n	%	n	%
Women	12	10,4	55	47,8	30	26,1
Husband	97	84,4	40	34,8	40	34,8
Together	6	5,2	20	17,4	45	39,1
TOTAL	115	100,0	115	100,0	115	100,0

Nutrition and shelter take the most important place among post-migration problems (Table 4). Approximately 70% of women stated that they consume more carbohydrates. The most important reasons for this are both being cheaper and receiving support (bulgur, flour, chickpea, etc.) from the place they migrated. In terms of housing, women who live in their own homes and in larger houses where they migrate have stated that they have become tenants in worse houses after migration. Stating that the family ties were weakened because of less time spent by the family, the women also emphasized that the kinship relations decreased very much. They indicated that eventhough better health services in Adana they could not get enough because of health insurance. Majority of women (80,9%) smoke cigarette and 24.3% consume alcoholic beverages. Majority of them started to smoke and drink because of stress of migration and problems they faced.

Table 4. Problems of women after migration

	Diasgree		Some		Agree		Mean	St.d
	n	%	N	%	n	%		
I am getting more tired.	5	4,3	22	19,1	88	76,5	2,72	0,53
I consume more canbohydrate (bread, pasta, wheat).	0	0,0	36	31,3	79	68,7	2,69	0,46
My kids don't listen to me.	6	5,2	34	29,6	75	65,2	2,60	0,58
I live in a bad house.	21	18,3	19	16,5	75	65,2	2,47	0,78
We spend less time as a family.	7	6,1	71	61,7	37	32,2	2,26	0,56
Kinship has decreased.	30	26,1	25	21,7	60	52,2	2,22	0,38
I'm having a panic attack.	13	11,3	72	62,6	30	26,1	2,14	0,59
Family ties started to get weak.	37	32,2	70	60,9	8	7,0	1,74	0,57
My position at home decreased.	33	28,7	82	71,3	1	0,9	1,72	0,46
I feel lonely.	42	36,5	65	56,5	8	7,0	1,70	0,59
I'm addicted to home.	1	0,9	77	67,0	37	32,2	1,68	0,48
I cannot get socialized.	39	33,9	76	66,1	0	0,0	1,66	0,47
I'm not getting enough health service.	38	33,0	77	67,0	0	0,0	1,66	0,47
There is no body when I needed.	78	67,8	37	32,2	0	0,0	1,32	0,46

A one-way ANOVA test was conducted to reveal whether education level affects income level. A statistically significant difference found between education level and income level ($F=3,684$; $p<0,028$). LSD post-hoc comparison test reveals that women who had a primary education level had lower income than middle school and high school level. It means that income level increases with the education level

Not only education level but also age might also affect income level. That is why another ANOVA test was conducted between income level and age groups and found that there is positive significant relationship between them (F=6,277; p=0,001). LSD test showed that the lowest income was earned age between 20-30 years. The high income group was aged between 41-50 and over 51 years. It is observed that income level increases with the increasing age.

Earlier the education level of women was lower than current time. To see if there is difference between age and education level ANOVA test also conducted. The test result also showed that there is a positive relationship between age and education level. (F=7,987 p=0,001). LSD test showed that women who had a high school diploma are younger than the women with the primary school education level. It can be said that with the changing social structure, the education level of women has inceased over time.

The events during the migration of women might differ depend on age and may affect the reason of migration. That is why ANOVA test was conducted between migration reason and age groups and found that there is positive significant relationship between them (F=11,009; p=0,000). LSD test showed that the least important reason was marriage between 20-30 years. The reason for migration for this group was education. The highest group was aged between 41-50 and over 51 years. It is observed that marriage migration increases with the increasing age.

CONCLUSION AND RECOMMENDATIONS

Not only in Turkey but also all over the world, more people are on the move more than ever before to have a better life for themselves. Although they have experienced some problems with migration, most of the women do not want to leave the city's opportunities and return their hometown. Also, they want their children to live in the city for better education and job opportunities.

In order to ensure that people do not leave the regions where they live, at least some of the opportunities in the cities should be provided by making investments in the emigrating regions. A successful and stable economy, agriculture, employment, housing and public works policies should be implemented. Importance should be given to infrastructure work in the migrated regions, and unfinished work should be done immediately.

The government and local governments have important duties to make the negative effects of migrations in Turkey. Long-term and determined central policies should be implemented. Public housing applications for low-income citizens who migrate to the city should be increased and they should be provided to live in more modern and contemporary housing. Slums should be prevented.

Unpaid vocational training programs should be increased to women with unskilled labor and entrepreneur women should be supported more. The number and quality of educational institutions should be increased and adequate and qualified education staff should be provided in order to provide better education especially for children. Gender inequality in education should be reduced. The number of literate women should be increased and entrepreneurship trainings should be provided in their regions.

Informative meetings and trainings should be organized to prevent women and children from gaining bad habits (smoking, alcohol, substance). More attention should be given to this issue in the media, especially on television. Because women declared that television and internet had an affect on changing family type from traditional to modern. In order to prevent these habits, children should be encouraged to sport and the areas where they can do sports should be increased. Psychological counseling centers should be established in order to find solutions to the psychological problems that women face during the migration process.

Women who want to divorce should be informed about their legal rights and supported. Because most of the women pointed out that women should not get divorced for social pressure. Improving health facilities in cities, increasing the quality and quantity of health personnel in quality, child and maternal health education should be provided, especially women should be informed about birth control.

As women tend to spend a significant amount of time in the city and in the areas close to their homes, it is important to create spaces where they can engage in outdoor activities and sports. Furthermore, existing locations should be enhanced through environmental regulations such as parks, pathways and sports facilities. To enhance women's awareness of utrition, specialized centers led by by nutrition experts (dietitians) should be established within their communities. These centers can then implement educational programs focused on promoting healthy eating habits.

As a result, more support should be sought for women in rural and urban life because women have more responsibilities. Healthy, conscious women are needed to raise healthy generations. The place and importance of women in the development of the country should not be forgotten and the existing problems should be identified and resolved as soon as possible, the rural-urban balance should be provided and the differences should be minimized. Women are the ones who will migrate; they should be patient and prepared for difficult working conditions.

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Chapter 4

Investigation of Biological Stress in Plants Specific to Drought Stress

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ABSTRACT

Stress, in its true sense, is basically a mechanical concept and has been defined as "the force applied to an object per unit area". However, it is difficult to define the word stress in a biological sense as it is in both a mechanical and psychological sense. Therefore, in a biological sense, stress has been defined by researchers in two ways. The first of these is "everything in the ecosystem that negatively limits all kinds of development, especially the reproduction of the plant", and the second is "an adverse force or effect that tends to prevent the functioning of normal systems". The ability of the plant to survive against unfavorable environmental conditions is "stress endurance" or "stress resistance"; The fact that the organism comes to thermodynamic equilibrium with stress is defined as "stress tolerance". The effects of water deficiency in plants on plants can be examined under five main headings. To these. Membranes and Water Stress, b. Photosynthesis and Water Stress, c. Stomas, Wind and Water Stress, d. Osmotic Regulators and Water Stress e. Root Growth and Water Stress

Key words: water stress, biologicsl stress, stress tolerance, photosynthesis**,** stomatal stress

INTRODUCTION

The constant exposure of the biosphere to abiotic stresses such as drought, salinity, temperature extremes, chemical toxicity, oxidative stress, etc. causes disparity in the natural state of the environment. These stress conditions lead to a series of morphological, physiological, biochemical, and molecular changes in plants, which negatively affect their growth and productivity.

Plants strive to survive by fighting against many stress factors throughout their growth cycle. The loser of this battle dies, while the winner continues to live by further developing the traits (s) that helped them win that battle. For example, trees and shrubs in northern temperate latitudes can survive extremely low temperatures in winter, alpine plants can survive cold, dry winds and high levels of UV radiation, and agriculturally important plants can survive prolonged periods of drought. Today, in addition to the stress factors caused by existing natural phenomena, soil, water and air pollutants caused by human activities have been added to the "environmental stress parameters" that plants must cope with. Excess levels of these parameters create stressful conditions that can have significant effects on plant survival. Therefore, the study of plant responses to environmental stress has long been a major research topic for physiologists and ecologists studying plant-environment interactions.

What is stress?

In daily life, stress is always used to express a negative situation. However, when taken literally, it is basically a mechanical concept and has been defined as "the force applied to an object per unit area.” Another form of expression is “tension.” Stress, as we use in our daily lives, refers to a situation that occurs in conditions that trigger the development of certain biological, physical, and cognitive reactions in the body, which exposes the person to a momentary threat or a problem that requires struggle. In the biological sense, it is difficult to define the word stress as precisely as it is in its mechanical and psychological definition. Nevertheless, J. Levitt argued that this physical terminology could also be used and applied to living organisms (Levitt, 1972; Turner and Kramer, 1980). The concept of stress has more general connotations in biology. For example, "anything of environmental origin that negatively limits all kinds of development, especially the reproduction of the plant in the ecosystem" can be accepted as stress (Grime, 1979; Shabo et al. 2008), " is an adverse force or effect that tends to prevent the functioning of normal systems. ” (Jones and Jones, 1989). Because environmental stress is also mentioned in the definition of biological stress, the issue becomes slightly more complicated. It is difficult to evaluate stress originating from the environment. Studies have shown that the responses of plants to changes in environmental conditions differ by at least as much as plant diversity. For example, are the conditions encountered in deserts or Arctic tundra that are not normal for many plant stress conditions for plants that grow and live and even reproduce there, or is it impossible for these plants to survive elsewhere without those conditions? Therefore, there is no single correct answer for the negative effects of environmental stress factors on plants in scientific studies, and the results of these studies have not received the support of all scientists working in the field of stress physiology (Jones and Jones, 1989). The ability of a plant to survive under unfavourable environmental conditions has been defined as "stress endurance" or "stress resistance" (Levitt, 1980). In short, even this definition has its problems, as it is highly subjective and varies between species and ecotypes.

Biological Stress Avoidance, Stress Tolerance, Stress Adaptation and Adaptation Mechanisms

Many plants can resist stress through stress avoidance or tolerance. Stress avoidance mechanisms are provided by modifications that a plant usually creates in its anatomical structure. With these modifications, even if there is stress in the environment, the effect of the stress is reduced. Examples of these modifications are the deep root systems that plants form to better utilize the water in the soil, to keep the water within the plant and to prevent water loss through evaporation, the thickening of the cuticle layer, the hairs they form on the leaves to reduce the effect of the sun's rays, and the formation of fleshy leaves (Salisbury and Ross, 1992).

On the other hand, Stress tolerance occurs when an organism reaches thermodynamic equilibrium with stress. In other words, the internal and environmental conditions of the plant are balanced. For example, drought tolerance allows the protoplasm of an organism to maintain its average growth and development capacity without damage when rehydrated after drying. The vegetative parts of most plants cannot tolerate even moderate dehydration, whereas the leaves of the fern plant can survive up to 7% water content (Figure 1).

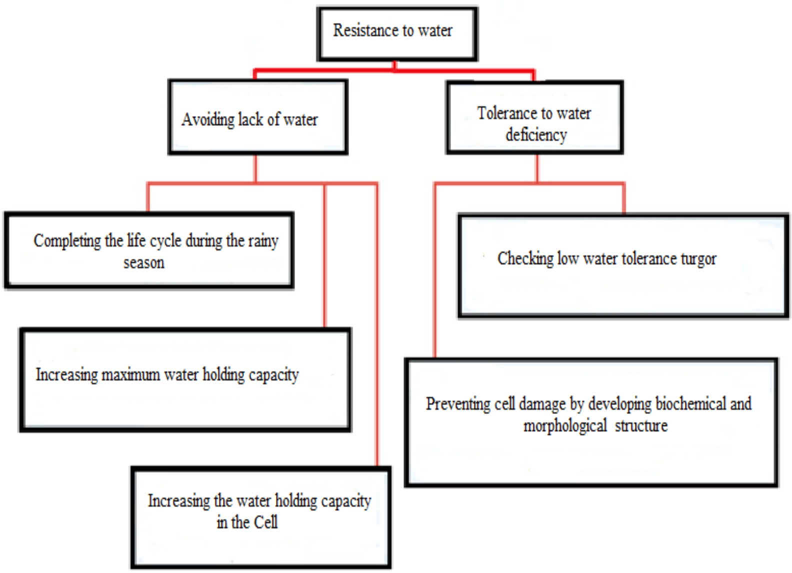

Figure 1. Tolerance and Avoidance in Mechanisms of Resistance to Water Deficiency Stress

The two other terms that require explanation are adaptation and adaptation. Both adaptation and adaptation are means of providing tolerance to a particular stress. Adaptation refers to heritable changes in structure or function that increase an organism's adaptability to stressful environments. Morphological and physiological modifications associated with crassulacean acid metabolism (CAM) in plants are examples of adaptation. Adaptation, on the other hand, refers to the physiological changes that occur in a plant throughout its life, but they are not hereditary (modification). The capacity to adapt is, of course, a genetic trait; however, the specific changes that occur in response to stress are not passed on to the next generation.

Water (Drought) Stress

Drought is the most important source of stress for agricultural production. Drought is one of the most important abiotic stresses affecting plant productivity worldwide, including our country (Oki and Kanae 2006; Osakabe et al.2014). However, many plants have developed morphological and physiological changes that allow them to survive in areas of insufficient rainfall and low soil moisture content. These morphological and physiological changes are planned only for plant survival, and factors such as high yield and quality etc. remain in the background. When water stress is mentioned, the stress caused by an insufficient amount of water is the first thought that comes to mind. However, water stress can also occur in excess water. Excessive water stress is caused by floods or overflows, and in such a case, the oxygen going to the roots of the plant decreases, and oxygen stress actually occurs. Decreased oxygen levels limit respiration, nutrient uptake, and other critical root functions. Stress from a lack of water, as we generally understand it, is much more common, and this phenomenon, which should be correctly expressed as "water-lack stress," is simply abbreviated as "water stress." Because water stress in natural environments is often caused by a lack of precipitation, it is often referred to as drought stress.

Water stress negatively affects plant growth and productivity. Therefore, "water use efficiency" (WUE), a parameter of crop quality and performance under water-deficient conditions, is an important selection trait (Yamaguchi-Shinozaki and Shinozaki, 2006; Ahuja et al., 2010; Skirycz and Inze, 2010; Osakabe et al. , 2011; Nishiyama et al., 2013; Ha et al., 2014).

In order for plants to grow and develop in a healthy way, they need to perform a healthy photosynthesis. However, high light intensity (EL) can also cause a decrease in the leaf/water potential and stomatal opening of the plant. Water stress, which leads to the downregulation of photosynthetic genes and reduced CO2 availability, is one of the main factors in EL stress (Osakabe and Osakabe 2012).

a. Membranes and Water Stress

Damage to cell membranes from water stress is determined by the deleterious effects of this deficiency on the protoplasm. For example, the removal of water may lead to a reduction in the protoplast volume and consequently an increase in the solute concentration in the cell, resulting in metabolic dysfunctions in the plant. Although the extent of membrane damage caused by water stress is not yet known, it has been observed that the removal of water from membranes disrupts the normal bilayer structure (cell wall + cell membrane) and makes it highly porous. When extremely porous membranes are rehydrated, they allow large amounts of solutes from the outside of the cell to leak. Due to the loss of membrane selectivity, cellular compartmentalization is generally disrupted and membrane-based enzymes lose activity. The loss of membrane integrity and protein stability can be exacerbated by a high cellular electrolyte consensus, accompanied by dehydration of the protoplasm. As a result, cell metabolism is impaired.

b. Photosynthesis and Water Stress

Photosynthesis, which is the most important factor for the survival of plants, is particularly affected by water stress. This effect occurred in two ways. First, when the plant senses a lack of water, it closes its stomata to prevent evaporation through transpiration, cutting off the chloroplasts' access to atmospheric carbon dioxide. This situation negatively affects the decrease in photosynthesis, and consequently, the growth and development of the plant. Second, there are direct effects of low cellular water potential on the structural integrity of the photosynthetic mechanism. (Lawlor, 2002; Flexas et al., 2006; Chaves et al., 2009). The direct effect of low cellular water potential on photosynthesis is that it reduces both electron transport activity and photophosphorylation. These effects damage the thylakoid membranes and ATP synthetase proteins.

c. Stomas, Wind and Water Stress

Plants often respond to acute water deficits by closing their stomata to allow water lost by transpiration from leaf surfaces to be reabsorbed and replaced by roots. It has been shown that the opening and closing of stomata in all plants examined to date is dependent on ambient humidity (Mansfield and Atkinson, 1990). Stomatal closure is regulated by hydroactive processes. Hydroactive closure occurs metabolically by reversing ion flow under the influence of Abscisic Acid (ABA) and other hormones. Since its discovery in the late 1960s, ABA has been known to play an important role in the closure of stomata due to water stress, with ABA accumulating in water-stressed (i.e., wilted) leaves (Fig. 2)

How ABA controls turgor in guard cells remains to be determined. Evidence suggests that ABA acts on the outer surface of the plasma membrane. Because no plasmodesmata were found to symplastically connect the guard cells to the mesophyll cells. For this reason, it is thought that ABA can reach the guard cells through apoplastic spaces, not symplastic. However, there are strong indications that ABA interferes with plasma membrane proton pumps and consequently K^+ uptake and stimulates K^+ influx from guard cells. In both cases, the guard cells lose their turgor, causing the stoma to close.

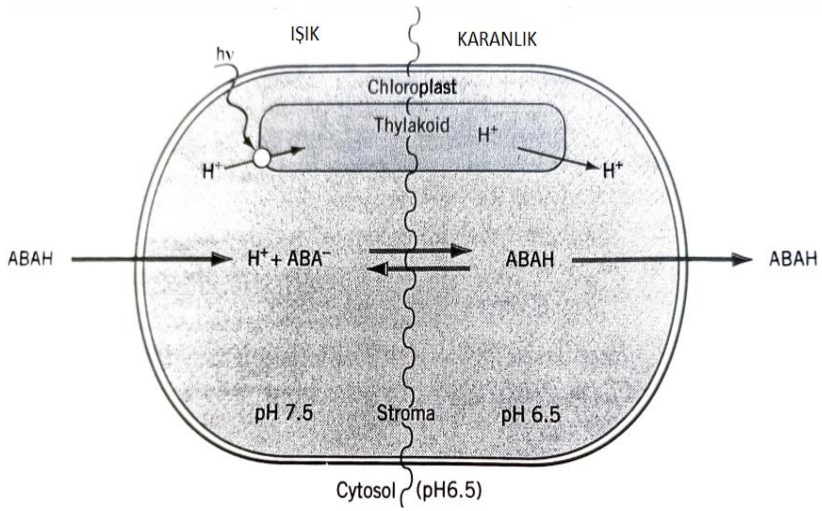

Figure 2. ABA storage in chloroplasts. Photosynthesis in the light creates a pH gradient between the stroma and the cytosol, directing protons into the interior of the thylakoid. The pH gradient favours the movement of ABAH into the chloroplast where it dissociates into ABA. The membrane is less permeable to ABA. In the dark protons leak back into the stroma, the pH decreases and ABAH returns to the cytosol.

Stomatal closure is not always dependent on the perception of a lack of water and the signals that appear in the leaves. In some cases, stomata appear to close in response to soil drying before there is a measurable reduction of turgor in leaf mesophyll cells (Mansfield and Atkinson, 1990). Several studies have shown that there is a feedforward control system that originates in the roots and transmits information to the stoma (Blackman and Davies, 1985; Zhang and Davies, 1987).

It was determined that the wind movement around the plant also provided closure of the stomata. The reason for this is that the moist air layer surrounding the leaf is reduced by the wind. As the wind speed reaches a certain limit, the amount of water lost from the plant by transpiration also increases. In windless weather and especially in the air layer just above the plant leaves, which are not under the direct influence of the sun, the concentration of water vapor increases. As a result, water loss in the form of steam is also reduced, depending on the difference in concentration of water vapor between the air space of the leaf and the air outside the leaf. By removing the water vapor molecules just above the plant leaf, the wind causes the water vapor concentration difference to increase outward from the leaf and thus the amount of water lost in the form of steam increases. The blowing wind not only drags the air with a high water vapor content just above the leaf and replaces it with dry air, but also causes a large amount of water lost in the form of steam as it moves the leaves. A light but continuous wind increases the amount of water that is lost in the form of steam more than a sudden and strong wind. Because when the wind suddenly rises and blows fast, the water transferred to the mesophyll cells through the xylem transmission pipes will not be sufficient, so the stomata close and the amount of water lost in the form of steam decreases. On the other hand, the wind causes a significant cooling effect on the leaves and reduces the amount of water lost in the form of steam by reducing the water vapor concentration difference from the leaves to the outside.

Both hydropassive and hydroactive stomatal closure have demonstrated mechanisms that allow plants to anticipate potential water availability problems, either through excessive loss of transpiration from leaves or chronic but non-lethal soil water deficiency.

d. Osmotic Regulators and Water Stress

Another obvious response to water stress in many plants is the reduction in osmotic potential caused by the accumulation of solutes. This process is known as "osmotic adjustment". Osmotic adjustment creates a more negative leaf water potential, helping to maintain the movement of water towards the leaf, consequently, leaf turgor.

Substances dissolved in the cell slowly accumulate during osmotic adjustment, reducing the rate of osmotic pressure drop created by water loss. Therefore, the decreases in osmotic potential due to osmotic adjustment are relatively small. Osmotic adjustment can play an important role in helping partially wilted leaves regain their turgor after the water problem has been resolved. Osmotic adjustment helps maintain leaf turgor, allowing plants to keep their stomata open and continue to receive CO2 for photosynthesis under moderate water stress conditions. However, osmotic regulators cannot provide the desired success in every plant. For example, while the success rate is high in sugar beet (Beta vulgaris), it is low in cowpea (Vigna unguiadata).

e. Root Growth and Water Stress

One of the early effects of water deficiency in plants is a decrease in vegetative growth. Shoot growth, and especially leaf growth, is more sensitive than root growth. For example, when the maize (Zea maize) plant was not watered, it was observed that there was a significant reduction in leaf expansion when the water potential in the plant tissues dropped to -0.45 MPa and growth stopped completely at -1.00 MPa. However, the same sensitivity was not observed in root tissues, normal root growth continued until the water potential of root tissues reached -0.85 MPa, and stopped when it dropped to -1.4 MPa (Westgate and Boyer, 1985).

It is not always possible to observe a direct relationship between cell growth and turgor in stressed plants. Therefore, it is necessary to investigate these underlying mechanisms. For example, while the water potential of corn leaves decreased in response to water stress, the water potential of the xylem decreased as well. The movement of water into the leaf depends on the maintenance of the water potential gradient between the xylem and the leaf. The reduced water potential in the xylem will reduce the magnitude of the xylem-leaf gradient, while there will be enough water in the leaf to maintain turgor, and insufficient water will be available to sustain cell growth. Studies have shown that to detect increases in solute concentration in tissues experiencing water stress, the growth rate must first decrease, and this increase cannot be detected until the growth rate begins to decrease (Matthews et al., 1984; Van Volkenburgh and Boyer, 1985).
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Chapter 5

Biochemical Compositions and Molecular Weight Profiles of Macroalgae

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ABSTRACT

Depending on the population growth in the world, there is an increase in food and energy demand. This situation causes climate changes. In order to meet the food and energy demand, studies on the search for sustainable resources other than existing resources are increasing. Decreases in water resources and agricultural areas due to climate changes make sea areas attractive.

Macroalgae are under 3 main groups as red, brown and green. In addition to the production in the form of collection from nature, there has been an increasing interest in their culture under controlled conditions in order to ensure the sustainability of macroalgae. It is closely related to the biochemical (such as ash, lipid, protein and carbohydrate) and molecular weight profiles where the macroalgae produced has the potential to be used in industries.Today, it is of great importance to use algae not only as nutrients but also as alternative raw materials in feed, fertilizer, medicine, cosmetics and textile industries. In particular, it is known that macroalgae containing bioactive peptides used in medicine have many properties such as antifungal, antiviral and antibacterial.

This review focuses on ash, lipid, protein and carbohydrates contents of 34 green, 85 brown and 93 red macroalgae. In addition, the molecular weight (MW) profiles of soluble proteins of macroalgae, which has attracted attention in recent years, were evaluated with data from the current literature. Further studies on the use and production of these naturally economic resources as raw materials in different fields should be encouraged**.**

Keywords: Red Macroalgae, Green Macroalgae, Brown Macroalgae, Biochemical Composition, Molecular Weight Profiles

Introduction

Experts draw attention to the fact that if the population increase continues at this rate, the world population will be 9.8 billion in 2050. They predict that this will primarily cause climate change as well as food and energy crises (Aratboni et al., 2019). Researchers have turned to alternative sources in order to meet the food demand arising from the expected population growth. At the same time, the decrease in agricultural areas and water resources due to climatic changes has made the use of marine areas attractive, therefore macroalgae production has gained importance (Kazir et al., 2019). Cai et al. (2021) indicated that macroalgae production supported by aquaculture increased to 34.7 million tonnes.

Macroalgae have 3 main phylum of such as Red Algae (Rhodophyta), Brown Algae (Phaeophyta) and Green Algae (Chlorophyta) (Shannon and Abu-Ghannam, 2019). Macroalgae are also used as raw materials in various industries due to their biochemical composition and the bioactive components (such as antioxidant, antibacterial, antiviral, anticarcinogenic, etc.) (Mchugh, 2003; Baytaşoğlu and Başusta, 2015; Ak et al., 2015; Vizetto-Duarte et al., 2016; Lorenzo et al., 2017; Ranga Rao and Rravishankar, 2018; Sørensen et al., 2019; Berik and Çankırılıgil, 2022; FAO, 2020). Macroalgae are thought to be an excellent protein source with the potential to replace animal and vegetable protein sources in future (Garcia-Vaquero and Hayes, 2016; Øverland et al., 2019). Also, macroalgae are ecologically and biologically important. (Özdemir and Erkmen, 2013; Kasimala et al., 2015)

The biochemical compositions of macroalgae are different from terrestrial plants and are affected by abiotic factors, especially the physico-chemical composition of water. Researchers stated that it is important to have information about the biochemical composition of algae as well as reveal their potential for use in various industrial areas (Burtin, 2003; Kaykaç, 2007; Mohamed et al., 2012). Researchers have revealed that the most important biochemical components of macroalgae are ash, lipid, protein and carbohydrates (McDermid and Stuercke, 2003; Omar et al., 2013; Fleurence et al., 2018). This review focuses on ash, lipid, protein and carbohydrates contents of 34 green, 85 brown and 93 red macroalgae. In addition, the molecular weight (MW) profiles of soluble proteins of macroalgae, which has attracted attention in recent years, were evaluated with data from the current literature.

Biochemical Composition of Macroalgae

Ash

Inorganic materials known as mineral elements, defined as ash, consist of parts that are outside of organic matter (Apriyantono et al., 1989). Although it has no nutritional value, many elements in ash have been reported to be essential for metabolic reactions (Rupérez, 2002, Hernández-Herrera et al., 2014; Briceño-Domínguez et al., 2014).

Davis et al. (2003) revealed that marine macroalgae are usually much higher than those in terrestrial sources because of their cell wall are excellent binding sites for metal retention. Handayani et al. (2004) indicated that the ash content of macroalgae changes by the amount of mineral absorbed. Rupérez (2002) and Gazali et al. (2018) showed that ash contents of macroalgae depend on the species, geographical, environmental factors.

Matanjun et al. (2008) and Serrano et al. (2015) showed that the high ash content of macroalgae is indicative of the presence of various mineral components. In the spring months, increases are seen in the amount of nutrient salts transported to the marine environment. Similar to protein fluctuations, while the ash contents of macroalgae are high, it decreases depending on the use of nutritional salts (Topçu, 2013).

Lipid

It is known that lipids ensures high level of energy in oxidation process than those of other biological compounds.

The lipid levels of macroalgae are very low compared to other seafoods (Morales, 2005; Marsham et al., 2007; Polat and Ozugal, 2008; Manivannan et al., 2008; Ivanova et al., 2013). For this reasons, macroalgae may not be a commercially attractive target for lipid production. Although the lipid content of macroalgae is low, their polyunsaturated fatty acid content is equal or higher than those of terrestrial plants (Ragonese et al., 2014; Maghraby and Fakhry, 2015).

Researcher revealed that the factors affecting lipids of macroalgae are seasonal period, habitats, species and maturity (Ito and Hori, 1989; Jensen, 1993, Lobban and Harrison, 1994; Fleurence, 1999, Kumari et al., 2010). Nelson et al. (2002) showed that the lipid contents of macroalgae are higher in the winter and spring but not the summer.

Chakraborty and Bhattacharya (2012) pointed out that the amount of lipids in macroalgae can change according to the density of the elements in their environment. Ahmad et al. (2012) determined that brown macroalgae have high lipid amounts according to red and green macroalgae species.

Protein

It is known that proteins have important functions in all the metabolic processes. Previous studies showed that algal proteins could be considered as alternative sources for human and animal nutrition because of essential amino acids is good levels (Fleurence, 2004; Becker, 2007). The protein amounts of macroalgae were higher than those of traditional protein sources, including milk (3.4%) (Staples and Thatcher, 2016; Gellrich et al., 2014). Also, Bleakley and Hayes (2017) indicated that production of macroalgae is more advantageous than terrestrial plants when evaluated in terms of productivity.

Researcher revealed that highest protein contents were generally found in green and red macroalgae in comparison to brown macroalgae (Arasaki and Arasaki, 1983; Darcy-Vrillon, 1993 ; Burtin, 2003; Fleurence, 2004; Sánchez-Machado et al., 2004; Marsham et al., 2007 ; Holdt and Kraan, 2011; Ibañez and Cifuentes, 2013; Zhou et al., 2015 ;Bleakley and Hayes, 2017; Wells et al., 2017; Øverland et al., 2019; Biris-Dorhoi et al., 2020). Changes in the protein contents of macroalgae could be due to factors such as maturity, species, seasons and geographic area (Sánchez-Machado et al., 2004; Marinho-Soriano et al., 2006; Dawczynski et al., 2007a,b; Stirk et al., 2007; Gressler et al., 2010; Chinnadurai and Kalyanasundaram, 2013). It has been noted by Cirik and Cirik (2017) that the protein amount of macroalgae collected in summer months is lower than in winter months due to seasonal nutritional fluctuations.

On the other hand, there are debates about the determination of protein amounts of macroalgae in present. The widely used method is Kjeldahl. According to this method, the nitrogen content of the samples is determined and converted to protein value using a conversion factor. However, some macroalgae have significant sources of non-protein nitrogen. For this reason, the most appropriate conversion factor to be used for each type of macroalgae is still not clear. Researchers state that this factor should be determined for each macroalgae (Salo-vaananen and Koivistoinen, 1996; Lourenco et al., 1998; Fujihara et al., 2001 ; Ezeagu et al., 2002). Nitrogen-to-protein conversion factors of green, brown, and red macroalgae were defined as 5.13, 5.38 and 4.92 by Lourenco et al. (2002).

Carbohydrates

The carbohydrates included in macroalgae turn them into an important source of nutrients. Also,carbohydrates provide energy for important metabolic processes (Dawczynski et al., 2007a,b; Khairy and El-Shafay, 2013; Kokilam et al., 2013; Gokulakrishnan et al., 2015). The carbohydrates of macroalgae is usually related with fiber which cannot be digested by digestive enzymes

(Radiena, 2018; Tapotubun, 2018). Polysaccharides such as agar, carrageenan, ulvan, fucoidan found in the cell walls of macroalgae are not digested by digestive enzymes, so they are a good fiber source and prebiotic (Wells et al., 2017)

Carbohydrate amounts of macroalgae could change according to the physiological state, temperature, salinity, pH, light intensity and geography, species and season (Munda and Kremer, 1977; Perfeto, 1998; Marinho-Soriano et al., 2006; Holdt and Kraan, 2011; Mendis and Kim, 2011; Sakthivel and Devi, 2015). Haroon et al. (2000) revealed that higher photosynthetic activity in the spring and summer months resulted in higher carbohydrate content. Rodde et al. (2004), indicated that the amount of carbohydrates reached the highest levels in the summer months. Marinho-Soriano et al. (2006) revealed that while carbohydrates of macroalgae tended to decrease protein and lipid content, light intensity and temperature had a positive effect on carbohydrate concentration.

Ortiz et al. (2006) indicated that carbohydrate contents of red and green macroalgaes were higher that of brown macroalgae, however, iodine and soluble fiber contentsof brown macroalgae were higher than those of other macroalgae groups. Previous studies showed an inverse relationship between proteins and carbohydrates in macroalgae (Mouradi-Givernaud et al., 1993, Marinho-Soriano et al., 2006, Kumar et al., 2015a,b).

Table 1, Table 2 and Table 3 shows the ash, lipid, protein and carbohydrate values of Green, Brown and Red macroalgae, respectively. Within the scope of the study, 34 green, 85 brown and 93 red macroalgae species were evaluated.

The lowest and highest values of ash, lipid, protein and carbohydrate belonging to Green macroalgae were 10,64% (*Caulerpa racemosa*)- 69,72% (*Codium bursa*), 0,15% (*Caulerpa racemosa*)- 18,1% (*Caulerpa racemosa*), 2,48% (*Codium bursa*)- 40,87% (*Lola capillaris*), 14,6% (*Ulva lactuca*)- 67,4% (*Caulerpa racemosa*), respectively.

The lowest and highest values of ash, lipid, protein and carbohydrate belonging to Brown macroalgae were 7,3% (*Cystoseira compressa*)- 72,02% (*Padina pavonica*), 0,02% (*Halopteris scoparia*)- 18,4% (*Padina tetrastromatica*), 1,2% (*Stypopodium schimperii*)- 35,4% (*Padina pavonica*), 3,73% (*Sargassum filipendula*)- 90,01% (*Sargassum polycystum*), respectively.

The lowest and highest values of ash, lipid, protein and carbohydrate belonging to Red macroalgae were 5,8% (*Pyropia acanthophora*)- 85,61% (*Tricleocarpa fragilis*), 0,12% (*Jania rubens*)- 8,88% (*Porphyra sp.*), 1,38% (*Jania rubens*)- 44% (*Porphyra tenera*), 4,28% (*Hypnea japonica*)- 86,58% (*Gracilaria edulis*), respectively.

The lowest and highest ash, lipid and carbohydrate amount were observed in red, brown and brown macroalgae, respectively.The highest protein amount was red macroalgae while the lowest protein amount was in brown macroalgae.

Øverland et al. (2019) showed that ash, lipid and protein changes of green, brown and red macroalgae were 11-55%; 0,3-2,8%; 3,2-35,2%, 15-45%; 0,3-9,6%; 2,4-16,8% and 12-42,2; 0,2-12,9; 6,4-37,6. When the values observed in the current study are compared with Øverland et al.(2019), it is noteworthy that the ash, lipid and protein values in the current study are in lower and higher ranges.

Table 1. Biochemical compositions of Green Algae (%)

S	A	L	P	C	R
Bryopsis corticolans	30.17	6.52	38.2		Pirian et al., 2020
Caulerpa lentillifera	14.1-37.15	0.17-1.11	10.41-12.49	53.08-59.27	Ratana-Arporn and Chirapart, 2006 Matanjun et al., 2009 Ahmad et al., 2012
Caulerpa prolifera	12.19	1.74	6.7		Naz et al., 2022
Caulerpa racemosa	10.64-45.34	0.15-18.1	10.52-29.1	48.97-67.4	Ahmad et al., 2012 Bhuiyan et al., 2016 Lalitha and Dhandapani, 2018 Pirian et al., 2020 Kasimala et al., 2020
Caulerpa sertularioides	29.1-41.18	1.1-13.04	11.15-35.06	24.05	Gosch et al., 2012 Lalitha and Dhandapani, 2018 Kasimala et al., 2020 Pirian et al., 2020
Chaetomorpha linum	17.68-45.38	1.76-4.84	5.56-19.29	39.87	Anh, 2020 Saygılı et al., 2022 Naz et al., 2022
Cladophora crispula	24.75	0.81	11.94	48.48	Anh, 2020
Cladophora glomerata	17.87-30.36	0.2-1.1	16.36-20.82	14.83-24.2	Manivannan et al., 2009 Mehdipour et al., 2014
Cladophora patentiramea	20.87	1.43	17.34	45.21	Anh, 2020
Cladophora rupestris	20.7		18.4	39.9	Olsson et al., 2020
Cladophora socialis	22.85	1.27	17.73	43.76	Anh, 2020
Cladophora sp	23.07-36.5	0.96	13.68-13.9	34.8-48.38	Olsson et al., 2020 Anh, 2020
Codium bursa	29.08-69.72	0.89-0.95	2.48-5.03		Frikha et al., 2011 Saygılı et al., 2022
Codium fragile	21.79-54.31	1.53-9.63	2.54-12.5	64.3	Irkin, 2009 Turan et al., 2015 Saygılı et al., 2022
Codium tomentosum	35.99	2.53-10.4	6.13-18.8	20.47	Manivannan et al., 2008 Rodrigues et al., 2015 Lalitha and Dhandapani, 2018

S	A	L	P	C	R
Enteromorpha clathrata	31.28-39.42	0.8-1.79	13.64	22.97-28.97	Kasimala et al., 2017 Kasimala et al., 2020
Enteromorpha compressa	26.36-34.12	0.81-1.3	12.27-13.61	17-46.11	Manivannan et al., 2009 Kasimala et al., 2020 Oucif et al., 2020
Enteromropha intestinalis	22.4-25.08	0.71-7.13	6.15-28.08	21.7-35.5	Chakraborty and Santra, 2008 Rohani-Ghadikolaei et al., 2012 Mehdipour et al., 2014
Enteromorpha sp.	32.64-36.38	2.24-2.27	9.45-14.1		Aguilera-Morales et al., 2005
Halimeda macroloba		0.26	28.94	17.2	Manivannan et al., 2009
Halimeda opuntia	37.28	1.42	7.2	24.85	Kasimala et al., 2020
Halimeda tuna		3.53	23.12	17.12	Manivannan et al., 2009
Lola capillaris		4.05	40.87	22.32	Chakraborty and Santra, 2008
Rhizoclonium kochianum	19.29	0.82	12.58	54.19	Anh, 2020
Rhizoclonium riparium		3.37	21.09	15.34	Chakraborty and Santra, 2008
Rhizoclonium sp	20.9	2.09	18.31	45.75	Anh, 2020
Ulva compressa			25.72-27.52		Patarra et al., 2011
Ulva fasciata		2.96	9.56		Ismail, 2017
Ulva İntestinalis	27.49-31.9	0.64-8	9-17.9	36.7	Benjama and Masniyom, 2011 Aras and Sayın, 2020 Olsson et al., 2020 Saygılı et al., 2022
Ulva lactuca	12.37-55.4	0.33-7.87	3.25-20.12	14.6-50.66	Wong and Cheung, 2000 Manivannan et al., 2008 Yaich et al., 2011 Khairy and El-Shafay, 2013 Turan et al., 2015 D'Armas et al., 2019
Ulva pertusa	27.2	4.8	15.4		Benjama and Masniyom, 2011
Ulva reticulata	17.58	0.75	13.47-21.06	15.37-55.77	Ratana-Arporn and Chirapart, 2006 Manivannan et al., 2009
Ulva rigida	14.71-52	0.3-5.94	6.4-25.98	18.1	Foster and Hodgson, 1998 Kaykaç et al., 2008 Irkin, 2009 Berik et al., 2022
Ulva sp.	28.77-29.6	0.38-3.4	9.24-33.6	33.6-49.09	Pycke et al., 2015 Jatmiko et al.,2018 Diken, 2018

S: Species; **A:**Ash; **L:**Lipid; **P:**Protein; **C:**Carbohydrate; **R:**References

Table 2. Biochemical compositions of Brown Algae (%)

S	A	L	P	C	R
Ascophyllum nodosum	20.2-30.89	3.62	5.9-8.7	31.7	Lorenzo et al.,2017 Olsson et al., 2020
Bifurcaria bifurcata	31.68	6.54	8.92		Lorenzo et al.,2017
Chnoospora minima		0.45	7.11	42.98	Kokilam et al., 2013
Chorda filum	39		6.3	29.2	Olsson et al., 2020
Cladostephus hirsutus	41.78	1.39	7.65		İrkin and Erduğan, 2017
Colpomenia sinuosa	28.1	1.5-2.33	9.2	22.46-32.1	Manivannan et al., 2008 Rohani-Ghadikolaei et al., 2012
Costaria costata	29.25-38.19	0.4-2.21	9.77-18.15		Wu et al., 2014
Cystoseira abies-marina			6.69-6.94		Patarra et al., 2011
Cystoseira baccata	19.1	10.92	12.46	57.52	Vizetto-Duarte et al., 2016
Cystoseira barbata	14.24-38.3	0.46-4.1	5.6-18.73		Kaykaç, 2007 Irkin, 2009 Frikha et al., 2011
Cystoseira compressa	7.3-24.61	2-9.45	9.5-14.14	35.45-73.09	Vizetto-Duarte et al., 2016 Oucif et al., 2020 Uslu et al., 2021
Cystoseira corniculata	28.97	5.45	30.43		Polat and Ozogul, 2009
Cystoseira hakodatensis		4.96	15.59		Nomura et al., 2013
Cystoseira humilis	20.35	5.22	10.34	64.09	Vizetto-Duarte et al.,2016
Cystoseira nodicaulis	13.45	4.31	9.2	73.04	Vizetto-Duarte et al.,2016
Cystoseira osmundacea	33.9	1.08	9.1		De la Garza et al., 2019
Cystoseira stricta	32.04	1.83	8.91	39.62	Oucif et al., 2020
Cystoseira tamariscifolia	23.85	9.57	12.52	54.06	Vizetto-Duarte et al., 2016
Cystoseira myrica	27.96-36.75	0.11-0.92	2.81-10.35	20.56-78.7	Alwaleed et al., 2019 Fouda et al., 2019 Kasimala et al., 2020
Desmarestia aculeata	25.4		11.5	30.1	Olsson et al., 2020
Dictyota ceylinica		2.61	3.33	18.52	Chakraborty and Santra, 2008
Dictyota ciliolata	50.91	0.51	7.66	24.25	Kasimala et al., 2020
Dictyota dichotoma	17.57-45.19	0.67-12.7	8.16-15.41	10.63-22.02	Polat et al., 2012 Parthiban et al., 2013 Kasimala et al., 2020
Ecklonia arborea	23	0.56	11.1		De la Garza et al., 2019

S	A	L	P	C	R
Egregia menziesii	33.1	0.67	11.8		De la Garza et al., 2019
Eisenia arborea (blades)	21.72-33.72	0.15-0.25	11.42-12.52		Landa-Cansigno et al., 2017
Ericaria amentacea	21.38	5.83	9.75		Naz et al., 2022
Fucus serratus	20.3		7.1-17.4	28.7	Marsham et al., 2007 Olsson et al., 2020
Fucus sp.	29.7	4.9	11.9	53	Pycke et al., 2015
Fucus spiralis	22.31	5.23	9.71-10.97	17.59	Patarra et al., 2011 Paiva et al., 2014
Fucus vesiculosus	20.71-24.4	3.75	7.1-12.99	26.6	Lorenzo et al., 2017 Olsson et al, 2020
Halidrys siliquosa	17.6		7.9	23.7	Olsson et al, 2020
Halopteris filicina	27.73	1.94	5.56		İrkin and Erduğan, 2017
Halopteris scoparia	17.35-28	0.02-2.85	7.45-9.79		Polat et al., 2012 Uslu et al., 2021
Hizikia fusiforme		1.4	11.6		Dawczynski et al., 2007a,b
Hormophysa cuneiformis	26.81	0.84	6.42	40.57	Ahmad et al., 2012
Hormophysa triquetra		0.11	15.34	49.06	Kokilam et al., 2013
Laminaria digitata	16.8		6.6-15.9	51.9	Marsham et al., 2007 Olsson et al., 2020
Laminaria sp.		1	7.5		Dawczynski et al., 2007a,b
Lyengaria stellata	33.68	0.27	8.16	34.8	Mohammadi et al., 2020
Nizamuddinia zanardinii	15.84	0.41	3.18	29.1	Mohammadi et al., 2020
Padina borengesnii	30.3	0.56	7.08	26.25	Kasimala et al., 2020
Padina gymnospora	45.04-45.08	0.13-1.4	4.13-17.08	21.88-41.66	Manivannan et al., 2008 Ahmad et al., 2012 Fouda et al., 2019
Padina pavonica	22-72.02	0.67-5.89	4.2-35.4	14.73-43.39	Manivannan et al., 2009 Polat and Ozogul., 2009 İrkin and Erduğan., 2017 D'Armas et al., 2019 Uslu et al., 2021 Saygılı et al., 2022
Padina tetrastromatica		0.55-18.4	1.26-11.39	50.9-59.3	Sethi, 2012 Kokilam et al., 2013
Petalonia fascia	18.42-27.23	1.21-4.21	12-23.87		Çetingül, 2001 Irkin, 2009 İrkin and Erduğan, 2017

S	A	L	P	C	R
Pterygophora californica	30.1	0.55	9.6		De la Garza et al., 2019
Saccharina japonica	31	2.61	13		Jurković et al.,1995
Saccharina latissima	11.8		6.9	55.7	Olsson et al., 2020
Saccorhiza polyschides	28.15	1.1	14.44		Rodrigues et al., 2015
Sargassum acinarum	32.01	0.3	6.3		Polat et al., 2012
Sargassum aspirofolium	19.6	0.17	3.5	39.25	Fouda et al., 2019
Sargassum boveanum	49.14	2.02	21.33		Pirian et al., 2020
Sargassum crassifolium	41.52	0.3	6.21	3.79	Dewinta et al., 2020
Sargassum cristaefolium	41.28	0.25	8.54	7.25	Dewinta et al., 2020
Sargassum filipendula	44.29		8.72	3.73	Robledo and Pelegrin, 1997
Sargassum fusiforme	27.2-37.76	3.52-4.61	8.46-11.98		Li et al., 2018
Sargassum horneri	21.8-36.7	0.1-10.19	5.64-12.8		Murakami et al., 2011 Nomura et al., 2013
Sargassum horridum	28.02-39.56	0.1-0.4	5.25-8.4	44.15-57.7	Di Filippo-Herrera et al., 2018
Sargassum ilicifolium	29.9	2	8.9	32.09	Rohani-Ghadikolaei et al., 2012
Sargassum kjellmannianum	17.83-19.49		11.7-15.09		Li et al., 2012
Sargassum latifolium	26.16	0.27	4.38	41.42	Fouda et al., 2019
Sargassum linearifolium	26.86	1.42	6.93	27.82	Kasimala et al., 2017
Sargassum linifolium		2.16	14.89		Ismail, 2017
Sargassum muticum	20.68-41				Shekhar et al., 2012 Jard et al., 2013 Hardouin et al., 2014 Rodrigues et al., 2015 Fouda et al., 2019
Sargassum oligocystum	21.27-22.54	3.51-5.66	7.12-9.26		Praiboon et al., 2018
Sargassum polycystum	21.87	0.45-0.71	5.85-7.78	34.93-90.01	Ahmad et al., 2012 Alwaleed et al., 2019
Sargassum sp.	26.95-27.94	0.91-1.37	20.6-20.69		Diken, 2018 Yenmiş and Naz, 2018
Sargassum subrepandum	26.86-29.49	1.42-3.61	3.2-6.93	10.21-28.11	Abou-El-Wafa et al., 2011 Kasimala et al., 2020
Sargassum tenerimum		1.46	12.42	23.55	Manivannan et al., 2008
Sargassum vulgare	13.19-33.97	0.45-12.21	6.16-15.76	34.18-67.8	Marinho-Soriano et al., 2006 İrkin and Erduğan, 2017 Arguelles et al., 2019 Aras and Sayın, 2020 Naz et al., 2022

S	A	L	P	C	R
Sargassum wightii	15-22	0.21-3	8-15.1	23.5-40.21	Manivannan et al., 2008 Kokilam et al., 2013 Kumar et al., 2015b
Scytosiphon simplicissimus	53.05	1.96	23.56		Irkin, 2009
Silvetia compressa	24.9	2.93	10.4		De la Garza et al., 2019
Sirophysalis trinodis	22.57	1.27	14.64		Pirian et al., 2020
Spatoglossum asperum		3.14	11.03	6.55	Pandithurai and Murugesan., 2014
Spatoglossum scroederi	34.58	3.07	5.21	40.04	D'Armas et al., 2019
Sphacelaria cirrosa	28.8		12	26.7	Olsson et al., 2020
Stypopodium schimperii	15.57-23	6.36-11.58	1.2-15.29		Polat and Ozogul, 2008 Polat and Ozogul, 2013 Uslu et al., 2021
Taonia atomaria	15.15	4.64-5.92	8.8-12.57	19.5	Polat et al., 2012 El-Sheekh et al., 2020
Turbinaria conoides	21.37	0.59	7.4	23.9-41.03	Manivannan et al., 2008 Ahmad et al., 2012
Turbinaria ornata		1.67	14.68	17.49	Manivannan et al., 2009 Parthiban et al., 2013
Turbinaria sp.	23.98	0.2	3.88	26.85	Fouda et al., 2019
Undaria pinnatifida	28.3	1-4.5	11-24		Dawczynski et al., 2007a,b Fleurence, 2004 Taboada et al., 2013
Zanardinia prototypus	36.75	6.75	11.19		İrkin and Erduğan, 2017

S: Species; **A:**Ash; **L:**Lipid; **P:**Protein; **C:**Carbohydrate; **R:**References

Table 3. Biochemical compositions of Red Algae (%)

S	A	L	P	C	R
Acanthophora nayadiformis	24.47	2.19	1.71		Polat and Ozogul, 2009
Acanthophora spififera	28.38	0.55	5.07	23.54-44.76	Manivannan et al., 2008 D'Armas et al., 2019
Agarophyton vermiculophyllum	19.6-24.5	1.2-2	6.2-21.6	37.6-48.9	Afonso et al., 2021
Ahnfeltia plicata	23.2		20.1	30.2	Olsson et al., 2020
Amphiroa rigida	81.23	0.24	2.05		Saygılı et al., 2022
Brogniartella byssoides	41.9		15.8	24	Olsson et al., 2020
Carradoriella elongata	42.89	1.87	5.31		Okudan et al., 2022
Catenella repens		0.17-5.29	2.78-16.03	21.52-35.74	Chakraborty and Santra, 2008 Banerjee et al., 2009
Centroceras clavulatum	36.69	0.75	4.78	32.24	D'Armas et al., 2019
Ceramium ciliatum	44.04-65.09	0.83-1.63	8.03-24.96		İrkin and Erduğan, 2017
Ceramium diaphanum	11.35	1.18	14		Frikha et al., 2011
Ceramium rubrum	37.05	0.36	22.72		İrkin and Erduğan, 2017
Ceramium sp.	32.8		15.8	35.2	Olsson et al., 2020
Chondracanthus acicularis	33.34	2.07	11.48		Irkin, 2009
Chondria dasphylla	48.54	0.6	7.64		İrkin and Erduğan, 2017
Chondrus crispus	27.2		10.3	52.6	Olsson et al., 2020
Corallina elongata	76.42	0.33-0.64	5.85-8	6.7-13.4	El-Sheekh et al., 2020 Oucif et al., 2020
Coralina mediterranea	39	2.1	17.1	26.6	Mohy El-Din, 2019
Corallina officinalis	74.04-76.93	1.37-2.49	4.01-6.18		İrkin and Erduğan, 2017 Ismail, 2017
Corallina panizzoi	74.04	2.32	6.05		Irkin, 2009
Cystoclonium purpureum	38.6		17.2	31.5	Olsson et al., 2020
Dasya rigidula	24.31-40.59	1.9-2.51	14.57-23.5		Polat and Ozogul, 2013
Delesseria sanguinea	31.2		18.3	25.9	Olsson et al., 2020
Digenea simplex		2.3	21.14	42.40	Alwaleed et al., 2019
Dilsea carnosa	24		15.2	47.7	Olsson et al., 2020
Ellisolandia elongata	76.44-76.75	0.19-0.43	5.21-6.05		Aras and Sayın, 2020 Saygılı et al., 2022
Eucheuma cottonii	46.19	1.1	9.76	26.49	Matanjun et al., 2008
Eucheuma denticulatum	28.79	0.54	7.65	57.79	Ahmad et al., 2012

S	A	L	P	C	R
Euchema spinosum	45.77	5.62	7.48	41.18	Sofiana et al., 2020
Furcellaria lumbricalis	32.9		17.1	29.7	Olsson et al., 2020
Galaxaura rugosa	38.31-72.97	0.53-4.02	5.34-17.82	16.91	Rasyid and Handayani, 2019 Pirian et al., 2020
Gelidiella acerosa	13.42	0.54-3.83	8.66-31.07	14.34-68.97	Chakraborty and Santra 2008 Manivannan et al., 2009 Rasyid and Handayani, 2019
Gelidium microdon			14.61-15.75		Patarra et al., 2011
Gelidium pristoides	14	0.9	11.8	43.1	Foster and Hodgson, 1998
Gelidium pusillum	21.15	2.16	11.31	40.64	Siddique et al., 2013
Gelidium spinosum	35.55	2.08	14.34		İrkin and Erduğan, 2017
Gigartina acicularis	33.34-48.1	1.85-3.13	11.48-13.3		İrkin and Erduğan, 2017
Gracilaria birdiae	22.5	1.3	16.2		Gressler et al., 2010
Gracilaria bursa-pastoris	31.28-56.09	0.43-2.15	5.95-15.9		Irkin, 2009 İrkin and Erduğan, 2017 Okudan et al., 2022
Gracillaria canaliculata	37.52	0.29	11.18	19.15	Kasimala et al., 2020
Gracilaria cervicornis	7.72	0.43	22.96	63.12	Marinho-Soriano et al., 2006
Gracilaria changgi	22.7-40.3	0.3-3.3	6.9-12.6	41.5	Norziah and Ching, 2000 Chan et al., 2014
Gracilaria cornea	29.06		5.47	36.29	Robledo and Pelegrin, 1997
Gracilaria corticata	23.1-51.16	0.2-1.8	12.18-19.3	23.53-43	Rohani-Ghadikolaei et al., 2012 Kasimala et al., 2017
Gracilaria crassa	43.2	1.3-1.99	5.2	17.07-42	Manivannan et al., 2009 Baghel et al., 2014
Gracilaria domingensis	23.8	1.3	13.8		Gressler et al., 2010
Gracilaria edulis	7.6-7.83	0.86-0.9	1.98-14.3	32.4-86.58	Debbarma et al., 2016 Radha, 2018
Gracilaria fisheri	21.2-22.9	1.7-2.7	11.6		Benjama and Masniyom,2012
Gracilaria folifera		3.23	6.98	22.32	Manivannan et al., 2008
Gracilaria gracilis	24.8-45.72	0.6-1.95	10.61-20.2		Rodrigues et al., 2015 İrkin and Erduğan, 2017
Gracilaria lemaneiformis	16.7	0.9	20.9	61.6	Wen et al., 2006
Gracilaria salicornia	19.2-38.9	0.51-2	1.86-9.6	76.18	Radha, 2018 Tabarsa et al., 2012
Gracilaria sp.	28.9	0.7	23.6	46.9	Neto et al., 2018
Gracilaria tenuistipitata	7.9-26	1.9-3.6	20.3-22.9		Benjama and Masniyom, 2012

S	A	L	P	C	R
Gracilaria verrucosa	6.05-28.71	0.27-3.15	9.47-27.38	74.11	Kaykaç, 2007 Ahmad et al., 2012 Parthiban et al., 2013
Grateloupia turuturu	18.5-24.8	0.6-2.6	20.2-22.9		Denis et al., 2010 Gressler et al., 2010
Halopithys incurva	42.28	0.47	9.72		Okudan et al.,2022
Halymenia floresii	19.16	2.46	3.05		Polat and Ozogul, 2013
Hypnea charoides	15.5-22.8	1.48-3.04	18.4-25.63	7.02	Wong and Cheung, 2000 Pirian et al., 2020
Hypnea japonica	22.1	1.42	19	4.28	Wong and Cheung, 2000
Hypnea musiformis	21.57-49.36	0.35-1.27	9.96-18.64	20.6	Irkin, 2009 Siddique et al., 2013 Ünal et al., 2020
Hypnea pannosa	18.65	1.56	16.31	22.89	Siddique et al., 2013
Hypnea spinella	33.07	1.44	8.02	34.46	D’Armas et al., 2019
Hypnea valentiae	21.8	2.8	8.34-16.5	23.6-31.8	Manivannan et al., 2008 Rohani-Ghadikolaei et al., 2012
Jania rubens	26.5-83.25	0.12-2.39	1.38-12.93	6.4-42.18	Polat and Ozogul, 2009 Polat and Ozogul, 2013 Khairy and El-Shafay, 2013 Turan et al., 2015 El-Sheekh et al., 2020
Kappaphycus alvarezii	27.49	0.57	4.86	41.15	D’Armas et al., 2019
Laurencia caspica	26.05-26.82	0.3-0.9	22.22-22.26	25.5-26	Mehdipour et al., 2014
Laurencia filiformis	38.4	6.2	29.6		Gressler et al., 2010
Laurencia intricata	33.5	1.1	11.1		Gressler et al., 2010
Laurencia obtusa	20.25-47.82	1.24	4.85-14.2	19.96	Turan et al., 2015 Okudan et al., 2022
Laurencia papillosa	22,96-67.88	0.94-6.73	2.36-34.65	15.52	Polat and Ozogul, 2009 Polat and Ozogul, 2013 Turan et al., 2015
Laurencia sp.	11.6	0.45	14.8	66	Ahmad et al., 2012
Liagora ceranoides	78.62	0.42	2.79		Okudan et al.,2022
Liagora sp.	63.55	0.23	8.01		Polat et al., 2012
Liagora viscida	74.22	0.44	4.32		Okudan et al., 2022
Nostoc flagelliforme	17.6	0.6	27.7	54.1	Wen et al., 2006

S	A	L	P	C	R
Osmundea pinnatifida	30.62-38.55	0.9-7.53	20.32-23.8	17.61	Patarra et al., 2011 Paiva et al., 2014 Rodrigues et al., 2015
Palisada perforata	26.21	2.12	32.05		Pirian et al., 2020
Phyllophora crispa	49.67	1.69	13.34		İrkin and Erduğan, 2017
Polysiphonia mollis		5.79	16.59	25.81	Chakraborty and Santra, 2008
Polysiphonia morrowi	19.95	0.64	25.17		Irkin, 2009
Porphyra columbina	6.5	0.3	24.6		Cian et al., 2014
Porphyra purpurea	21.3	2.8	33.2		Taboada et al., 2013
Porphyra sp	28.16	1-8.88	24.82-31.4	25.37	Dawczynski et al, 2007a,b Paiva et al., 2014
Porphyra tenera	8.7	0.7	34.20-44	40.70	Arasaki and Arasaki,1983 Marsham et al., 2007
Porphyra umbilicalis	10-20.4	0.2-4.1	29.6-40	46.2	Cofrades et al., 2010 Pycke et al., 2015
Pterocladiella capillacea	13.02-23.68	1.76-3.11	9.62-23.72	47.98-50.96	Khairy and El-Shafay, 2013 Naz et al., 2022
Pyropia acanthophora	5.8	2.1	15.9	45.3	Kavale et al., 2017
Pyropia orbicularis	16.5	0.8	23.2	53.7	Uribe et al., 2018
Rhodomela confervoides	32.2		14.8	34	Olsson et al., 2020
Sphaerococcus coronopifolius			19.51-19.6		Patarra et al., 2011
Spyridia filamentosa	27.15-33.31	0.43-1.28	2.2-15.65		Polat and Ozogul, 2008 Polat and Ozogul, 2013
Tricleocarpa fragilis	85.61	0.23	2.93		Okudan et al., 2022

S: Species; **A:**Ash; **L:**Lipid; **P:**Protein; **C:**Carbohydrate; **R:**References

Molecular Weight Profiles of Macroalgae

Cahu and Infante (1995) and Zambonino Infante et al. (1997) reported that protein ingredients used in feeds affect the development of the digestive systems of fish. Ronnestad et al. (1999) and Holt (2000), molecular definitions of protein ingredients planned to be used in feeds will contribute to making more suitable formulations for fish cultured. Kolkovski (2004) and Kolkowski (2008) suggested that protein ingredients with 1000 to 10000 dalton MW can be used in the formulation of aquaculture feeds.

Researchers have shown that environmental and culture conditions, species diversity, genetics and growth stages can affect the biochemical composition of macroalgae (Degeorges and Masquelet, 2002; De Vicose et al., 2012; Khan et al., 2018; Araujo et al., 2021).

Diken (2018) observed that the MW profiles of *Sargassum sp.* and *Ulva sp.* were the highest in the 2532 Da ≥ group. Yenmiş and Naz (2018) reported that the lowest and highest leaching ratios at different times of *Sargassum sp.* were observed in 2532–13000 Da and 2532 Da≥, respectively. Aktaş et al. (2019) showed that the use of feed material such as copepod meal, dry *Daphnia sp.* (dryD), Artemia metanauplii, Artemia nauplii, fish meal, *Daphnia magna* (freshD)) except for Tubifex in feeds may cause the high leaching of 2532 Da≥. Saygılı et al. (2022) determined the MW profiles of 8 macroalgae such as Brown Algae (*Padina pavonica*), Red Algae (*Jania rubens*, *Amphiroa rigida*, *Ellisolandia elongata*) and Green Algae (*Codium bursa, Chaetomorpha linum*, *Ulva* intestinalis, Codium *fragile,*) collected from Turkey. The highest and lowest MW profiles in 8 macroalgae were observed in 2532 Da ≥ and 2532-13000 Da except for *Padina pavonica* and *Ulva intestinalis*. The results of the MW profile analysis showed that the studied macroalgae are an exogenous source of free amino acids. During the use of these macroalgae, which has a high content of exogenous free amino acids in feed, It should be taken into account that the MW profiles of 2532 ≥ Da will result in high leaching rates due to its high content.

Until now, the number of studies on the MW profiles of macroalgae is insufficient. MW profile values obtained in previous macroalgae studies are given in **Figure 1**, **Figure 2** and **Figure 3**.

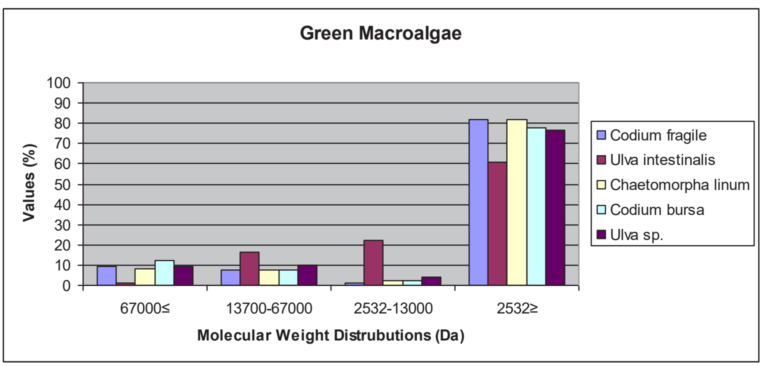

Figure 1. Molecular weight distributions of Green macroalgae. (Diken, 2018; Saygılı et al., 2022).

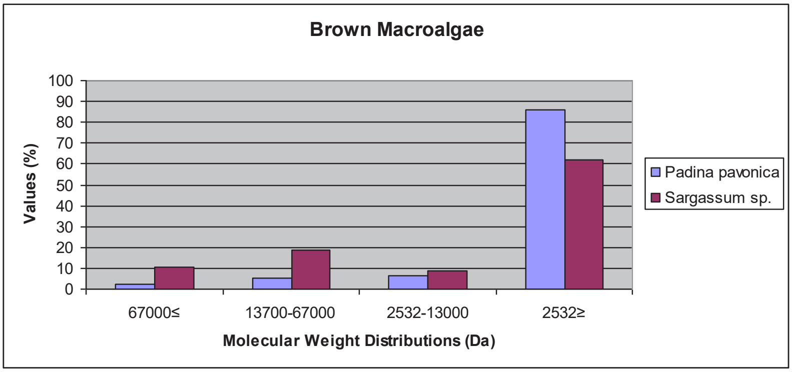

Figure 2. Molecular weight distributions of Brown macroalgae. (Diken, 2018; Saygılı et al., 2022).

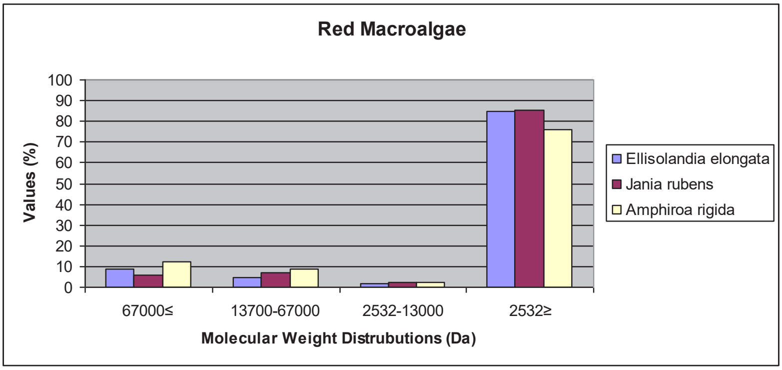

Figure 3. Molecular weight distributions of Red macroalgae. (Saygılı et al., 2022).

Brown (*Sargassum sp.*, *Padina pavonica,*), Red (*Jania rubens, Amphiroa rigida*, *Ellisolandia elongata*) and Green (*Ulva* sp., *Codium fragile, Chaetomorpha linum, Codium* bursa, *Ulva intestinalis*) macroalgae were studied (Diken, 2018; Saygılı et al., 2022).

The highest and lowest MW profile values of green, brown and red macroalgae were determined in 2532 Da≥ and 2532-13000 Da except for *Ulva intestinalis* and *Padina pavonica* (Diken, 2018; Saygılı et al., 2022). The lowest and highest values of green, brown and red macroalgae obtained in 2532 Da≥ were 60,84%-81,58%, 62,04%-85,91% and 76,17%-85,36%, respectively (Diken, 2018; Saygılı et al., 2022). The MW profile observed in 2532 Da≥ of *Ulva sp.*was 76,56% while the MW value of *Ulva intestinalis* was 60,84% (Diken, 2018; Saygılı et al., 2022). This data showed that there could be significant differences between species groups belonging to the same genus.

Conclusion

Despite the fact that our country's aquaculture potential in terms of existing resources is higher than many countries where high aquaculture production is realized, it is noteworthy that the use of macroalgae is lower than the Far East countries.

Today, it is of great importance to use algae not only as nutrients but also as alternative raw materials in feed, fertilizer, medicine, cosmetics and textile industries. In particular, it is known that macroalgae containing bioactive peptides used in medicine have many properties such as antifungal, antiviral and antibacterial.

Mineral elements known as ash are found in high amounts in macroalgae, although they do not have direct nutritional value. Considering that these components have important roles in metabolic reactions, their potential to be evaluated in different industrial areas in the future should be investigated.

When the results of the studies are evaluated, it becomes clear that the lipid levels of macroalgae cannot be seen as a commercial target compared to the ash, protein and carbohydrate levels. In contrast, previous literatures have agreed on the investigation and evaluation of fatty acid potentials.

It should be taken into account that environmental factors such as harvest season, temperature and harvest location may affect the protein content of macroalgae, which has the potential to be a sustainable protein source in the future. In order to ensure the high efficiency of algae, it is of great importance to determine the periods when their biochemical compositions are highest. In this concept, when the results are evaluated, it is suggested that macroalgae will be attractive species as additives for the food industry as a protein source. In addition, the high carbohydrate content of macroalgae indicates that they can be an important source of phycocolloids for industrial uses.

On the other hand, one of the most important factors affecting the use of macroalgae in the feed industry is nutritional release known as leaching. The MW profiles of the present study also raise the possibility that different species may have different leaching potentials. In order to clearly demonstrate the potential of macroalgae to be used in the feed industry, it is necessary to determine the leaching potentials of feeds produced with innovative methods in the future.

Further studies on the use and production of these naturally economic resources as raw materials in different fields should be encouraged.

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Chapter 6

Enhanced Screw Withdrawal Strength of Polyurethane (PU) Composites for Wood Sandwich Panel Core Layer

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ABSTRACT

The aim of the study was the produce of polyurethane foam (PUF) composites characterized by their reduced weight, diminished water absorption (WA), and heightened screw withdrawal (SR) strength. To achieve this goal, waste-derived MDF fine dust, egg white (EW) and urea formaldehyde (UF) were incorporated into the polyurethane matrix in calibrated proportions. The formulations were prepared and subjected to foaming processes employing a mechanical mixer. SR strength, water absorption (WA) behavior, and thickness swelling (TS) tendencies, analyzed according to related Turkish Standards (TSE). According to obtained results, MDF fine dust and EW effectively increased the SR strength in the PUFs. The interaction of UF with EW led to a decrease in SR strength, but in other configurations, it resulted in its enhancement. The densities of the samples increased with the incorporation of EW and MDF fine dust, while UF addition reduced densities due to its impact on structural density. In response to moisture, the presence of MDF and EW decreased TS, yet increased water absorption due to their higher foaming propensity. Overall, the findings of this study confirm the viability of using PUF composites as core layers of wood sandwich panels. This study offers the prospect panels characterized by low density and enhanced resistance to water-induced effects. Moreover, the strategic inclusion of waste-derived MDF fine dust presents an ecologically sound approach, offering potential for more sustainable and environmentally responsible production practices.

Keywords: Polyurethane, organic filler, wood panel, mechanical properties, rigid foam

INTRODUCTION

Polyurethane (PU), first discovered around 80 years ago, has evolved into a thriving multibillion-dollar industry due to its remarkable versatility achieved through the combination of various polyols (PO) and isocyanates (ISO) (Eling et al., 2020).

Polyurethane foams (PUFs) share similarities with other cellular solids as they consist of polyhedral cells that pack in a three-dimensional arrangement, effectively filling the available space. The three-dimensional cell structure of PUFs classifies them as foams (Gibson and Ashby, 1997). The unique combination of thermoplastic, elastomeric, and thermoset characteristics in PUs makes them exceptionally versatile materials. Their extensive use, particularly in foamed variants, can be attributed to their lightweight nature and ability to attain specific properties, while also facilitating the production of sandwich structures and material composites through a single processing step (Engels et al., 2013).

Over the years, various manufacturing techniques have been employed to tailor the properties of PUFs to specific requirements (Jamil et al., 2017). The availability of a diverse range of PO and ISO as raw materials allows for modification of the cellular structure to suit various applications. This has resulted in the widespread use of PUFs in numerous sectors, such as leather finishing, automotive, furniture, refrigeration, sports, transportation, insulation, and marine applications, owing to their versatility and adaptability through adjustments in constituent proportions (Sair et al., 2018; Wang and Li, 2018; Zhang et al., 2018). Additionally, the ability to produce PUFs in different physical states, including viscous liquids, low-density soft foam, flexible and semi-flexible foam, and hard foam, coupled with their cost-effectiveness, has further contributed to their popularity among manufacturers (Khan et al., 2020).

PUFs are commonly used as core materials in sandwich panels. These sandwich structures find diverse applications in industries such as aerospace, marine, automotive, construction, and many others, including the manufacturing of ocean current turbine blades (Scalici et al., 2018; Shariyat and Roshanfar, 2018; Suzuki and Mahfuz, 2018; Yossef and Chen, 2018). In our study, we aim to produce a PU composite which can be used as a core material in wood sandwich panels. Thus, we focused the screw withdrawal strength of PU composites because it is one of the more important properties of the wood panels.

A wide variety of materials are used in the surface layers of sandwich panels (Figure 1), from lightweight metal-based structures to laminated composite sheets. With the development of technology, PUFs have been widely used in sandwich structures and have been the subject of important scientific research in recent years. The ability of PUFs to mix their essential elements in different proportions resulting in varying densities and hardness values allows a variety of mechanical, dynamic and thermal properties to be achieved, leading to a broad research focus on different additives, particularly to increase lightness (Khan et al., 2020).

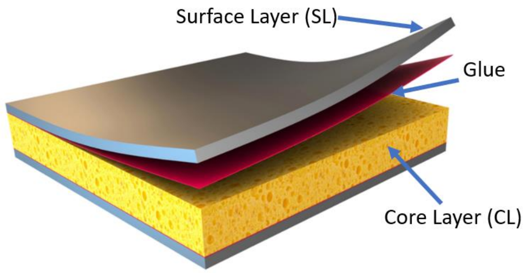

Figure 1. Sandwich panel structures (Khan et al., 2020)

The one-step manufacturing process, known as in-situ foaming, offers significant potential for producing foam core panels. PUF has proven to be well-suited for in-situ foaming applications. Higher ISO and PO content resulted in increased foam cell density, leading to enhanced bending strength, internal bond, and screw withdrawal resistance of the foam core panels. Additionally, varying the foam ingredient ratios had no effect on thickness swelling, while water absorption was influenced by the proportions of the foam components (Choupani Chaydarreh et al., 2017).

Rigid PUFs can be manufactured with a wide density range of approximately 40–1000 kg/m^3, depending on the structure of their PO. Foams with lower density (<60 kg/m^3) are ideal for insulation applications, while those with higher density (>500 kg/m^3) are better suited for decorative purposes (Ionescu, 2005).

The ISO index, which represents the ratio of ISO to PO, plays a significant role in determining the properties and applicability of rigid PU foam. When the ISO to PO ratio is increased, the mechanical properties of the foam experience substantial improvement, resulting in enhanced toughness and load-bearing capacity (stiffness). Additionally, higher ISO groups (NCO) to OH ratio contribute positively to the foam's mechanical properties, while increasing the molecular weight of the PO has a negative impact on these properties (Kumar and Kaur, 2013; Xiao et al., 1983).

It is desired that the PUF has both low density and a rigid structure for the core layer of the wood composite panel. Xu et al. (2007) introduced a novel approach to enhance rigid PUF properties by directly integrating organoclay into the foam matrix, acting as both a nucleating and blowing agent due to bound water content. Incorporation of up to 4 phr of organoclay led to refined cell structures, increased tensile and compressive strengths (maximized at 2 phr), attributed to improved internal strength from finer cell structures and heightened hydrogen bonding.

In contemporary research, a predominant approach aimed at augmenting the mechanical properties of PUFs involves the integration of a broad spectrum of reinforcements. These reinforcements encompass nanoparticles such as carbon nanotubes and carbides, as well as traditional reinforcements like fibers and textiles, and further extend to the utilization of natural additives. (Dolomanova et al., 2011; Meng et al., 2018; Ramirez and Jaramillo, 2018; Szatkowski et al., 2017). This approach has led to the development of PUFs that showcase impressive attributes such as exceptional impact resistance, reduced weight, favorable strength-to-weight ratio, notable flexibility, and resistance against corrosion and abrasion.

Urea formaldehyde (UF) is one of the most used thermoset resin in wood composite industry. UF was used many wooden products because it was obtained easily and abundantly (Kelleci et al., 2022a). Thus, in this study UF was added in PUFs so that determining the how UF affect the mechanic properties of PUFs.

In this study, rigid PUF composites were prepared using waste medium density fiberboard (MDF) fine dust and egg white (EW). The aim of the research was to achieve rigid PUF composites suitable for wood sandwich panels' core layer, possessing high screw withdrawal strength, low density, minimal thickness swelling, and water absorption in humid environments. Apart from its use as fuel in heating boilers, waste MDF fine dust cannot be effectively utilized for any other product production. This study will enable the transformation of waste MDF fine dust into high-value-added products. The focus of the study was solely on the production and characterization of the core layer for wood sandwich panel, rather than the entire wood sandwich panel.

MATERIAL AND METHODS

M*aterials*

In this study, commercially available PU wood adhesive was utilized to prepare PUF. PU is also known as skeleton adhesive, marine adhesive, or marine glue in the market. The PU adhesive had an ISO content of 10-12 %, with a viscosity range of 5000-7500 centistokes (cSt). The PU adhesive was purchased from a local supplier.

Waste MDF fine dust was employed in the study as a filler material in PU. The fine MDF dust was picked up from furniture manufacturing workshops located in Bolu/Türkiye province. After collecting the MDF dust from these workshops and bringing it to the laboratory, it was sieved using a 1 mm x 1 mm mesh. Waste MDF particles below 1 mm in size were used as filler within the PU. Additionally, egg white was employed as another filler material in the PU. The natural ovalbumin content in egg white possessed foaming and adhesive properties. Egg white was purchased from a local supermarket.

UF was supplied from Yıldız Entegre Particle board factory. UF has 65 % solid concentration, 1,284 g/cm^3 density, 300 centistokes (mm^2/s) and 45 second jelly time in 100 °C.

MDF dust, UF and egg white (EW) were mixed with PU in the proportions given in Table 1 to obtain PUF with low density (170-480 kg/m^3), solid-state characteristics, and high screw withdrawal strength.

Table 1. Material ratios in PUF samples

Sample code	Description	PU (g)	MDF (g)	EW (g)	UF (g)
PU-CTRL	Control sample	100	-	-	-
PU-MDF	MDF fine dust added	100	50	-	-
PU-MDF-UF	MDF fine dust and urea formaldehyde added	100	50		20
PU-EW	Egg white added	100	-	10	-
PU-EW-UF	Egg white and urea formaldehyde added	100	-	10	20

Preparation of samples

Totally 5 sample groups were prepared, including the control group (Table 1). In the preparation of the control group, only PU was used. 100 g of PU was poured into a glass container and mechanically stirred at 1000 rpm for 30 seconds without any additives. Subsequently, the PU underwent a reaction with the oxygen of air, leading to an increase in volume (Figure 2a). Upon releasing the volume expansion, the density of the resulting PUF decreased to a range of 60-70 kg/m^3. This reduction in density significantly diminished the screw withdrawal strength (SR). In order to achieve densities within the range of 170-490, necessary for meeting standard SR strength, the samples were mechanically stirred again during the volume expansion phase, approximately at the midpoint of the reaction time. This process ensured the reposition of the volume to its initial level.

For all samples, 100 g of PU was employed. The addition of MDF powder into the PU was done in the proportion specified in Table 1, followed by mechanical stirring at 1000 rpm for 30 seconds. The inclusion of MDF resulted in the mixture reaching a dough-like consistency, rendering the preparation more challenging. The UF addition was introduced into the mixture at the 15th second, and the entire mixture was stirred for a total of 30 seconds at 1000 rpm. Similarly, the incorporation of egg white (EW) into the PU was carried out akin to the MDF addition process. The mixture formed with EW exhibited a smoother incorporation compared to MDF. While 50 g of MDF powder was added, 10 g of EW was used. This disparity in quantity was driven by considerations of material availability and cost in composite production. MDF powder could be procured in abundance at a lower cost, whereas egg white could not be readily obtained in significant quantities at a low cost. Therefore, to better reflect real production conditions, different ratios of filler materials were employed in the samples. PUFs were keep at room temperature for 24 hours and analysis samples were prepared by cutting with an iron saw (Figure 2b, 2c, 2d, 2e, 2f).

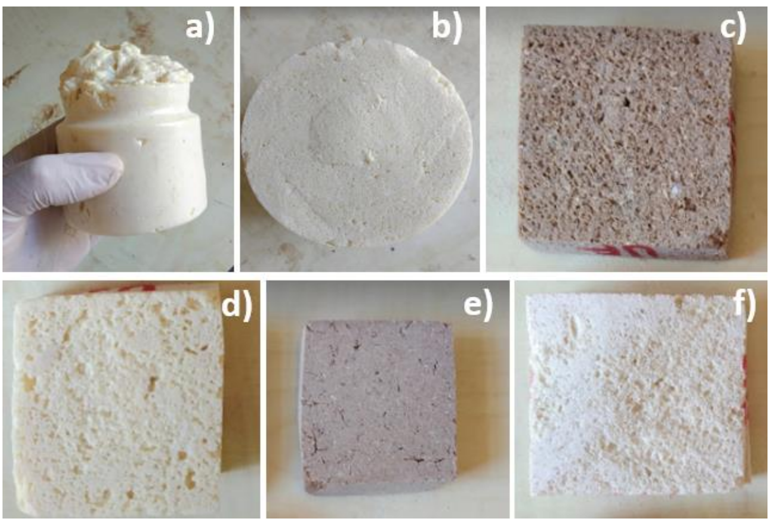

Figure 2. PUF samples. a) Foamed PUF, b) PU-CTRL, c) PU-MDF, d) PU-EW, e) PU-MDF-UF, f) PU-EW-UF

Methods

Mechanical characterization of the samples was conducted using Screw Withdrawal Analysis (SR). Physical analyses were conducted by 2-hour and 24-hour Thickness Swelling Analysis (TS_{2h} and TS_{24h}), Water Absorption (WA_{2h} and WA_{24h}), and density (DN) analyses. The analyses were carried out according to TS EN 320, TS EN 317, and TS EN 322 standards, respectively. The analysis results were analyzed using the SPSS software package. To determine whether there were significant differences among the samples ($P<0.05$), a One-Way ANOVA analysis was performed. Also, Duncan's analysis was employed to identify similar groups among the samples.

RESULTS AND DISCUSSION

In the preparation of the analysis samples, the mixing durations and methods were the same for all samples. However, the amounts of EW and MDF added in the PU were different. As a result, densities of the samples were different (170-480 kg/m^3). Different amounts of filler materials were used because waste MDF powder can be obtained in large quantities and at a low cost in the market. However, EW cannot be obtained in large quantities at a low cost. For this reason, to reflect real production conditions, waste MDF powder was used at a ratio of 50 %, while EW was used at a ratio of 10 %.

Physical and mechanic analysis results of PUF composites

When examining the sample densities (Table 2), it was determined that the highest density achieved with the addition of 50 % waste MDF fine dust. The addition of UF was not changed the densities with added waste MDF dust. However, in the samples with added EW, the density decreased with the addition of UF (from 318 to 170 kg/m^3). The density of the PUF control sample was 203 kg/m^3.

TS_{2h} and TS_{24h} were different for the same group. For instance, the Thickness swelling (TS_{2h}) of the samples soaked in water for two hours was greater than those soaked for 24 hours in the EW added. Normally, the sample soaked for a longer duration should have exhibited more swelling. But it did not happen as expected. A similar result was observed in the PU-CTRL sample as well. When SR analysis result was examined, it was determined that results were statistically significant ($P<0,05$). Duncan analysis result show that the PU-CTRL and PU-EW-UF were in same group. Sample with the highest SR strength was the PU-MDF-UF.

Table 2. Analysis results of PUFs samples

Samples	TS_{2h} (%)	WA_{2h} (%)	TS_{24h} (%)	WA_{24h} (%)	SR (N/mm)	Density (kg/m^3)
PU-CTRL	3,0 (±1,1)* c**	13 (±2,3) b	0,1 (±1,7) a	21 (±5,1) a	3,3 (±0,7) a	203 (±22) b
PU-MDF	0,7 (±0,7) ab	3 (±0,5) a	2,3 (±0,5) c	24 (±4,7) a	6,6 (±2,1) bc	481 (±16) d
PU-MDF-UF	2,0 (±1,1) bc	20 (±3,5) b	2,9 (±1,1) c	56 (±4,3) b	7,6 (±2,3) c	483 (±29) d
PU-EW	1,7 (±0,8) ab	41 (±2,3) c	0,8 (±0,5) b	56 (±4,4) b	5,2 (±0,8) b	318 (±5) c
PU-EW-UF	2,1 (±0,9) c	52 (±1,3) d	0,9 (±0,8) b	58 (±8,5) b	2,0 (±0,3) a	170 (±10) a

*: Standard deviation, **: Duncan analysis group

When Figure 3 was examined, it was seen that the highest TS_{2h} was in PU-CTRL but lowest TS_{24h} in again in PU-CTRL according to soaking time that is 2 hour and 24 hours. When PU-CTRL sample keep 2 hours in water, it was shown highest thicknesses swelling. Contrary, when it was kept 24 hours in water, then taken out and measure its thickness, it was seen that thickness decreased. PU-CTRL volume was decreased trough water. It was determined that the EW showed the enhanced TS properties when it was added in PU. WA quantities were high at all sample because PUFs had foamed structures that is they have many cavities in their matrix.

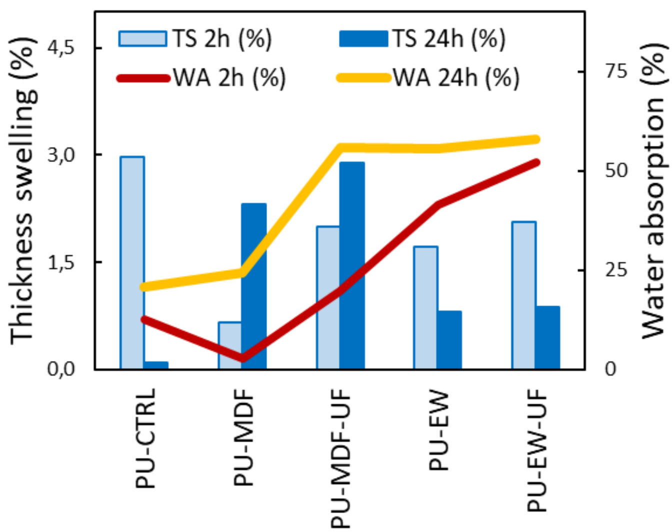

Figure 3. Physical properties of PUFs

SR strength varies according to the type of wood, moisture content, cross-section, specific gravity, screwing method, dimensions, and surface smoothness of the material (Soltis, 1999). In a study conducted in Turkey, the highest nail withdrawal strength was observed in oak wood. This was followed by beech, cedar, red pine, black pine, and Scots pine, with the lowest value recorded in chestnut wood (Ferah, 1991).

Several studies have reported that when the moisture content of wood material falls below the fiber saturation point, the tensile strength (SR) of the wood decreases (Bacher, 1964; Kanamori et al., 1978; Rammer et al., 2001).

Furthermore, it was observed that there existed no discernible correlation between the length of the screw and the withdrawal strength. However, a linear relationship was identified between the screw diameter and the withdrawal strength (Kjucukov and Encev, 1977a, 1977b).

In our study, the orientations of the composite did not alter the tensile SR as the composite obtained was an isotropic material. When examining Figure 4, it can be observed that the addition of MDF dust and EW increased the SR strength.

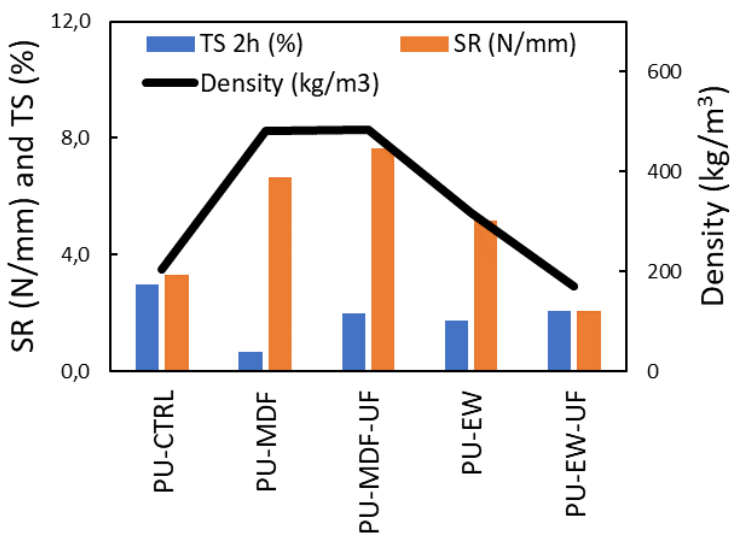

Figure 4. Screw withdrawal resistance and density, thickness swelling relations in PUFs.

In a study conducted using different wood species, it was determined that the SR strength of Plywood produced with poplar wood veneer was 10 N/mm in radial direction. Based on this, it can be stated that the tensile strength of PUF produced using waste MDF powder is equivalent to that of poplar wood (Celebi and Kilic, 2007).

In terms of screw withdrawal strength, the magnitude of the force varies depending on whether it is applied statically or dynamically. Research conducted on SR has determined that under static conditions, tensile strengths are higher compared to dynamic conditions. It has been reported that as the duration increases and the specific gravity decreases, reductions in SR strength occur (Broker and Krause, 1991; Kim, 1979; Noguchı, 1961).

In wood materials, the SR strength varies in the radial and tangential directions. In a study, it was determined that the SR strength in the radial direction was 8.544 N/mm, whereas in the tangential direction, it was 11.649 N/mm in poplar wood (Celebi and Kilic, 2007). In our study, the produced PUF composites exhibited isotropic behavior. The composites had equal tensile strength (SR) in both the radial and tangential directions. This is attributed to the absence of fiber orientations in the composites, as seen in wood materials. Also, in a study it was reported that the wood dust decreased the mechanical properties of polylactic acid (PLA) and polyhydroxybutyrate (PHB) composites (Kelleci et al., 2022b). But in our study, MDF dust increased the screw withdrawal strength.

If wood surface is going to be coated, it should be smooth (Istek et al., 2017). In the presented study, the surfaces of the PU foam panels lack smoothness; they are quite rough. They are not suitable for direct surface treatment. Therefore, they are suitable for use in the core layer of the wooden sandwich panel.

CONCLUSIONS

This study aimed to produce lightweight, low water absorption, and high screw withdrawal (SR) strength polyurethane foam (PUF) composites that could be used as core layers in wood sandwich panels. For this purpose, waste MDF fine dust and egg white (EW) were added to the PU along with urea-formaldehyde (UF) in specific proportions. Mixtures were prepared and foamed using a mechanical mixer. The SR strengths, water absorption (WA) amounts, and thickness swelling (TS) ratios of the samples were determined according to relevant Turkish Standards Institute (TSE) standards. According to the analysis results, the addition of MDF dust and EW increased the SR strength of the samples. The addition of UF reduced the SR strength when used together with EW but increased it in other samples. The densities of the samples increased with the addition of EW and MDF dust, while UF addition decreased the densities. The thickness swelling ratios (TS_{2h}) of samples soaked in water for 2 hours decreased with the addition of EW and MDF. WA increased because the samples with MDF and EW had a higher degree of foaming, resulting in a more porous structure that absorbed more water. The study concluded that PUFs could be used as core layers in wood sandwich panels, allowing the production of lighter and less water-sensitive wood sandwich panels. Additionally, the utilization of waste MDF fine dust could contribute to a more environmentally friendly production process.

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Chapter 7

Recent Advancements in Mitigating Abiotic Stress in Plants: Novel Strategies and Emerging Technologies

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ABSTRACT

Plants are susceptible to various environmental conditions that can impact their growth and development. Abiotic stress factors, such as water deficits, extreme temperatures and nutrient deficiencies, have negative effects on plants by disrupting conditions those necessary to their survival. Abiotic stress can trigger a range of plant responses that attempt to minimize or adapt to these challenging conditions, including morphological and physiological adjustments as well as biochemical changes. Stress tolerance is a complex issue and traditional methods have often proven inadequate. However, recent developments in technology and science have incorporated innovative approaches, such as biostimulants, nanotechnology, genome editing, plant microbiome management and biochar application. These methods offer effective ways to enhance plant growth and improve stress tolerance. For example, bio-stimulants improve plant resilience and nanotechnology enhances plant resistance to abiotic stress. Genome editing allows the modification of stress response genes, leading to the development of stress-tolerant plant varieties. Plant microbiome management and biochar application are also effective strategies for improving plant resilience to abiotic stress, which is predominant in populations affected by hunger challenges. These approaches have significant potential benefits that can maintain sustainable agriculture, contributing to food security in the future.

Keywords: Abiotic stress factors, Stress tolerance, Biostimulants, Nanotechnology, Sustainable agriculture.

INTRODUCTION

Plants are challenged by the adverse or positive effects of many environmental conditions throughout their lives. A plant can complete its development under optimum environmental conditions. When conditions occur above or below optimum range, some adverse changes are observed in the plant. These changes can be counted as a retardation in growth and development, a decrease in yield and quality also partial or fully death of the plant. Abiotic stresses, like drought, high salinity, cold and heat have a significant negative impact on the survivability, biomass production and yields of important crops, reducing them by up to 70% (Thakur et al., 2010; Kaur et al., 2008; Vorasoot et al., 2003).

In order to fulfill the food demand of the growing global population, it is essential to double world food production by the year 2050 (Qin et al., 2013; Tilman et al., 2002). For this reason, significant efforts have been directed toward understanding the reaction mechanisms of plants against abiotic stress factors, such as drought, salinity and extreme temperatures. These stress factors pose a serious threat to crop productivity and yield therefore, developing stress-tolerant plants has become a crucial area of research in recent years. As delving deeper into the underlying mechanisms of plant stress responses, we can gain greater insight into how we can engineer plants to become more resilient and productive in the face of these challenges.

Abiotic stress factors

Abiotic stress factors are factors that have important effects on the growth and development processes of plants. These factors create negative effects on plants by disrupting the balance of environmental conditions vital for the survival of plants. Abiotic stress factors such as deficit water, extreme salinity, high or low temperatures, radiation and nutrient deficiencies can cause drastic changes in the physiological processes of plants. Plants have developed various adaptation mechanisms to cope with these stress factors. These adaptation mechanisms include various strategies such as increasing the water and nutrient uptake of plants, maintaining their photosynthetic capacity and repairing damaged cells. Abiotic stress factors also pose a great threat to plant breeding and agriculture and can adversely affect plant health. Therefore, the development of plant stress management and adaptation strategies can increase the productivity of plants by making them more resistant to abiotic stresses (Pareek, 2019; Zhu, 2016).

Drought stress has significant effects on plants, impacting their physiological and biochemical processes and ultimately hampering their productivity

(Seleiman et al., 2021). When plants are subjected to drought, it led directly to a reduction in water potential and turgor pressure in growing cells, hindering their growth (Bashir et al., 2022). Additionally, root, stem, leaf and fruit growth may decrease under drought conditions (Bashir et al., 2022). Plants respond to drought stress through various mechanisms, such as altering their metabolic pathways and biochemical processes (Hemati et al., 2022). For instance, water deficit conditions created by drought stress can disrupt cellular homeostasis and limit crop production (Hemati et al., 2022). Furthermore, drought stress negatively affects plant water interactions and reduces their water-use efficiency (Farooq et al., 2009).

To mitigate the adverse effects of drought stress on plants, researchers and farmers have been exploring different approaches. These include implementing irrigation techniques, developing drought-tolerant plant varieties through breeding programs and applying organic or synthetic compounds to enhance plant resilience to drought stress (Seleiman et al., 2021). By understanding the physiological and biochemical feedback of plants to drought stress, scientists aim to develop strategies that can help plants cope with water scarcity and improve their overall drought tolerance.

Another stress factor salinity negatively affects the growth and development of plants. Accumulated salts in the soil, especially sodium, chloride and occasionally other salts can disrupt plants' normal physiological functions. These salts can make it difficult for plants to take up water, hindering root water absorption and disrupting the plants' osmotic balance (Chaitanya et al., 2014; Shabala and Cuin, 2012).

Salinity stress can lead to osmotic stress and ion toxicity in plants. Osmotic stress occurs when plant cells lose water due to high salt concentrations, leading to dehydration. Ion toxicity, on the other hand, results from the excessive accumulation of salt ions in plant tissues. This condition can lead to cellular damage, reduced photosynthesis activity and cessation on plant growth. Risen salt levels in the soil hinder the ion balance of plants, water uptake and induce oxidative damage, resulting in lower crop yields and reduced crop quality (Munns and Tester, 2008).

Heat and cold stress can have significant effects on plants. When exposed to extreme temperatures, plants may experience slowed chemical activity and growth. Heat stress in plants can result in leaf rolling and cupping. To mitigate the effects of heat stress on plants, it is important to provide adequate care, especially during hot weather. This includes ensuring proper watering, providing shade or shelter, and implementing mulching techniques. By taking these precautions, the negative impacts of heat stress on plants, including vegetables can be minimized. Similarly, when plants are subjected to high temperatures for a prolonged period, they may experience heat stress. Without precautions, heat stress can have detrimental effects on plants and reduce yield capacity. It is crucial for farmers to implement crop management strategies to shield crops from a heat stress (Fahad et al., 2017).

Cold stress, on the other hand, can affect various aspects of plant physiology, such as photosynthesis, respiration and membrane thermostability. These alterations can negatively impact plant growth, development and yield (Manasa et al., 2022). Understanding the effects of cold stress on plants is valuable for implementing strategies to mitigate its impact.

Overall, heat and cold stress can significantly affect plants and their ability to grow and thrive. Understanding the signs and symptoms of stress, as well as implementing appropriate measures, can help minimize the negative effects and promote healthier plants.

There are other abiotic stress factors that affect plants, growth and health. These include radiation stress (ionizing and non-ionizing), nutrient deficiency, heavy metal contamination, air pollution and mechanical stress. Radiation stress includes excessive UV radiation that damages DNA and proteins, affecting photosynthesis and growth. Plants accumulate UV-absorbing compounds and repair damaged DNA. Nutrient deficiency affects plant health, growth and metabolism, especially nitrogen, phosphorus, potassium shortages. Heavy metal contamination from metals such as lead and cadmium impairs nutrient uptake, cellular processes and enzyme activity. High levels of pollutants such as air pollution, ozone, sulfur dioxide impair plant growth. Mechanical stress includes wind, rain, physical damage, deteriorating structures and stability. Plants adapt by mechanisms such as accumulation of UV-absorbing compounds and DNA repair. Understanding these responses is vital for plant health, agricultural sustainability and ecological balance.

Plants are defined as sensitive and tolerant according to their responses to abiotic stress factors. Stress-tolerant plants are that show better adaptation to various abiotic and biotic stress factors and are less adversely affected by these factors. These plants can generally continue to grow even under stress conditions, make better use of water and nutrients, and are generally more robust. Stress-sensitive plants, on the other hand, are more sensitive to stress conditions and are rapidly affected negatively. In these plants, stress factors can cause immediately noticeable effects on growth and development. Stress tolerance and susceptibility among plants depends on environmental conditions as well as genetic traits. Abiotic stress conditions cause different mechanisms to occur in sensitive and tolerant plants (Fig. 1), (Anjum et al., 2014; Farooq et al., 2012).

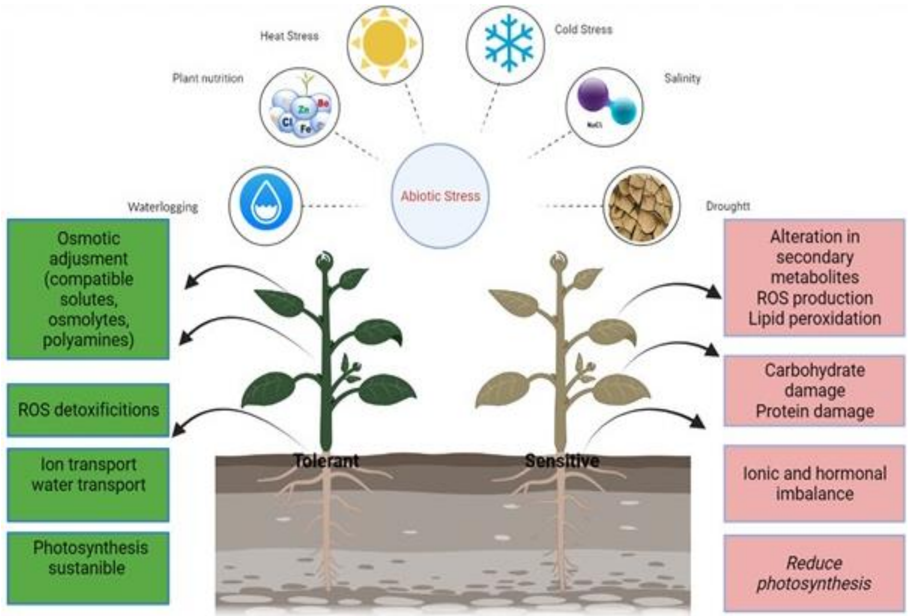

Figure 1. Effects oof Abiotic Stress on Tolerant and Sensitive Plants

Plant responses to abiotic stress

Plants develop a variety of responses to abiotic stress factors that either adapt or try to minimize the impact. These responses can be grouped under 3 headings. Morphological responses are changes of leaf size, root lenght, leaf defoliation. Physiological parameters are stomatal conductance, osmotic adjustment, regulation photosyntetic activity. Some biochemical parameters that are reactive oxgen species (ROS), antioxidant enzymes and phytohormones.

When plants are exposed to abiotic stress, such as drought, salinity, extreme temperatures or other environmental factors, they exhibit various morphological responses to cope with these challenges. These morphological adaptations help plants minimize stress-induced damage and improve their survival chances (Zhang et al., 2022; Kashyap et al., 2021).

One common morphological response of plants to abiotic stress is the alteration of root architecture. Under stress conditions, plants may exhibit changes in root length, root diameter and branching patterns as a strategy to explore a larger soil volume and enhance water and nutrient uptake (Patakas, 2012). Additionally, the development of longer root hairs can increase the surface area available for nutrient absorption (Zhang et al., 2022).

Shoot architecture is another aspect of plant morphology that can be influenced by abiotic stress. In response to stress, plants may undergo modifications in their shoot growth, such as reduced shoot height, altered leaf morphology (e.g., rolling or folding of leaves to minimize water loss through evapotranspiration) and changes in leaf area and stomatal characteristics (Kashyap et al., 2021; Patakas, 2012).

Abiotic stress can also affect the overall size and biomass expenditure of plants. In some cases, plants may reduce their overall size by limiting vegetative growth and diverting resources towards reproductive structures, such as flowers and seeds to ensure reproductive success under challenging conditions (Kashyap et al., 2021).

It is worth noting that the morphological responses of plants to abiotic stress are multifaceted and depend on the specific stressors and plant species involved. Additionally, these responses are often accompanied by physiological and biochemical changes that collectively contribute to stress tolerance (Zhang et al., 2022; Patakas, 2012).

When plants face water scarcity (drought stress), they often respond by closing their stomata. Stomata are small pores on the surface of leaves that regulate gas exchange, including water vapor loss through transpiration. Closing stomata helps conserve water but can also limit carbon dioxide uptake for photosynthesis. Abiotic stresses can lead to the generation of ROS, such as hydrogen peroxide and superoxide radicals, which can damage cellular components (Fig 2), (Hetherington et al., 2003; Mittler, 2002).

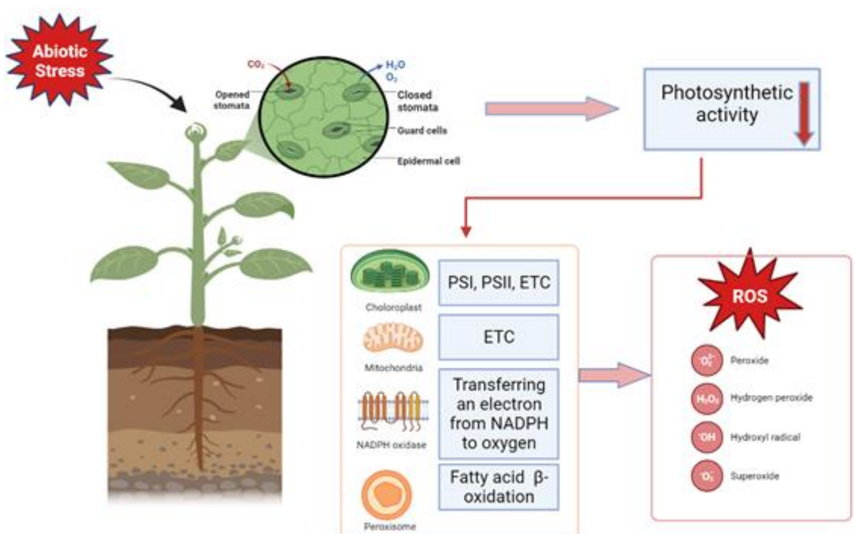

Figure 2. Abiotic Stress Responses in Plants and ROS Generation

Abiotic stresses represent formidable challenges that can hinder the growth and survival of plants. By recognizing the physiological and biochemical responses triggered by these stressors, scientists, farmers and researchers can implement targeted strategies to mitigate stress-induced damages. Through the integration of traditional agricultural practices, innovative technologies, and enhanced plant breeding methods, we can foster a sustainable approach to agriculture that ensures the health, productivity, and resilience of plants in the face of changing climatic conditions.

Stress tolerance is an area where traditional approaches are no longer adequate due to its complexity. In recent years, with the development of technology and science, innovative approaches have also emerged. Some of these approaches are methods such as biostimulants, nanotechnology, genome editing, plant microbiome management and biochar applications. Biostimulants are natural compounds that improve the growth and development processes of plants. These compounds help plants cope with stress and achieve better yields (Yaronskaya et al., 2006). Nanotechnology is an advanced technological approach that allows nanomaterials used in plants to effectively penetrate plant cells and genes (Dubchak et al., 2010). Genome editing is a technology used to precisely modify the genetic makeup of plants. In this way, desired traits can be strengthened in the genes of plants and they can be made more adaptable to stress factors (Jain, 2015). Plant microbiome management is a strategy for regulating the balance of microorganisms living around the roots of plants. The right communities of microorganisms can help plants cope with stress by increasing their nutritional intake and increasing their resistance to disease (Haichar et al., 2014). Biochar (biochar) is a carbon material produced from organic wastes and is an efficient component that remains in the soil for a long time. When used in the soil, it increases the water holding capacity and improves the nutrient uptake of plants, allowing them to develop better under stress conditions (Lutfunnahar et al., 2021). These innovative approaches are used in agricultural applications to help plants grow healthier and more efficiently under stressful environmental conditions. Due to the developing technology and science, more sustainable and effective solutions are produced in agricultural production.

MITIGATING ABIOTIC STRESS WITH SOME DIFFERENT PRACTICES

Biostimulants

Biostimulants, a diverse category of compounds, encompass both organic and synthetic substances that find application across various stages of plant growth, including soil preparation, seed treatment and plant nutrition. These compounds affect plant development by boosting tolerance to abiotic stress by altering fundamental and structural processes. Regardless of the plant's nutrient level, these chemicals are beneficial at low concentrations due to enhancing nutritional effectiveness, abiotic stress tolerance and crop quality characteristics. These chemicals exhibit comparable effect when administered exogenously to the recognized plant hormone groups like auxins, gibberellins and cytokinins (Jardin, 2012; Yaronskaya et al., 2006).

Certain elements, such as aluminum (Al), silicon (Si), sodium (Na), selenium (Se) and cobalt (Co) are considered beneficial for the growth and development of specific plant species. While these elements are not universally necessary for all plant types, they do exist in both plants and soils as inorganic salts. The physiological effects induced by these beneficial elements play a significant role in promoting plant tolerance to abiotic stress. These effects encompass a range of processes, such as osmoregulation, cell wall rigidification, thermal regulation, improved plant nutrition, regulation of antioxidant responses, biosynthesis of plant hormones and metal detoxification. For instance, osmoregulation, one of the key mechanisms influenced by biostimulants, plays an important role in maintaining the water balance within plant cells. This process becomes particularly crucial under abiotic stress conditions, such as drought or salinity, where water availability becomes limited. Biostimulants can enhance osmoregulation by influencing the accumulation of compatible solutes within plant cells, which helps maintain cell turgor and prevent water loss. This adaptive strategy allows plants to navigate water scarcity more effectively, thereby bolstering their survival and growth. The presence of beneficial elements in plants and soils is essential for the growth, development and survival of specific plant species. Hence, their importance should not be overlooked, and adequate measures should be taken to ensure their availability in the soil for plant uptake (Pilon-Smits et al., 2009).

When applied correctly to crops, this technique can have a direct impact on the physiological processes of the plants, leading to several potential benefits for their growth, development and ability to respond to various stressors. These stressors can include drought, saline environments and toxic components like aluminum, which can have a significant impact on the health and productivity of crops. By utilizing this technique, farmers and agricultural professionals can help to mitigate the negative effects of these stressors and promote healthier, more resilient crops that are better equipped to thrive in a variety of environments (Jardin, 2015).

Biostimulants represent a cutting-edge approach in modern agriculture, distinguishing themselves from traditional nitrogen, phosphorus and potassium fertilizers by virtue of their unique composition comprising an assemblage of composition of various organic compounds, such as humic acids, seaweed extracts, vitamins, amino acids, ascorbic acid and other substances (Fig 3). Unlike conventional fertilizers, which primarily provide essential nutrients to plants, biostimulants act as powerful regulators that interact with plants on a biochemical level, triggering specific responses that enhance growth and development. By targeting specific pathways and signaling mechanisms, biostimulants accelerate plant development, resulting in improved seed germination, increased shoot and root growth and enhanced overall crop vigor. Also, when plants faced with adverse environmental conditions like drought, salinity or extreme temperatures that hinder their growth and productivity. Biostimulants step in as a shield against such stresses, helping plants cope with unfavorable conditions more effectively. They stimulate the synthesis and accumulation of stress-related protective compounds, such as antioxidants, osmoprotectants and phytohormones, which contribute to improved stress tolerance and resilience (Yakhin et al., 2017).

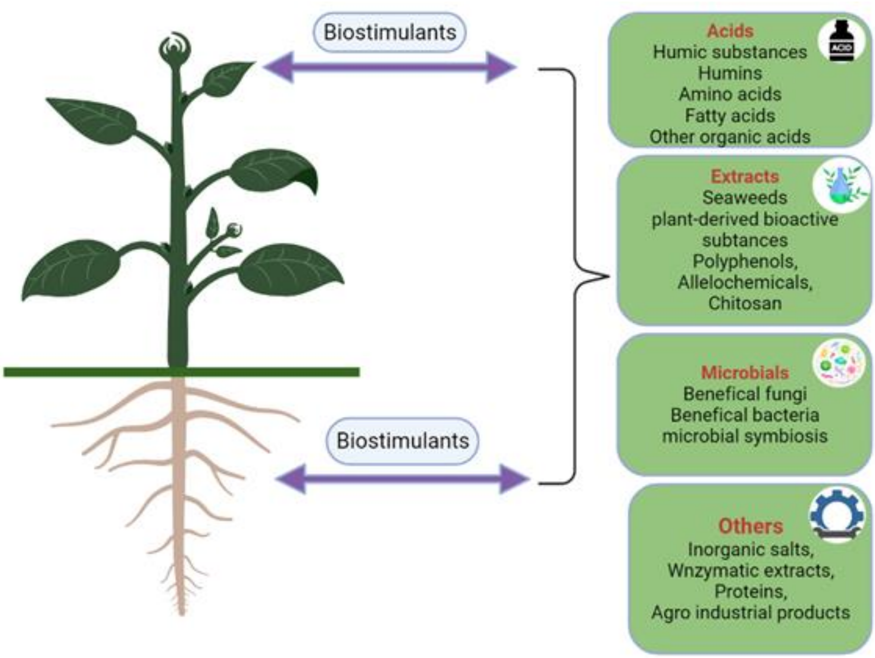

Figure 3. Illustrating Diverse Classes of Plant Biostimulants

Moreover, the versatility of biostimulants allows them to enhance nutrient uptake and utilization efficiency in plants, making them particularly valuable in nutrient-poor or degraded soils. Through their interaction with the rhizosphere and root systems, biostimulants facilitate the solubilization and release of nutrients from the soil matrix, ensuring plants have access to the essential elements they need for optimal growth.

Biostimulants, once applied to seeds or during early plant development, exhibit the ability to expedite root formation and growth, thereby enhancing seedling recovery under adverse conditions, such as water shortage. As hormonal and nutritional supplements, these chemicals, particularly the organic ones, reduce the fertilizer requirements of plants, increase their output and tolerance to water and climatic stress (Russo and Berlyn, 1991).

Plants experiencing water deficit often encounter the damaging effects of free radicals. However, the presence of biostimulants enhances the activity of antioxidants, effectively reducing the toxic effects of these radicals and fortifying the defense mechanism of plants through increased levels of antioxidants. Biostimulants derived from humic compounds have been specifically studied for their protective role against saline stress (Türkmen et al., 2004). When applied to plants under salinity, humic compound-based biostimulants demonstrated the potential to facilitate osmotic adjustment by maintaining water uptake and cell turgor (Azevedo and Lea, 2011). In experiments with *Phaseolus vulgaris* L. under salinity concentration (120 mM NaCl), the treatment of humic acids elevated proline levels while reducing membrane leakage, indicating enhanced adaptability to salt-induced environments. Similarly, the application of humic acid extracts on rice (*Oryza sativa* L.) led to improved performance of antioxidative enzymes and scavenging enzymes of reactive oxygen species (ROS), which are essential for neutralizing harmful free oxygen radicals generated during drought and salinity in plants (García et al., 2012).

Biostimulants derived from diverse biological sources, such as algae, arbuscular mycorrhizal fungi (AMF), fungi, and bacteria are bioactive compounds that effectively boost salinity tolerance in plants. These biostimulants contribute to increased germination rates, improved growth characteristics (length, fresh weight and dry weight), enhanced plant quality, productivity and ultimately higher crop yields (Van Oosten et al., 2017).

Extracts of seaweed are a potential strategy for alleviating abiotic stress in plants. According to a study conducted by Bradáová et. al., (2016), extracts of seaweed and rhizobacteria including growth promoting rhizobacteria (PGPRs) improved maize's tolerance to low root zone temperatures. The application of

Algafect (extracts from *A. nodosum*, *Fucus* spp., and *Laminaria* spp.) at a dosage of 16 mg kg^{-1} to low root zone temperature of 12–14°C resulted in significant improvements for maize plants. Reduced leaf damage, improved shoot and root development and an increase in root length density were seen in treated plants. This results also verifies the relationship between seaweed extracts and elevated SOD (superoxide dismutase) activity in both root and leaf tissues, highlighting their essential function in enhancing the antioxidant defense system (Bradáová et al., 2016).

Literatures suggest that these biostimulants have protective qualities against abiotic stress, indicating their potential contribution to improving the resilience and sustainability of agriculture. When used properly, biostimulants can increase the root and shoot vitality of plants. However, it is essential to choose a biostimulant with caution, as its effects might vary greatly depending on the plant type.

Nanotechnology

Nanotechnology, a rapidly expanding scientific field, encompasses the study, manipulation, and application of materials, systems, and processes operating at the nanoscale, which is typically defined as 100 nanometers (nm) or smaller. The prefix 'nano' signifies a size range spanning from 1 to 100 nm, in which matter exhibits unique properties and behaviors. These small components have a significant impact on the macroscopic characteristics of materials, as nanomaterials are composed of incredibly tiny particles. One of the primary characteristics of nanomaterials is their increased surface area compared to the same quantity of larger material. Nanoparticles exhibit enhanced chemical reactivity due to this elevated surface area, which can significantly impact their mechanical, thermal and electrical properties. The high reactivity of nanoparticles can induce desirable properties, such as high activity and selectivity. Moreover, the high surface-to-volume ratio of the particles means that they have increased potential metabolic activity and responsiveness (Dubchak et al., 2010).

It is important to understand that interaction between nanoparticles and plant systems. It is mainly involving chemical reactions such as ion membrane transport activity, oxidative damage and lipid peroxidation generate reactive oxygen species, which can lead to the disruption of cellular functions and even cell death. Once nanoparticles enter plant cells, they interact with sulfhydryl and carboxyl groups, causing alterations in protein functions. NPs could form complexes with membrane transporters or root exudates before being absorbed by plants. The absorption of nanoparticles by plants can affect plant growth, development and reproduction, which can ultimately impact crop yields (Watanabe et al., 2008).

Nanomaterials can travel from leaves to roots, stems, developing grains and even from one root to another. The xylem serves as the primary pathway for transportation and absorption of NPs to the shoot and leaves (Fig 4). These nanoparticles can penetrate the leaf cuticle and enter the cell cytoplasm (Peralta-Videa et al., 2011). Once inside the cytoplasm, nanomaterials may attach to various cytoplasmic organelles and alter metabolic activities at those sites (Zhang and Monteiro-Riviere, 2009).

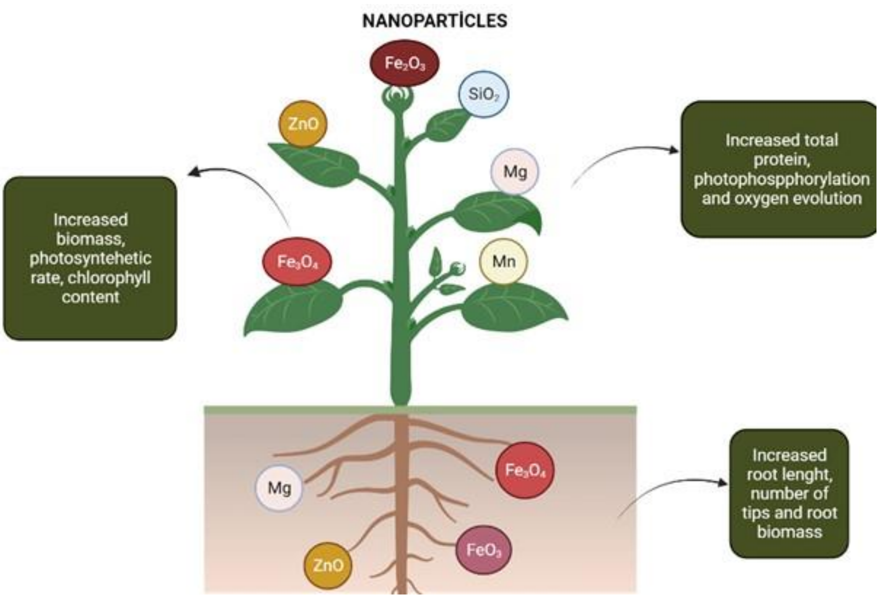

Figure 4. Nanoparticles for Mitigating Abiotic Stress and Their Effect on Plants

Numerous studies have shown that the impact of nanoparticles on plant growth and development is dependent on their concentration. Nanoparticles play a role in the upregulation of antioxidant enzymes such as SOD, CAT and POD (Laware, 2014). Recent research indicates that applying varying concentrations of silica nanoparticles enhances drought stress tolerance in hawthorn plants (*Crataegus* sp.). In hawthorn seedlings, physiological and biochemical responses vary based on different concentrations of silica nanoparticles and levels of drought stress which ranging from moderate to severe stress (Ashkavand et al., 2015). When applied to two sorghum cultivars with different drought susceptibility, silicon application resulted in increased drought tolerance for both cultivars, as evidenced by a reduced shoot-to-root

(S/R) ratio, possibly indicating improved root growth and the maintenance of photosynthetic rate. Additionally, the proline concentration significantly increased in response to silica nanoparticle treatment under stress, as compared to conventional silica fertilizer (Kalteh et al., 2018).

In an intriguing study that the implementation of nano-TiO_2 to spinach plants resulted in a involve the interaction of oxidative stress responses. The nano-TiO_2 treatment led to a reduction in the concentration of superoxide radicals, hydrogen peroxide and malonyldialdehyde, thus mitigated oxidative damage in the plants. Furthermore, the presence of nano-TiO_2 triggered a significant increase in the processes of essential antioxidant enzymes, such as superoxide dismutase, catalase, ascorbate peroxidase and guaiacol peroxidase (Lei et al., 2007).

The use of Fe nanoparticles in some plants resulted in increased yield and yield aspects during both flowering and granulation stages, with a more pronounced effect observed during the flowering stage compared to seed formation under drought stress environments without Fe nanoparticle application. Similarly, the utilization of silver nanoparticles (AgNPs) has shown promising advancements in alleviating the adverse impacts of deficit water stress on plant growth and mitigating yield loss (Hojjat, 2016).

The application of nanofertilizers could be a viable strategy for addressing soil toxicity and other stress-related issues. The effects of silicon nanoparticles and silicon fertilizer on the physiological and morphological characteristics of basil under salinity stress are considered to be encouraging. Results demonstrated a considerable increase in growth and development indices, chlorophyll content and proline level in basil (*Ocimum basilicum*) treated with silicon nanoparticles and silicon fertilizer during salinity (Kalteh et al., 2018).

Few research has examined the influence of nanomaterials on antioxidants and other chemicals. For instance, treatment of *Brassica juncea* with silver nanoparticles enhanced the activity of antioxidant enzymes such as ascorbate peroxidase, guaiacol peroxidase and catalase, causing a reduction in reactive oxygen species (ROS). Providing Ag nanoparticles with a size of 6 nm at a concentration of 5 mg/l similarly stimulated the antioxidant system of *Spirodela polyrhiza*, as shown by elevated superoxide dismutase, catalase, and peroxidase activity. Moreover, this treatment significantly boosted the ROS levels, glutathione and malondialdehyde (Sharma et al., 2012).

When *Brassica juncea* seedlings were treated with gold nanoparticles (GNPs), the activity of antioxidant enzymes, including ascorbate peroxidase, guaiacol peroxidase, catalase and glutathione reductase, exhibited a notable increase. Additionally, the accumulation of H_2O_2 and proline was also significantly enhanced. Interestingly, the contents of H_2O_2 and proline demonstrated an upward trend with increasing GNP concentration (Gunjan et al., 2014).

Nanoparticles have emerged as remarkable agents that contribute to enhancing the stress tolerance of plants through a myriad of processes. One of their significant effects is the improvement of root hydraulic conductivity and water absorption, enabling plants to cope more effectively with limited water availability and drought stress. This enhanced ability to take up water plays a crucial role in maintaining turgor pressure and overall plant health under challenging environmental conditions.

Understanding the intricate mechanisms underlying nanoparticle-plant interactions holds great promise for devising innovative strategies to improve crop productivity, mitigate environmental stress and ensure food security in the face of changing climatic conditions. As we continue to delve into the complexities of nanoparticle-plant relationships, we uncover novel opportunities to harness their potential for creating resilient and thriving plant cultures in a rapidly changing world.

Genome editing

Plant genome editing techniques have witnessed remarkable advancements in recent years, paving the way for unprecedented opportunities in functional genomics and crop improvement. Among the diverse array of genome editing tools available, four primary categories stand out, each distinguished by its unique approach to precise DNA modification. These groundbreaking techniques are meganucleases, zinc-finger nucleases (ZFNs), transcription activator-like effector nucleases (TALENs) and the revolutionary CRISPR/CRISPR-associated protein 9 (Cas9) system, all of which have revolutionized the field of genetic manipulation (Adli, 2018).

While genome editing has been successfully utilized to enhance the nutritional content and production of plants, among other aspects (Sedeek et al., 2019), its usage for developing plants resistant to abiotic stress remains relatively limited. However, with the advent of highly efficient genome editing tools such as CRISPR/Cas, numerous opportunities arise for enhancing the abiotic stress resistance of plants. Moreover, genome editing allows for a deeper understanding of the involvement of various stress signaling in abiotic stress adaptation. By employing site-specific endonucleases (SSEs), genome editing provides a powerful tool for achieving genomic alterations without integration (Jain, 2015).

Nevertheless, the prevalence of off-target mutations remains a crucial concern in genome editing. Specifically, CRISPR/Cas9, one of the prominent genomes editing technologies, often identifies imperfect matches, leading to nonspecific cleavage of nucleotide sequences. Although it is expected that rigorous breeding and selection processes in various crop improvement efforts will isolate these off-target mutations, they still pose a significant challenge to the efficient use of genome editing in plants. To address this issue, researchers have developed software tools such as CRISPR-GE and CRISPR-P, which aid in the accurate construction of guide RNA (Mao et al., 2019; Xie et al., 2017).

Genome editing has emerged as an invaluable and highly efficient tool for crop development projects, offering ease and specificity in manipulating plant genomes. Its potential applications in functional genomics and plant breeding have opened new avenues for enhancing crop traits. Particularly, genome editing holds promise for creating crops resistant to abiotic stress, providing a potential solution to address world hunger challenges. Nevertheless, several technological and legislative challenges must be addressed and overcome before genome editing can be effectively implemented to revolutionize global agriculture.

Plant Microbiome Management

The plant-associated microbiome plays an essential function in plant health and development. Its activities include defending plants against infections, promoting plant nutrient absorption, regulating plant hormone signaling and increasing tolerance to abiotic stress (Berg et al., 2014; Haichar et al., 2014).

In natural environments, plants coexist with a diverse array of microbes residing in various plant parts. The utilization of microorganisms for stress mitigation in agricultural systems has been an important practice (Turner et al., 2013).

The use of bioinoculants has gained significant attention in recent years as an effective approach to promote plant growth and development, increase agricultural yield, and help plants deal with various challenges. Bioinoculants consist of beneficial microorganisms, such as biofertilizers, biopesticides, bioherbicides and bio-control agents, that can be used either as single microbial strains or as consortia of carefully selected microbial strains (Ahirwar et al. 2019).

Bioinoculants are typically delivered to the rhizosphere of plants, either directly or indirectly through seeds to ensure that they have a beneficial effect on the plant. The rhizosphere is the region of soil surrounding the plant's roots, where a diverse community of microorganisms exists, including bacteria, fungi, and other microorganisms (Jambhulkar et al., 2016). These microorganisms can interact with the plant in different ways, such as by producing growth-promoting substances, protecting the plant from harmful pathogens and helping the plant absorb nutrients from the soil (Chaudhary et al., 2020).

Microorganisms that mitigate abiotic stress include plant-growth-promoting rhizobacteria (PGPRs) and plant-growth-promoting fungi (PGPFs) (Fig 5). These beneficial bacteria employ various strategies to reduce abiotic stress, such as synthesizing phytohormones, lowering ethylene oxide levels, enhancing dehydration response and stimulating genes encoding antioxidant proteins. Bacteria residing in the plant's root secrete phytohormones that foster seedling growth and ameliorate salt stress (Porcel et al., 2016). Additionally, plant-growth-promoting bacteria like *Pseudomonas* sp. and *Bacillus* release indole acetic acid and siderophores, promoting plant development under stressful conditions. The reduction of ethylene levels further supports root growth, ultimately leading to healthier plants (Al-Arjani et al., 2020).

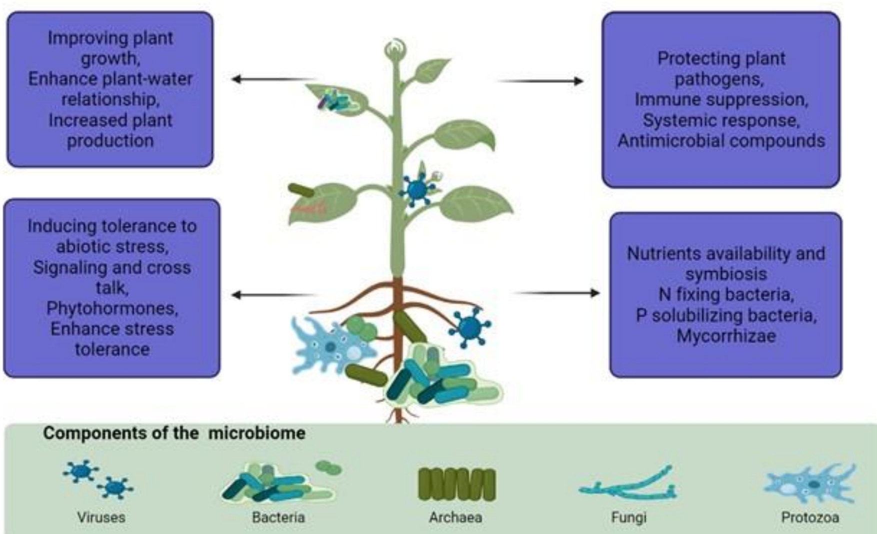

Figure 5. Interactions of Plant and Microbiome

Numerous studies indicate that bacteria play a significant role in abiotic stress-induced plant growth. This is due to the activation of primary metabolisms, which results in higher plant growth, enhanced photosynthesis, increased nutrient absorption and increased antioxidant enzyme activity. Additionally, secondary metabolites like flavonoids, phytoalexins, phenylpropanoids and carotenoids contribute to abiotic stress tolerance, with both fungal and bacterial species increasing their production under stress (Chen et al., 2017).

Under drought stress, the root microbiomes of rice (*Oryza sativa*) and sorghum (*Sorghum bicolor*) exhibit higher levels of Actinobacteria. In a study involving 30 plant species subjected to drought stress, it was found that *Streptomyces* species dominated the root endosphere population. This dominance of *Streptomyces* species provided drought resistance to the plant species, enhancing the root development of sorghum seedlings due to their growth-promoting effects. Actinobacteria may also dominate the soil bacterial population during drought conditions. As soil becomes dry, diffusion channels are reduced, leading to nutrient deficits. Bacteria, store osmolytes within their cells to lower internal solute potential and prevent water loss in response to such conditions (Reise and Waller, 2009; Xu and Zhou, 2006).

Microbiomes utilize their metabolic and genetic capabilities to assist plants in alleviating abiotic stress. Among the most significant rhizospheric occupants known for mitigating various abiotic stresses in plants are *Pseudomonas, Azotobacter, Azospirillium, Rhizobium, Pantoea, Bacillus, Enterobacter, Bradyrhizobium, Methylobacterium, Burkholderia, Trichoderma* and *cyanobacteria* (Munir et al., 2022).

In a study by Simmons et al., (2014), *Streptomyces* sp. was used to alleviate salt stress and promote growth in Micro-Tom tomato plants. Rhizobacteria-induced drought resistance and resilience are characterized by changes in phytohormone levels, defense-related proteins, enzymes, antioxidants and epoxypolysaccharides (RIDER). These modifications enhance a plant's ability to withstand abiotic stressors (Raymond et al., 2004).

In summary, the plant-associated microbiome and bioinoculants are effective approaches to promote plant growth, increase agricultural yield, and help plants deal with various challenges. The microbiome's activities include defending against infections, promoting nutrient absorption, regulating hormone signaling and increasing tolerance to abiotic stress. Beneficial bacteria like PGPRs and PGPFs employ various strategies to reduce abiotic stress and numerous studies indicate that bacteria play a significant role in abiotic stress-induced plant growth. By harnessing the activities of beneficial microorganisms, farmers and researchers can enhance plant growth, increase agricultural yield and help plants withstand various abiotic stress challenges. However, it is important to continue investigating and refining these approaches to ensure their effectiveness for different crops and environmental contexts. By capitalizing on the power of the plant-associated microbiome, it can work towards building resilient and productive agricultural systems for the future.

Biochar Applications

Biochar is a black biomass comprised of carbon, generated at high temperatures (700 °C) from organic wastes (such as agricultural residues, animal or poultry manure) by pyrolysis in a closed furnace in the absence of oxygen or in conditions with insufficient oxygen. Biochar has received considerable interest in recent years because to its potential to mitigate global climate change by sequestering atmospheric CO_2 in soil. In complement to its carbon content, biochar also has the ability to feed plants with nutrients and minerals, particularly in highly degraded, nutrient-poor and weathered environments (Chaganti and Crohn, 2015; Lutfunnahar et al., 2021).

In degraded soils, the use of biochar alone or in mixture with other substrates is anticipated to improve crop resistance to both abiotic and biotic stressors. By strategically using biochar, provides agricultural advantages such as better soil structure, greater soil fertility and improved ability to manage soils pollutants, metalloids and other contaminants (Mansoor et al., 2021). However, the effectiveness of biochar for boosting plant stress resistance is reliant on a variety of elements, such as biochar's properties, rate of application, soil composition and the prevailing meteorological conditions at a specific area (Fig 6) (Hasnain et al., 2022).

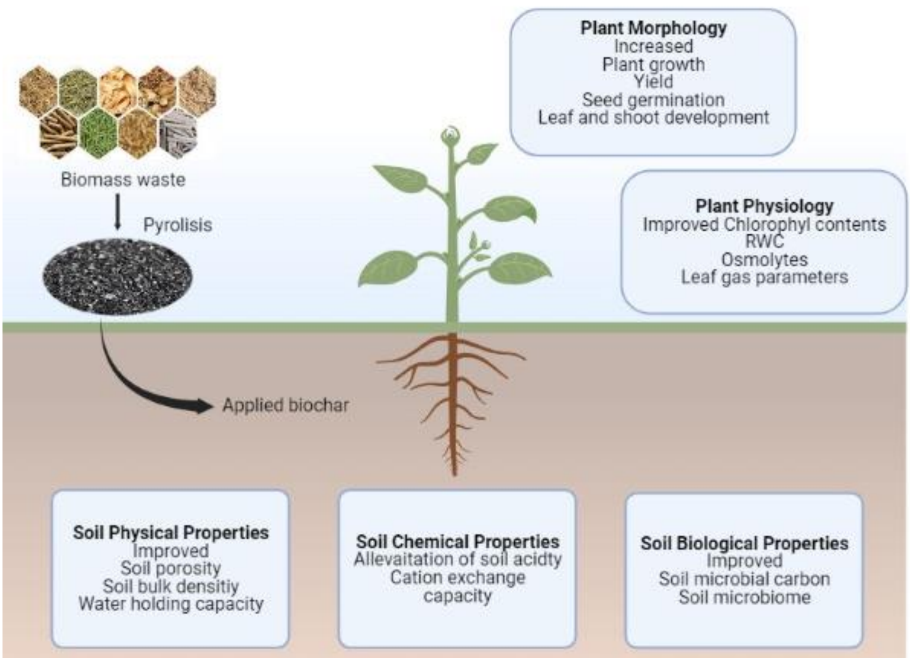

Figure 6. Effect of Biochar on Soil and Plant Features

When biochar is utilized for salinity mitigation, it has been observed to improve soil physiochemical and biological parameters related to sodium removal, such as absorption ratio and electrical conductivity, thereby reducing salt stress. Additionally, biochar significantly enhances soil enzyme activity in saline soil when applied at varying ratios. The application of furfural biochar to salty soil leads to a decrease in pH while enhancing soil organic carbon, cation exchange capacity, and phosphorus availability. When used in conjunction with saline irrigation, biochar increases both yield and biomass. Furthermore, adding biochar along with suitable microbiological inoculants to saline soil enhances plant biomass compared to the control plot (Wani et al., 2022).

The use of biochar in drought conditions can have a significant impact on plant growth, leading to improved crop yields and overall plant health. A substantial number of research has been executed on the effects of biochar on plant growth in drought conditions. The results show that the application of biochar generally enhances the growth of various plant species, leading to increased plant height and leaf area in crops such as rice, okra, maize and reed. The ability of plant cells to adjust osmotically, accumulate organic solutes, regulate water influx and reduce efflux, plays a crucial role in their response to changes in environmental conditions. This mechanism helps maintain turgor pressure, which is essential for structural support and proper functioning of cells. In addition, it allows plants to protect themselves against the harmful effects of reactive oxidative species, which can cause biomembrane damage and decrease photosystem II efficiency. The adjustments in plant cells, coupled with biochar-amended soils, contribute to reducing water stress on plants. This alleviation of water stress eases the burden on photosynthesis, leading to higher rates of growth. The increase in photosynthetic activity is manifested through improved water use efficiency, stomatal conductances and photosynthetic rates. These positive impacts on plant physiology highlight the potential benefits of incorporating biochar as a soil amendment, providing a promising avenue for enhancing plant productivity and resource utilization in a sustainable manner (Agegnehu et al., 2016, Jabborova et al., 2021, Olmo et al., 2014, Ullah et al., 2021, Hasnain et al., 2022).

Research studies have consistently shown the positive impact of post-treatment with biochar for heavy metal-polluted soils. In one such study, combining biochar with Rhizophagus clarus significantly improved various parameters in maize grown in cadmium-spiked soil. Compared to control conditions, the addition of biochar resulted in a 93% increase in maize dry biomass, a 32-61% increase in root growth and a 1% increase in phosphorus concentration. Additionally, the use of acidified biochar enhanced the availability of essential nutrients like nitrogen, phosphorus, potassium and calcium, displaying its potential to mitigate metal stress and improve plant growth in contaminated soils (Rafique et al., 2019).

The application of biochar increases the accessibility of soil nutrients to plants, resulting in improved physiological processes and higher yields. In salt-stressed plants, biochar reduces Na+ uptake and increases K+ uptake. The applied plants demonstrate reduced Na+ uptake, mineral accumulation, conductance and phytohormone modulation, all contributing to salt tolerance (Serrano, 2021).

The application of biochar to plants presents a promising and innovative approach to mitigating abiotic stress in plants. The intricate relationship between soil health, plant growth and environmental challenges deepens, biochar has emerged as a valuable tool in promoting plant resilience. Through its ability to enhance soil structure, improve water retention and foster nutrient availability, biochar serves as a multifaceted solution to counteract the detrimental effects of abiotic stressors.

CONCLUSION

In conclusion, the recent advancements in mitigating abiotic stress in plants have brought about novel strategies and emerging technologies that have the potential to use in agriculture.

Biostimulants, nanotechnology, genome editing, plant microbiome management and biochar application are all promising approaches that can help plants withstand environmental stressors. Biostimulants enhance plant growth and improve stress tolerance while nanotechnology improves plant resistance to abiotic stress. Genome editing allows scientists to modify plant genes responsible for stress responses, enabling the development of stress-tolerant plant varieties. Plant microbiome management and biochar application are also effective strategies for improving plant resilience to abiotic stress.

These approaches are essential for addressing world hunger challenges and ensuring sustainable agriculture. Furthermore, these strategies can not only improve plant resilience but also enhance crop productivity and nutritional content. It is important to note that the efficacy of these approaches depends on various factors such as plant type, environmental conditions and the specific approach that used. Therefore, extensive research and careful consideration are necessary when implementing these strategies. However, the potential benefits of these approaches are significant and their continued development and implementation can contribute to a more sustainable and food-secure future.

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Chapter 8

Determination of Vegetation Structure and Biomass Estimation in Kaplanlı Village Natural Rangeland in Isparta Province Using Geographic Information Systems (GIS)

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ABSTARCT

INTRODUCTION

Vegetation is a community composed of many plant species that grow together, interact with each other and exist on a particular land area. Nowadays, the main objective of vegetation studies revolves around determining the species composition in plant communities and subsequently examining their characteristics (Altın, 1996).

According to the data from the Food and Agriculture Organization (FAO) for the year 2020, the global extent of rangelands amounts to approximately 3.4 billion hectares (FAO, 2020). Rangeland, which are among the most common terrestrial biomes found in arid and semi-arid regions, provide essential ecosystem services and significant benefits to human beings (Holechek, 2013; Sala et al., 2017). Moreover, rangelands constitute approximately 91% of the land dedicated to animal production and serve as a source of genetic and biological diversity for a significant majority of plant species. In addition to being indispensable natural resources for the shelter and conservation of animals, they also play a crucial role in protecting the soil from erosion (Dursun and Babalık, 2018; di Virgilio et al., 2019; Babalık and Dursun, 2021).

Rangeland, as a valuable source of high-quality roughage, have experienced a 70% reduction in Türkiye over the past 50 years. However, studies and statistical data have revealed significant discrepancies, indicating considerable variations among the sources used. The total area of grasslands and rangelands in our country is 14.6 million hectares (TSI, 2019; Dursun and Babalık, 2018). While the average forage yield of rangeland in Türkiye is approximately 70 kg/da, this figure represents about 33% of the world average (Babalık and Dursun, 2021).

Based on the 2021 data from the Turkish Statistical Institute (TSI), it is observed that our country has approximately 23.8 million animal units and an approximate demand of 71.3 million tons of roughage. According to the data from the General Directorate of Plant Production (GDPP) regarding the roughage deficit, there is a shortage of 27 million tons of roughage. Currently, the effects of global climate change are being strongly felt. Considering the increasing droughts in our country in the coming years, it is possible that the roughage deficit may further increase (Anonymous, 2022).

When examining the literature, it can be observed that there is no standardized method for monitoring and assessing rangelands on a global scale. Various systems are used depending on different rangeland areas. The development of different methods is related to variations in climate, land use practices and ecological conditions from region to region. Consequently, different results emerge, leading decision-makers and policymakers to guide users towards different alternatives (Işık et al., 2022).

Scientific research is conducted in various fields such as ecology, geology, etc., to determine and map areas with high growth potential for plants in rangeland ecosystems (Loveland and Merchant, 2004). These types of mapping efforts help in better understanding natural resources and contribute to improving land management decisions. For example, mapping techniques can be used in areas of rangelands that are subject to overgrazing pressure or where local extinction is likely (Svoray et al., 2013). Additionally, differences between the potential and actual distributions of plant species, which hold ecological significance and play an important role in determining the capacity of a rangeland, can be identified (Sharifipour et al., 2023). Monitoring vegetation is essential for understanding the cause and effect relationship of environmental changes and has long been at the center of grazing plans and rangeland improvement efforts (McCord and Pilliod, 2022).

Due to prolonged and overgrazing, as well as the lack of improvement and maintenance work, the vegetation structure of rangelands, including those in the Isparta region, has been significantly disrupted, leading to reduced forage yields. Similar to rangelands in our country, the rangelands in the Isparta region have also been overgrazed, exceeding their carrying capacity, resulting in the destruction of a significant portion of the plant cover. In order to solve the problem, re-vegetation of these areas and improvement of existing vegetation cover are necessary. Therefore, it is essential to understand the balance between vegetation cover, topography and soil factors both in the rehabilitation of degraded areas and in the improvement of existing ones to transform them into productive rangelands (Babalık and Dursun, 2021).

The aim of the study was to determine the plant species present in Kaplanlı Village natural rangeland, assess the ground coverage of rangeland plants, measure above-ground and below-ground biomass, estimate the carrying capacity for grazing and investigate the general soil properties of the rangeland. Nowadays, with the advancements in technology, both Geographic Information Systems (GIS) and remote sensing techniques allow for the monitoring and tracking of vegetation cover and changing ecosystem parameters. This is of significant importance for our country's development, especially in areas with diverse flora and where pastoral-based animal husbandry is practiced.

2. MATERIALS AND METHODS

2.1. Material

This research was conducted in the natural rangeland of Kaplanlı Village, located within the boundaries of Keçiborlu district in the province of Isparta, Türkiye, during the vegetation period of the year 2022 (Figure 1). Keçiborlu district is bordered by Isparta city center to the southeast, Dinar, Dazkırı and Başmakçı districts of Afyon province to the west, Uluborlu district to the north and Burdur province and Burdur Lake to the south. The study area has an average elevation of 1020 meters and a general orientation of north-northwest. The selected rangeland area for this study covers 867 decares and is subject to continuous grazing, falling within the C3 square of the quadrat system used by Davis (1964-1985) in the Flora of Türkiye. The region is generally characterized by a Mediterranean-Continental climate. The winter months are cold and rainy, while the summers are hot and dry.

In the vicinity of the study area, sparse woodlands stands can be found on slopes and plains, while towards the hills, there are forested areas consisting of pine species (*Pinus* spp.) and oak species (*Quercus* spp.). The surrounding areas of settlements are utilized for the cultivation of fruits, roses (*Rosa* spp.) and oil crops (Aydemir, 2022).

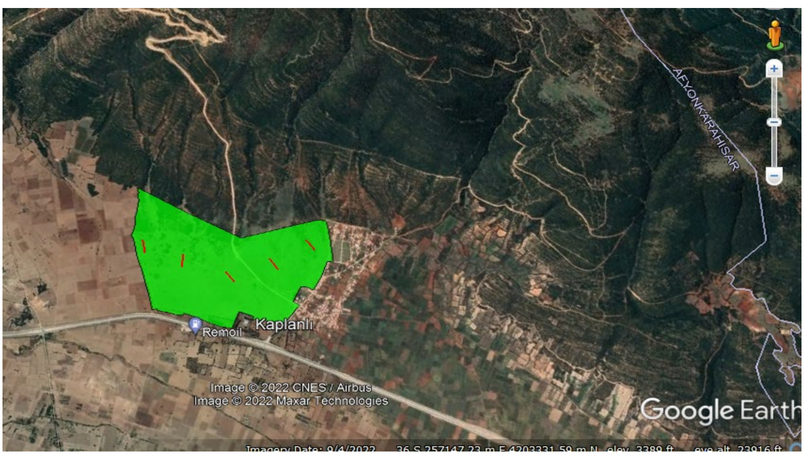

Figure 1: Location of Kaplanlı Village rangeland

2.2. Method

Transect and quadrat methods were employed in the field to determine the characteristics of the rangeland vegetation in the study area. Soil samples were collected to reveal the general soil structure of the research area. These soil samples were analyzed in the Soil Physics Laboratory of the Department of

Watershed Management, Faculty of Forestry, Isparta Applied Sciences University. In the laboratory, various soil properties such as texture, organic matter content, bulk density, pH, electrical conductivity and lime content were determined. For the determination of vegetation characteristics, criteria such as climate and soil factors, dry forage yields of the rangeland, slope, elevation, aspect, carrying capacity and above-ground and below-ground biomass values were taken into account. The elevation of the rangeland areas from the sea was determined by "altimeter", the direction in the sample areas was determined by "compass" and the slope was determined by "inclinometer". The following procedures were carried out in this research (Figure 2).

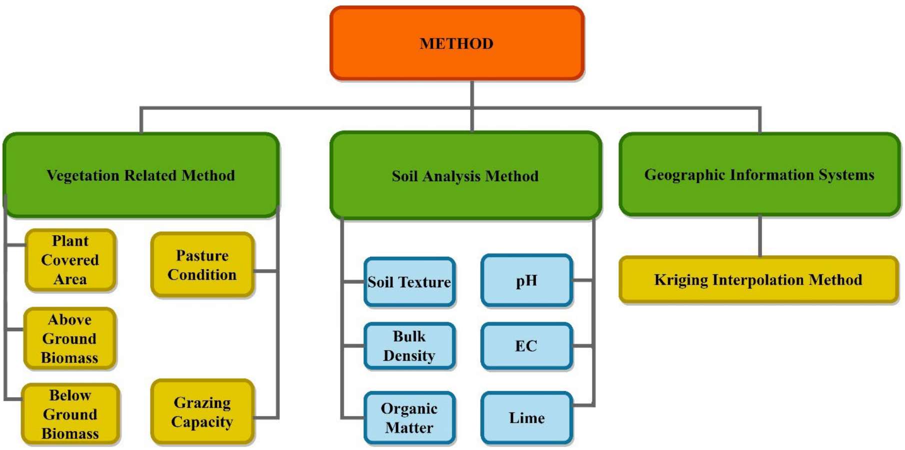

Figure 2: Chart of the methodology

CORINE classification was utilized to determine the land cover classes. The land cover classes were coded according to CORINE as follows: artificial areas (1), agricultural areas (2), forest and semi-natural areas (3), wetlands (4) and water bodies (5) (CORINE, 2023) (Table 1).

Table 1: Land use classification of Keçiborlu district

CORINE 2018	Area (Hectares)	Percentage (%)
Artificial Areas (1)	884.30	1.79
Agricultural Areas (2)	21078.90	42.68
Forest and Semi-Natural Areas (3)	24154.96	48.91
Wetlands (4)	1526.15	3.09
Water Bodies (5)	1744.35	3.53

2.2.1. Determination of vegetation structure

To determine the vegetation structure in the research area, the "transect method," preferred by researchers such as Angassa (2014), Sasaki et al. (2009), Babalık and Dursun (2021), Chebli et al. (2023), Chen et al. (2023) and Jamil et al. (2023) was used. This method involves implementing five transect lines, each measuring 100 meters in length, in the rangeland area. The transect measurements involved determining the percentage of plant covered area by calculating the ratio of the total plant covered area to the total transect area (Gökkuş et al., 1995). The following formula was used for this calculation.

$$\text{Percentage of Area Covered by Plants (\%)} = \frac{\text{Number of Transects Encountering Plants}}{\text{Total Number of Measured Transects}} \text{X } 100$$

The transect method, which was used to determine the percentage of area covered by plants, was also employed in determining the botanical composition. The quadrat method, actively utilized by researchers such as Sasaki et al. (2009), Angassa (2014), Babalık and Dursun (2021), Chebli et al. (2023) and Wang et al. (2023) was applied to quantify the above-ground and below-ground biomass of the rangeland area. In this method, 1x1 square meter quadrats were used. Five quadrat measurements were taken from each transect line. For determining the above-ground biomass, the plants within the 1 m^2 quadrat were harvested from the ground level, placed in a plastic bag and collected. For the determination of below-ground biomass, the harvested vegetation was removed while preserving the roots to a depth of 20 cm, taking into account the active root depth (Figure 3).

Figure 3: Implementation of the transect and quadrat methods in the research area

After these procedures, the harvested vegetation was bagged in a way that no soil remained and then washed. Following the washing process, the samples were dried at 70°C for 24 hours and weighed to convert the measurements to kg/da (Smet and Ward, 2006) (Figure 4).

Figure 4: Drying and weighing processes of above-ground and below-ground biomass

The determination of rangeland condition was based on the a plant covered area obtained through transect measurements, as indicated in Table 2 (Bakır, 1975).

Table 2: Rangeland condition

Plant Covered Area (%)	Rangeland Condition
75-100	Excellent
50-75	Good
25-50	Fair
0-25	Poor

To determine the grazing capacity in the research area, the following formula, commonly used by researchers such as Özgür et al. (2017), Dursun and Babalık (2018), Dursun et al. (2018) and Ok and Çaçan (2023) was applied. This formula takes into account the general average yield values of the rangeland (Gökkuş et al., 1995)

$$\text{Animal Units} = \frac{\text{Rangeland area} * \text{Forage quantity per unit area} * \text{Percentage utilisation}}{\text{Daily forage requirement} * \text{Number of grazing days}}$$

2.2.2. Physical and chemical properties of the soils

Determination of soil texture was conducted using Bouyoucos' hydrometer method and a texture triangle (Bouyoucos, 1951). Soil samples were emptied from the cylinders, placed in an oven and kept at 105°C for 24 hours. The oven-dry weight of the sample was then divided by the volume of the cylinder to determine the bulk density values in gr/cm³ (Özyuvacı, 1975). The Walkley-Black wet combustion method was used to determine the organic matter content of the soil, with 0.5g samples passing through a 0.2 mm sieve (Kacar, 1996; Karagül, 1994). The pH of the soil samples was measured using an Orion 420 A digital pH meter in a 1:2.5 ratio of soil to distilled water (Gülçur, 1974). The lime content was determined using the calcimetric lime determination method on a 1gr soil sample (Langon and Heald, 1982). Electrical conductivity was measured using a WTW Multiline F/Set-3 device in a 1:5 ratio of soil to distilled water (Gülçur, 1974).

2.2.3. GIS

GIS and other related tools are effectively utilized in determining rangeland management strategies (Yomralıoğlu, 2002). Kriging interpolation method is a technique used to estimate the values of new points by taking a weighted average of the values of nearby known points (Uyan, 2019; Alaboz et al., 2021). Kriging interpolation method calculates a variance value for each point to be estimated, allowing for the determination of the values of unknown points (Akar, 2017; Alaboz et al., 2020). Using the Kriging method, above-ground and below-ground biomass maps were generated for different seasons (summer-autumn).

2.2.4. Evaluation of the data

Statistical Analysis was conducted using the SPSS 20.0 software package (SPSS Inc. 2011) to determine whether there were significant differences in above-ground and below-ground biomass between the summer and autumn seasons. Independent samples t-test was used for this analysis.

3. RESULTS

3.1. Plant covered area

The proportion of plant covered area in the June measurement was found to be 34.20% for poaceae, 25.90% for fabaceae and 23.20% for other plant families. In the October measurement, these proportions were found to be 29.50% for poaceae, 24.90% for fabaceae and 21.30% for other plant families. The average plant covered area was found to be 31.85% for poaceae, 25.40%

for fabaceae and 22.25% for other plant families. The overall average plant covered area was calculated as 60.10% in June, 54.40% in October and the overall average was 57.25% (Table 3).

Table 3: Plant covered area data for Kaplanlı Village rangeland

	Families	Plant Covered Area(%)	Plant Covered Area (%)
June Measurement	Poaceae	%34.20	%60.10
	Fabaceae	%25.90	
	Other	%23.20	
	Bare Land	%16.70	%39.90
	Total	%100.0	%100.0
October Measurement	Poaceae	%29.50	%54.40
	Fabaceae	%24.90	
	Other	%21.30	
	Bare Land	%24.30	%46.60
	Total	%100.00	%100.0
Average	Poaceae	%31.85	%57.25
	Fabaceae	%25.40	
	Other	%22.25	
	Bare Land	%20.50	%52.75
	Total	%100.00	%100.0

3.2. Above-ground biomass

In the measurement conducted in June, the share of above-ground biomass in poaceae, fabaceae and other families was found to be 70.83 kg/da, 53.64 kg/da and 82.63 kg/da, respectively. In the measurement taken in October, these values were 49.59 kg/da, 41.86 kg/da and 76.65 kg/da, respectively. The average values, accordingly, are 60.21 kg/da, 47.25 kg/da and 79.64 kg/da. The overall average above-ground biomass was calculated as 207.10 kg/da in June, while it decreased to 168.10 kg/da in October. The average for both seasons combined was calculated as 187.60 kg/da (Table 4).

Table 4: Distribution and mean values of above-ground biomass in the rangeland area

	Families	Above-ground biomass (kg/da)	Total (kg/da)
June Measurement	Poaceae	70.83	207.10
	Fabaceae	53.64	
	Other	82.63	
October Measurement	Poaceae	49.59	168.10
	Fabaceae	41.86	
	Other	76.65	
Average	Poaceae	60.21	187.60
	Fabaceae	47.75	
	Other	79.64	

3.3. Below-ground biomass

Below-ground biomass of Kaplanlı Village rangeland in June measurements were found to be 122.50 kg/da, 92.77 kg/da and 142.92 kg/da for poaceae, fabaceae and other families, respectively. In October, the values were 87.53 kg/da, 73.88 kg/da and 135.29 kg/da for the same families. The mean values indicate that the contributions of poaceae, fabaceae and other families were 105.01 kg/da, 83.33 kg/da and 139.11 kg/da, respectively. The overall mean below-ground biomass was calculated as 358.2 kg/da in June, 296.7 kg/da in October and the average below-ground biomass was 327.45 kg/da (Table 5).

Table 5: Distribution of below-ground biomass by families in the rangeland area

	Families	Above-ground biomass (kg/da)	Total (kg/da)
June Measurement	Poaceae	122.50	358.2
	Fabaceae	92.77	
	Other	142.92	
October Measurement	Poaceae	87.53	296.7
	Fabaceae	73.88	
	Other	135.29	
Average	Poaceae	105.01	327.45
	Fabaceae	83.33	
	Other	139.11	

3.4. Rangeland condition

The rangeland condition was calculated as 60.10% in June measurements, 54.40% in October measurements and the average condition was determined as 57.25% based on the percentage of the area covered by vegetation (Table 6).

Table 6: Condition of Kaplanlı Village rangeland

Seasons	Plant Covered Area (%)	Rangeland Condition
June Measurement (Summer)	60.10%	Good
October Measurement (Autumn)	54.40%	Good
Average	57.25%	Good

In this context, when considering the seasons, the rangeland condition is determined as good in the summer, autumn and overall categories.

3.5. Grazing capacity

To determine the grazing capacity in the research area, the general average productivity values of the rangeland were used in the following formula. According to the formula, the grazing capacity of Kaplanlı village rangeland calculated as 30.1animal units.

$$\textbf{Animal Units} = \frac{867 * 187.6 * 0.5}{15 * 180} = 30.10\ \text{Au}$$

3.6. Soil characteristics

To assess the general soil structure of the rangeland area, soil samples were collected from the field and analyzed in the laboratory of the Department of Watershed Management at Isparta Applied Sciences University, Faculty of Forestry. The soil analysis revealed that the soil texture of the rangeland area is classified as clay loam. The bulk density of the soil is determined as 1.30 gr/cm^3, the organic matter content is 1.47%, the pH value is 7.76 (alkaline), the calcium carbonate (lime) content is 28.88% and the electrical conductivity is 0.212 uS/cm (Table 7).

Table 7: Average soil analysis results for Kaplanlı Village rangeland

Analysis Name	Result
Texture (%)	Clay loam
Bulk Density (g/cm^3)	1.30
Organic Matter (%)	1.47
pH Determination	7.76
Calcium Carbonate Content (%)	28.88
Electrical Conductivity (uS/cm)	0.212

3.7. GIS features

It is possible to say that with GIS and remote sensing techniques, the quality of rangelands, the estimation of biomass quantities and the determination of grazing capacities can be achieved. Moreover, the condition of rangelands can be monitored throughout the vegetation period (Bozkurt et al., 2008).

3.7.1. Generation of above-ground and below-ground biomass maps for the summer season

Maps of above-ground and below-ground biomass for the summer season were generated using the Kriging method. Figure 5 and Figure 6 present the maps of above-ground and below-ground biomass for the summer season. The minimum value of above-ground biomass for the summer season was calculated as 86.99 kg/da, while the maximum value was 513.92 kg/da (Figure 5).

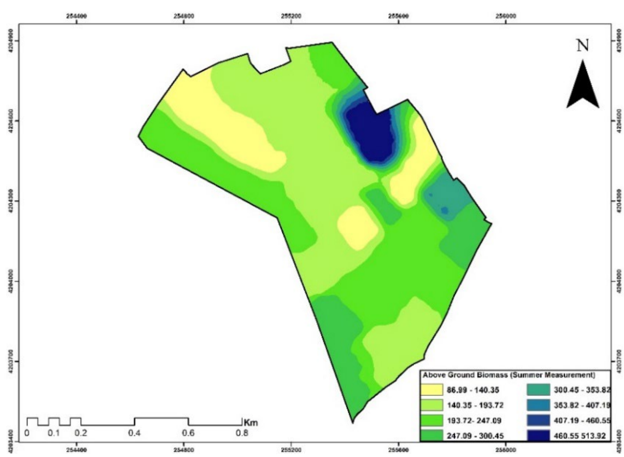

Figure 5: Map of above-ground biomass for the summer season

The lowest summer season below-ground biomass is calculated as 146.30 kg/da and the highest is calculated as 1027.0 kg/da (Figure 6).

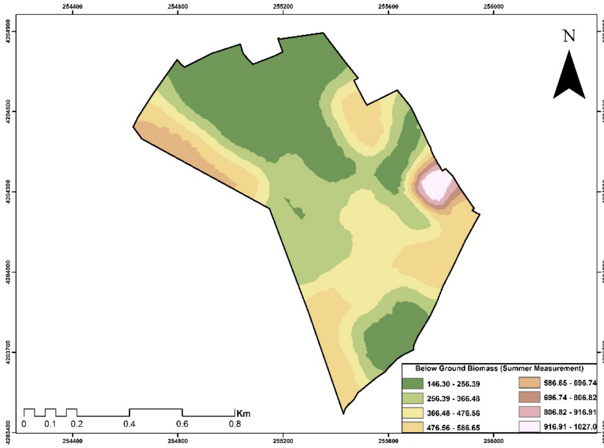

Figure 6: Below-ground biomass map for the summer season

3.7.2. Generation of above-ground and below-ground biomass maps for the autumn season

The maps of above-ground and below-ground biomass for the autumn season using the Kriging method are provided in Figures 7 and 8. The minimum value for above-ground biomass in the autumn season is calculated as 69.96 kg/da, while the maximum value is 308.33 kg/da (Figure 7).

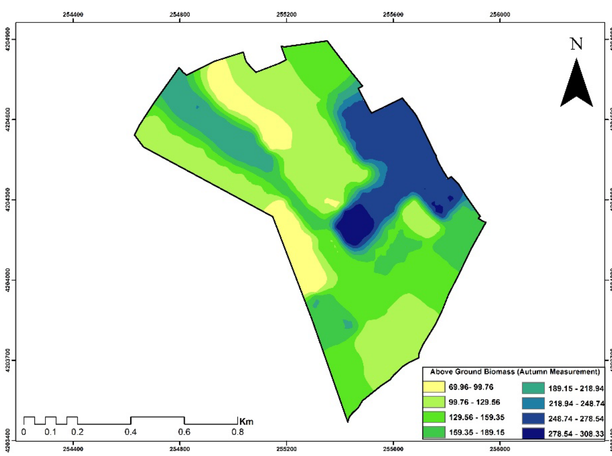

Figure 7: Above-ground biomass map for the autumn season

The minimum value for below-ground biomass in the autumn season is calculated as 59.91 kg/da, while the maximum value is 637.37 kg/da (Figure 8).

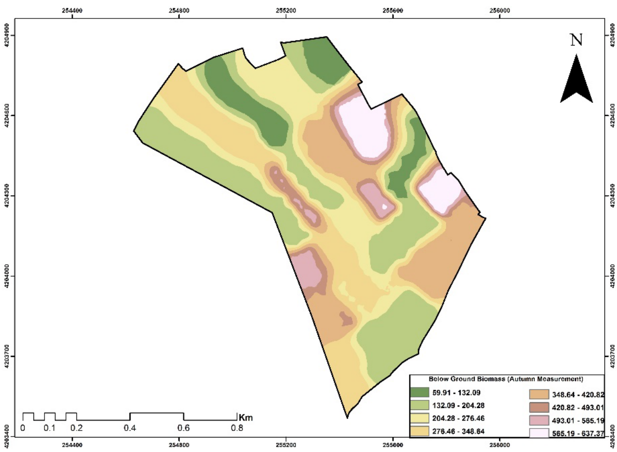

Figure 8: Below-ground biomass map for the autumn season

3.8. Evaluation of the data

Differences in above-ground and below-ground biomass between the summer and autumn seasons were evaluated using an independent samples t-test. A statistically significant difference at a significance level of $p<0.05$ was observed in terms of above-ground and below-ground biomass between the summer and autumn data of the rangeland area. Furthermore, a statistically significant difference at a significance level of $p<0.05$ was detected in the June and October data in terms of above-ground biomass in the rangeland area. Similarly, a statistically significant difference at a significance level of $p<0.05$ was found in the June and October data in terms of below-ground biomass in the rangeland area.

4. DISCUSSION AND CONCLUSION

In the research conducted in Kaplanlı Village rangeland, various physical and chemical properties of the soil, as well as vegetation characteristics in different seasons such as plant-covered area, botanical composition, above-ground biomass, below-ground biomass, rangeland condition and grazing capacity were examined. The following results were obtained regarding these characteristics. It was determined that the rangeland soil in the research area belongs to the clay loam texture class. The organic matter content of the rangeland soil was calculated as 1.47%, lime content as 28.88, pH as 7.76, EC as 0.212dS/m and bulk density as 1.30 gr/cm^3. The average plant-covered area was 57.25%, above-ground biomass was 187.60 kg/da, below-ground biomass was 327.45 kg/da and grazing capacity was 30.1 animal units, indicating a good rangeland condition.

In research conducted in various regions of our country, researchers have found different values for above-ground biomass values as 283.9 kg/da (Özer, 1988), 136.3 kg/da (Babalık, 2008), 143.54 kg/da (Çaçan and Başbağ, 2016) and 309.0 kg/da (Babalık and Matrasulov, 2020). The above-ground biomass value found in the research area was lower than the values of other researchers determined by Babalık (2008) and Çaçan and Başbağ (2016), but higher than the values reported by the above researchers. This difference is thought to be due to different topographic factors, climate characteristics and grazing practices in the regions where the studies were conducted.

Below-ground biomass values as 398.0 kg/da (Dursun, 2017), 560.7 kg/da (Ercan, 2018), 307.2 kg/da (Sönmeyen, 2019) and 546.64 kg/da (Çaçan and Başbağ, 2016). Among these data, it was found that the below-ground biomass value was close to the findings of Sönmeyen (2019) but lower than the findings of other researchers. It is believed that these differences occur due to grazing taking place during the periods when plants are growing and causing soil compaction.

The research is based on determining the below and above ground biomass and generating maps. Additionally, highlighting differences between seasons is also crucial for the research. Mapping this significant issue visually and numerically allows the production of potential and risk maps for rangeland areas. Consequently, it is believed that this will greatly facilitate decision-makers in determining future rehabilitation measures. The concept of rangeland biomass is crucial for rangeland vegetation and holds importance for parameters such as assessing rangeland condition and determining grazing capacity. Understanding biomass is necessary for our country, which possesses a rich flora and particularly for the development of rangeland-based livestock farming.

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