Global Climate Change:

Agriculture and Food Science Perspective

Edited by
Assoc. Prof. Hülya DOĞAN, Ph.D.
Assist. Prof. Hafize FİDAN, Ph.D.

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EDITORS

Assoc. Prof. Hülya DOĞAN, Ph.D.
Assist. Prof. Hafize FİDAN, Ph.D.

AUTHORS

Prof. Dr. Duygu BAKİ ACAR
Prof. Dr. Halil Erhan EROĞLU
Prof. Dr. Sezai ERCİŞLİ
Prof. Dr. Shakeel AHMAD
Prof. Dr. Ümit BUDAK
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Assoc. Prof. Gürsel ÖZKAN, Ph.D.
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Assoc. Prof. Hülya DOĞAN, Ph.D.
Assoc. Prof. Hakan KELES, Ph.D.
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Assoc. Prof. Muhammed KÜPE, Ph.D.
Assoc. Prof. Mustafa KAN, Ph.D.
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Res. Assist. Ece TUNÇ
Ahmad Abdul WAHAB, Ph.D. Student
Berna KELES, M.Sc. Student
Muhammad Amir JAVED, M.Sc. Student
Muhammad Tahir ABBAS, M.Sc. Student
Rana Mudassir Manzoor KHAN, M.Sc. Student

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CONTENTS

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PREFACE

Dear readers,

The global climate has changed in the last 100 years due to anthropogenic activities, and the temperature has warmed by about 0.5°C due to greenhouse gas emissions. This issue has attracted international interest, and particularly scientific communities will continue to search for solutions to slow this process, which directly and indirectly affects the quality of life of billions of people worldwide.

This warming continues due to today's intense human and economic activities and increases in greenhouse gases released into the atmosphere. Climate change is increasing its impact due to anthropogenic processes as well as natural internal processes and this is why climate change will cause effects expected to emerge at global and regional scales.

The effects of climate change are more visible on agriculture, forest and vegetation, clean water resources, sea level, energy, human health and biodiversity, which can affect them directly or indirectly in various ways. In addition to all these, climate change can cause social and economic problems and put pressure on agriculture. Under the climate change scenario, soil and water regimes change due to the change in agricultural production. Although the temperature increases and the increasing amount of carbon dioxide resulting from climate change positively affect the number of farm and agricultural products in some regions in the short term, these components may cause product quality and production reductions in the long run. Agricultural production is directly dependent on the region's climatic conditions since it is carried out by selecting crops suitable for the climate of a given area and applying appropriate farming methods. Consequently, the bio-industry is experiencing a production decline due to adverse climate changes with notable regional characteristics.

In the long term, climate change stresses water and other resources, renders soils unproductive, worsens the condition of farmland, causes widespread desertification, and, in particular, causes the increase of pests and diseases in crops. Climate change can disrupt food availability, reduce access to food, and affect food quality. For example, projected increases in temperatures, changes in precipitation patterns, changes in extreme weather events, and reductions in water availability may all result in reduced agricultural productivity.

Today, in order to eliminate these negativities due to climate change, first of all, the situation needs to be determined with climate change scenarios. Afterward, these effects are minimized by effectively implementing adaptation and the mitigation strategies level should be lowered.

This book could be a helpful tool to understand where we are in the global stand and where we are heading in the climate change in agriculture and food industries. We would like to thank all researchers and the İKSAD publishing house who contributed to the preparation of this book.

EDITORS
Assoc. Prof. Hülya DOĞAN, Ph.D.
Assist. Prof. Hafize FİDAN, Ph.D.

CHAPTER 1

THREATS TO CEREAL PRODUCTION UNDER CLIMATE CHANGE

Ph.D. Student|Ahmad Abdul WAHAB[1], M.Sc. Student | Muhammad Amir JAVED [2], M.Sc. Student | Rana Mudassir Manzoor KHAN[3],M.Sc. |Iqra Zakir[4], M.Sc. Student |Muhammad Tahir ABBAS [5], Ph.D. | Mukhtar AHMED[6], Ph.D. | Muhammad TARİQ [7], Assoc. Prof. | Mustafa KAN [8], Assoc. Prof. | Hülya DOĞAN [9], Prof. Dr. | Shakeel AHMAD [10*]

[1]Bahauddin Zakariya University, Department of Agronomy, Multan, Pakistan. ahmadabdulwahab95@gmail.com
[2]Bahauddin Zakariya University, Department of Agronomy, Multan, Pakistan. mamirdevaj@gmail.com
[3]Bahauddin Zakariya University, Department of Agronomy, Multan, Pakistan. mudassirmanzoor41@gmail.com
[4]Bahauddin Zakariya University, Department of Agronomy, Multan, Pakistan. iqrazakir54@gmail.com
[5]Bahauddin Zakariya University, Department of Agronomy, Multan, Pakistan. tahirkhadal@gmail.com
[6]Pir Mahar Ali Shah, Arid Agriculture University, Department of Agronomy, Rawalpindi, Pakistan. ahmadmukhtar@uaar.edu.pk, Orcid ID: 0000-0002-7223-5541
[7]Central Cotton Research Institute, Multan, Pakistan. mtariq131@gmail.com, Orcid ID: 0000-0002-6099-273X
[8]Kirsehir Ahi Evran University, Agricultural Faculty, Kırşehir, Turkey. mustafa.kan@ahievran.edu.tr, Orcid ID: 0000-0001-9198-5906
[9]Yozgat Bozok University, 5Department of Seed Science, Yozgat, Turkey. hulya.dogan@bozok.edu.tr, Orcid ID: 0000-0003-1970-4123
[10]*Bahauddin Zakariya University, Department of Agronomy, Multan, Pakistan. shakeelahmad@bzu.edu.pk, Orcid ID: 0000-0002-5848-2773

INTRODUCTION

Near the end of this century, average temperature of the world is forecasted to increase due to an increase in release of greenhouse gases in atmosphere. With an increase in temperature, phenology and yield of agriculture crops will be affected adversely. This will directly result in decrease in yield of crops and indirectly cause food insecurity. In this chapter it is discussed that how change in climate is affecting cereal production and what steps we can adapt to mitigate effect of these changes without compromising yield of cereal crops.

1. THREATS TO GLOBAL AGRICULTURE UNDER CLIMATE CHANGE

The most problematic challenge to the world's effort for survival right now is worldwide climate change. The current climates and their components are very different from those of the past, adding further complications to the field of climatology (Chakraborty et al., 2014). The evidence of increasing worldwide average ocean and air temperatures, extensive glacier melting, and increasing global sea level all point to a warming of the planet's climates (IPCC, 2007). Increased temperatures globally, fluctuating in wind patterns, rainfall, evapotranspiration, and unpredictable weather conditions, such as floods, storms, salinity, temperature fluctuations drought and, may result from continued climatic changes (Karkanis et al., 2018).

The agricultural sector plays a vital role in the development of the national economy (Ahsan et al., 2020). Agriculture is established worldwide and farmers from all over the world, use available inputs to grow and improve crop yields (Banerjee and Adenaeuer, 2014). All the crops require feasible environmental conditions to grow properly. Climate change is a major threat to the agriculture sector and has become crucial for the sustainable development of a nation (Howden et al., 2007) and lower crop productivity (Dube et al., 2016; Coulibaly et al., 2020). Climate change is affecting the agriculture sector by changing the temperature, weather conditions, rain patterns (Ahmad et al., 2019) and crop growth periods.

In the 21st century, climate change uncertainty that affects the agriculture sector highly that lower crop yield and production (Taylor et al., 2012; Kirtman et al., 2013). Due to climate change, net carbon intake decreased by raising rates of plant respiration. This would reduce food production amount and may potentially lead to the invasion of other things such as weeds, diseases, and other invasive species (Hogy et al., 2008). Fluctuation temperature shifts in rainfall pattern and severity, and variations in carbon dioxide (CO_2) concentration are all factors in climate change. All these variables have an impact on soil health, plant biodiversity, planted area, soil salinity and sea levels (Jackson et al., 2011) and lower crop productivity (Dube et al., 2016; Araos et al., 2016; Schauberger et al., 2017; Coulibaly et al., 2020).

The main issue affecting crop output globally is drought. Water shortages will become more frequent as a result of global warming, especially in many of Africa's existing water-shortage nations. Droughts are expected to affect 67 percent of the world's population by the year 2050 (Ceccarelli et al., 2004). Beginning and end of growing season, more drought was observed, while water shortage at the flowering or grain-filling stages reduced yield and, drought during the growing season has a significant negative impact on crop development or failure of crops entirely (Tumwesigye et al., 2002). Due to global warming, the melting of glaciers increased which caused the lowering of water sustainability, and 10-30% of water demand increased by crops due to an increase in evapotranspiration (Saif-ullah, 2017). Reservoir efficiency will decline as evaporation rates rise. More precipitation falls on land that is incapable to absorb it as a result of much more intense weather, causing floods damages as opposed to an increase in groundwater and soil moisture. Glaciers in some regions are vanishing, endangering the water supply (Hitz et al., 2004).

Due to climate change, greenhouse anthropogenic gas emissions are related to increasing amounts of CO_2 concentration in the atmosphere that directly affects crop growth and yield (Kimball, 2016) also connected to increased water consumption effectiveness (Morgan et al., 2011). In assessing the impact of the changing climate on agriculture (Deryng et al., 2016) in which CO_2 impact on crop production varies greatly that are different region-wise (McGrath and Lobell, 2013; Deryng et al., 2016). Floods and extensive droughts cause complete failure of crops and deter planting, whereas excessive heat events can cause cell damage, early or delayed flowering, and direct injury to an enzymatic system and reproductive parts of plants (Hasanuzzaman et al., 2013; Kadam et al., 2014) may disrupt crop growth and decrease yields (Boone, 2008; Lesk et al., 2016). Rainfall would rise due to global warming in some regions, extending the rainy season or increasing the humidity. These could encourage the growth of fungal diseases, when combined with warmer temperatures. The load from diseases and insect vectors may also rise with high temperatures and humidity (Alexey et al., 2007).

2. CEREAL CROPS

Cereal crops supply vital energy and nutrients to the standard human diet. Grain crops are also known as cereals crops. Cereal crops are members of the Gramineae family and belong to the Poaceae family. These are also known as grasses which have narrow leaves and parallel lines. Due to their widespread use as food in more nations than any other crop, several kinds of cereals are also referred to as staple food crops, for example, wheat, rice maize, etc. (Naz et al., 2019). There are 10 cereal crops that growing worldwide are wheat (*Triticum aestivum* L.), rice (*Oryza sativa* L.) maize (*Zea mays* L.), sorghum (*Sorghum bicolor* L.), millet (*Pennisetum americanum* L.), barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), rye (*Secale cereale* L.), triticale (x Triticosecale Wittmack) and quinoa (*Chenopodium quinoa* L.). From 2000 to 2019, the primary crop production jumped up to 53%, reaching a record production of 9.4 billion tonnes in 2019. In all areas, cereals were main source of dietary energy in 2018, with proportions between 24% in Oceania and in Africa and Asia was 50%. (FAOSTAT, 2017). In Asia, cereal production was higher (Fig. 1a), and more harvested area of cereal crops in 2019 (Fig. 1b). In 2019, the highest production of maize was produced in the American continent, while the highest production of rice and wheat was produced in Asia (Fig. 2a, Fig. 2b, and Fig. 2c). Since cereal crops like wheat, maize, and rice are primary foods for majority of the world's people. To fulfil the need of estimated 9.8 billion people by 2050, the volume of food cereal must rise by 70–100% (Godfray et al., 2010). Table 1 describes the production of cereal crops producing countries. The main maize-producing countries were the USA, China, Brazil, Argentina and Ukraine. Among these five countries, the USA produced the highest maize production. In wheat production, China produced the highest production then India, Russia, USA and France. In rice production, major producing countries were China, India, Indonesia, Bangladesh and Vietnam.

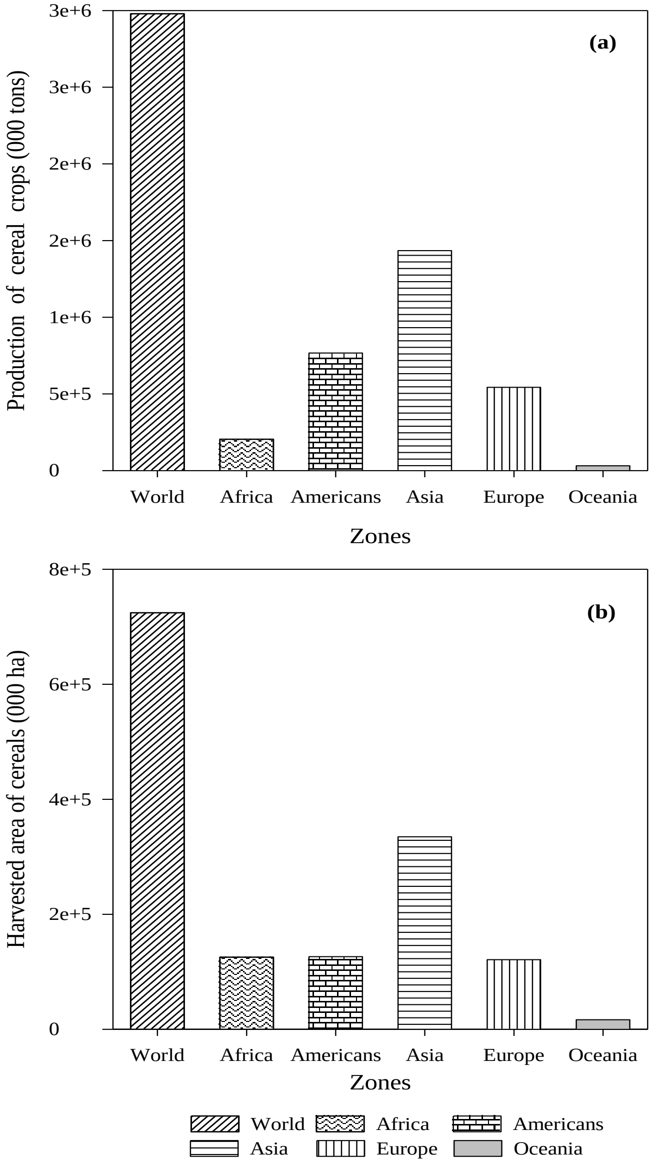

Figure 1. Production (a) and harvested area (b) of cereals crops during 2019 [Source: FAOSTAT, 2017].

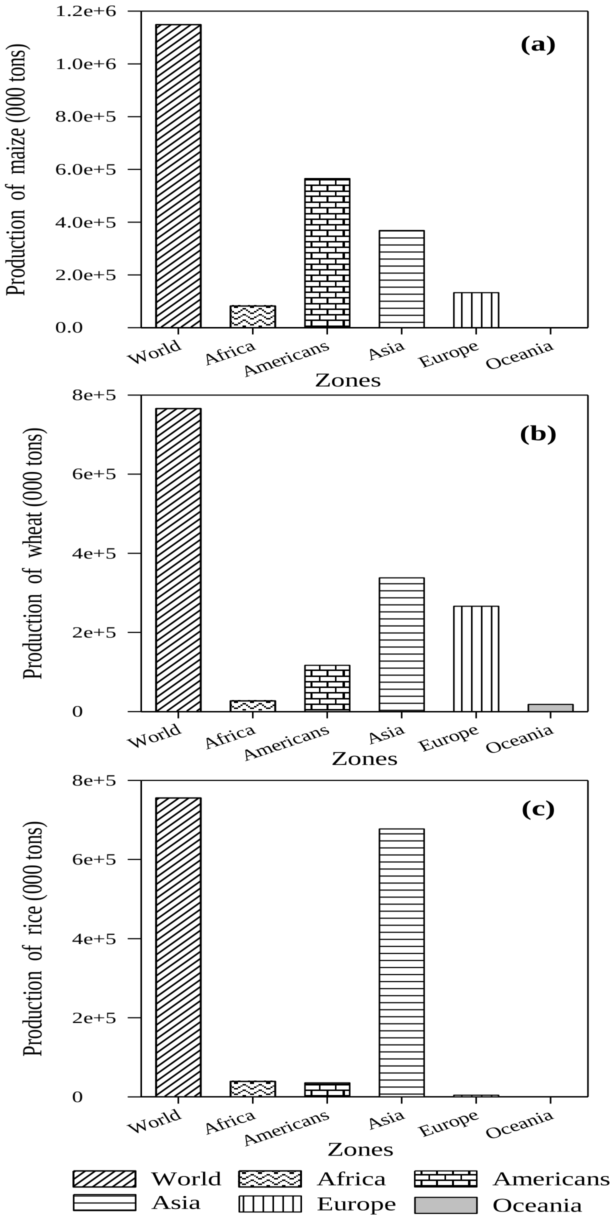

Figure 2. Production (000 tons) of primary cereal crops (a) maize, (b) wheat , and (c) rice during 2019 [Source: FAOSTAT, 2017].

Table 1. List of largest producing countries of agricultural crops (thousand tones) in 2016 and 2019

Ranking	Year	Country	Maize	Country	Wheat	Country	Rice
First	2016	USA	384700	China	131700	China	211100
	2019		347048		133601		211045
Second	2016	China	231800	India	93500	India	158800
	2019		260958		103596		177645
Third	2016	Brazil	64100	Russia	73300	Indonesia	77300
	2019		101139		74453		54604
Fourth	2016	Argentina	39800	USA	62800	Bangladesh	52600
	2019		56861		52258		54586
Fifth	2016	Ukraine	28100	France	29500	Vietnam	28100
	2019		35880		40605		43449

Source: FAOSTAT (2017)

3. FOOD SECURITY

During the last half century, although the world's population has been doubled but it was considered as the time of dramatic increase in food production resulting in the reduction of proportion hungry people (World Bank, 2008; FAOSTAT, 2009; Godfray et al., 2010). Nevertheless, in seven more than one person has still not access to sufficient protein and nutrient containing food and facing some sort of malnutrition (FAO, 2009; Godfray et al., 2010). The world population is increasing day by day. There are different ways by which climate change affect the food security as well as human health (Fanzo et al., 2017). One of the main sources by which climate change affect quantity of food directly by lowering the yield of crops and indirectly by affecting the availability and quality of water, pollination procedure, insect and diseases attack. Another route by which climate change affecting is by increasing the emission of CO_2 in atmosphere, affecting the quality of food and biomass. The risk of food safety during storage and transport has also increased by climate change. The climate drivers can be categorized on the base of food production and availability as seasonal change (i.e. warming patterns extending growing season), model climate change (i.e. change in climate resulted in change in cropping varieties planted), extreme weather events (i.e. increased temperature disturbing critical growth stage, drought or flooding) and atmospheric conditions i.e. concentrations of CO_2, dust and short-lived climate pollutants. For the production of crop the water resources will be affected by changing the rate of evaporation and precipitation, levels of ground water and dissolved O_2 contents (Cruz-Blanco et al., 2015; Sepulcre-Canto et al., 2014; Huntington et al., 2017; Schmidtko et al., 2017). Other variables that effect the crop production, processing and transport are wind, solar radiation, humidity and (in coastal areas) storm surge and salinization (Mutahara et al., 2016; Myers et al., 2017). Severe climate events affect the availability and production of food by causing the flooding (Rao et al., 2016). According to the World Bank report due to flood disaster in Pakistan in 2022 poverty level will increase from 3.7% to 4% in Pakistan. Due to the climate change it was observed that from 1981-2010 globally, yield of the wheat, maize and soybean was reduced by 1.8%, 4.1% and 4.5%, respectively (Ilzumi et al., 2018).

4. CLIMATE CHANGE IMPACT ON CEREALS

Climate change in past few decades is thought to have a considerable impact on crop production and phenological phases **(**Lobell et al., 2011; Maddonni, 2012). Changes in phenological stages are key signs of climatic changes (Xiao et al., 2013). Previous research has demonstrated that changes in rainfall patterns changes, and rising temperatures have a major effect on food production (Mahmood et al., 2012; Janjua et al., 2010). Several studies have reported additional evidence of reduced cereal output in any geographical area as a consequence of changing climate (Neupane et al., 2022). Changing in climate is an unavoidable reality. Greenhouse gases (GHGs) are accountable for rising global temperatures by holding gases in the atmosphere as GHGs blanket thickens and the defensive ozone layer depletes. Cereal crop yields in the future altered severely due to climate change (Fatima et al., 2020). Due to global warming, increasing temperature affects the pre and post-fertilization process, and the viability of pollen decreased that decline in crop yield sharply. Crop output was reduced as a result of less duration for assimilating buildup and photosynthetic process (Fatima et al., 2020). The speed of increasing temperature of the earth has resulted in a diverse effect on the land of agriculture (Huang et al., 2016; Corwin, 2021). The impact of climate change on productivity of primary cereals is presented in Figure 3.

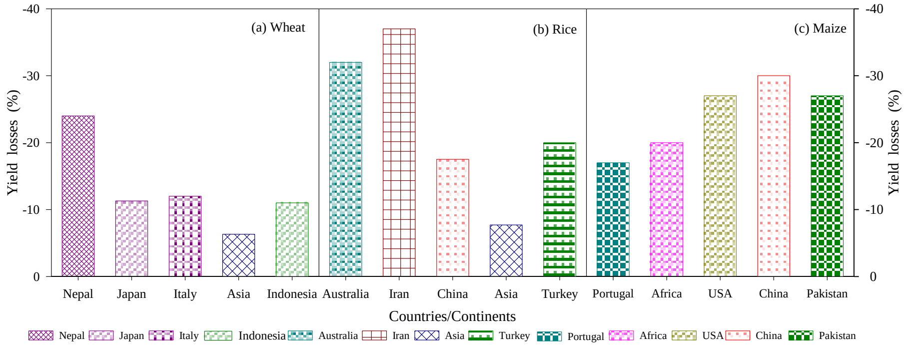

Figure 3. Climate change impact on yield losses of primary cereals {(a) wheat, (b) rice and (c) maize)} across different countries/continents [Source: Modified from Ahmad et al. (2020) and adopted from Fatima et al. (2020)].

4.1. Wheat

Wheat is also adversely affected by the change in the climate. An increase in temperature more than 30°C causes a huge loss in yield of wheat as exposure of wheat to more than 30°C temperature for 24 hours results in 12.43% reduction in yield (Shew et al., 2020; Fatima et al., 2020). It is also reported that the increase of +1, +2, and +3°C temperature resulted in the decrease of yield by 8.5%, 18.4 and 28.5%, respectively (Shew et al., 2020). It is also reported that an increase of 1°C temperature causes 7% reduction in yield of wheat crop (Sonkar et al., 2019). You et al. (2009) stated that by increasing in 1°C temperature the yield of wheat was reduced from 7 to 10%. Heat stress also causes the abortion of floret during anthesis stage in wheat crops and during flower formation increase in temperature of more than 30°C results in complete sterility of wheat plant (Saini et al., 1982; Wang and Liu, 2021). In France, wheat yield was analyzed by using the modeling approach for 65 years (1950-2015) which was based on the weather data and historic yield of winter wheat. The model projected that in the middle of century (2037-2065), due to climate change yield of wheat would be decreased by 3.5-12.9%, and by the end of century wheat would be decreased by 14.6-17.2% (Gammans et al., 2017). In China, scientists stated that due to increasing in temperature during last two decades the yield would be decreased by 4.5% (You et al., 2009). Climate change also changed the phenology trends in wheat. Sowing and harvesting dates are shifting regularly. In Pakistan from 1980-2014, the sowing and emergence were delayed by 9.5 and 1.3 days per decade whereas the anthesis and maturity were earlier by 5.3 and 5.4 days per decade (Ahmad et al., 2019). It is also reported by Ahmad et al. (2019) that phenology phases sowing-anthesis (S-A), anthesis-maturity (A-M) and sowing-maturity (S-M) also reduced by 5.5, 4.6 and 5.7, respectively. In China phenology trends also shifted. From 1981-2010 the highest phenology stages delaying trend was observed in north-south China (Liu et al., 2018). Same as the highest trend in the reduction of phenology stages was observed in north-east China (Wang et al., 2008). Other climatic effects also cause the loss of wheat yield. Low vapor pressure and atmospheric dryness are also other factors affecting wheat crop (Li and Lie, 2022). By increasing the vapor pressure, the stomata closed which resulted in limited use of water causing a reduction in yield (Zhu and Troy, 2018). Solar radiation is another factor affecting the photosynthesis and accumulation of biomass (Wang et al., 2020). An increase in solar radiation resulted in a decrease of wheat yield by increasing the evapotranspiration rate in China except the southeast region where yield was increased (Tao et al., 2012). From 1981 to 2009 in north China the yield of wheat decreased by 20% due to 10% reduction in solar radiations (Tao et al., 2014). In Manitoba (Canadian province) it was observed that wheat yield was reduced by high moisture was higher (42%) which was followed by water scarcity (28%), frost (10%), hail (10%), temperature (8%) and all other factors (2%) (Wilcox et al., 2015; Carew et al., 2017). Climate change is causing water scarcity which is a reason for the reduction of wheat yield. Ngwako et al. (2013) conducted an experiment of two wheat varieties with three irrigation treatments (irrigation up to extension of stem development, irrigation from the extension of stem to the physiological maturity and third one is irrigation throughout growth season) compared with control (no) irrigation. The results revealed that for both varieties grain yield was significantly increased by the irrigation treatments as compared to the control treatment. It was observed that by irrigation treatments grain numbers per spikes, tiller's number, grain yield, protein content, and harvest index were 26.07%, 20.58%, 44.72%, 3.31% and 16.7% higher than in control treatment. Table 2 showed that in Northern China from 1981-2009, wheat yield increased by 1-13% but in Southern China, wheat yield decreased by 1-10% (Tao et al., 2014). In the future up to 2100, wheat yield decreased by

14.6–17.6% and 8-23% in France and Turkey, respectively (Gammans et al., 2017; Eruygur and Ozokcu, 2016).

Table 2. Variation in wheat yield during past and in future various countries

Country	Year	Variation Yield (% decrease)	Reference
China	1997-2017	4.50%	You et al., 2009
Northern China	1981-2009	1-13%	Tao et al., 2014
Southern China	1981-2009	1-10%	Tao et al., 2014
France	2037-2065	3.5-12.9%	Gammans et al., 2017
France	2100	14.6-17.2%	Gammans et al., 2017
Turkey	2100	8-23%	Eruygur and Ozokcu, 2016

4.2. Rice

Rice yield was reduced and reported with different scenarios of climate change in Vietnam (Yu et al., 2010). During 2030s, a decrease in grain yields of between 4.2% and 12.5% might be predicted under all scenarios of climate change in Vietnam (Monre, 2009). Based on 1986-2012, 27-year data of winter-summer and summer-autumn rice were processed, in which the average maximum temperature adversely affected the grain yield of both seasons. They confirmed that climate variability (disease, pest, storm, drought, etc.) has a negative impact on the production of rice, in which frequent drought spells caused more adverse impact on rice yield (Chung et al., 2015). In South China, the production of rice declined, and the global temperature accelerated. The temperature rises by 1°C while the growing season is underway, and the production of wheat will drop by 3% to 10%. The yield of rice diminishes as a result of the rise in nighttime temperatures brought on by global warming. The tendency is for greater minimum temperatures to diminish rice yield (Wassmann et al., 2009). The trend of increasing maximum daily temperature may reduce the fertility of rice spikelets and decrease rice yield but rice yield may be increased with the increasing concentration trend of atmospheric CO_2 (Dharmarathna et al., 2012). Due to climate change, high temperature decreases the crop duration (Jagadish et al., 2008) duration of grain filling is reduced (Kim et al., 2011), resulting in the quality and quantity of rice lowered (Fitzgerald and Resurreccion, 2009). For 29 years (1981-2009) in China and across the World, the duration of phenological phases was shortened between sowing to nursery transplanting (2.9 days decade^{-1}), nursery transplanting to anthesis (1.6 days decades^{-1}), and A-M (5.2 days decade^{-1}), respectively. (Bai et al., 2016; Zhang et al., 2013; Das et al., 2020; Li et al., 2015; Subash et al., 2012). Zacharias et al. (2010) reported that increases in temperature effects the phenological stages of rice and wheat and its cultivar's yields. Reduction in 7-8 days in the phenological phase (anthesis-maturity) of rice, yield decreased to 26% (Conroy et al., 1994). Increasing in CO_2 concentration, grain amylose percentage enhanced which is major part in cooking quality and zinc and iron concentrations also lowered. CO_2 and temperature combined increasing lower the rice grain protein content (Ziska et al., 1997). Ahmad et al. (2019) reported that in Pakistan, during 1980-2014 the phenological stages were earlier 7.9, 6.6, 5.0- and 5.0-days decade^{-1} of sowing (S), emergence (E), anthesis (A) and maturity (M), respectively, while phenological phases were 1.4, 4.1- and 6.4-days decade^{-1} of S-A, A-M and S-M were shortened (Table 3). Shrestha et al. (2013) reported that in Madagascar, during 2008-2010 the phenological stages of rice were earlier 5.4, 3.2, 6.2- and 4.8-days decade^{-1} of S, E, A and M, respectively, while phenological phases were 4.1, 3.2- and 6.2-days decade^{-1} of S-A, A-M and S-M were shortened. Wang et al. (2019) in China, during 1992-2013 the phenological stages of rice were delayed 2.2, 1.9, 2.8- and 3.4-days decade^{-1} of S, E, A and M, respectively, while phenological phases were 0.8, 1.7- and 2.4-days decade^{-1} of S-A, A-M and S-M were extended. The flour quality made from grains grown at extreme temperatures is worse for baking bread. Reduced protein contents in grains of wheat may be another impact of high CO_2 (Conroy et al 1994a). Numerous studies have demonstrated that global warming may negatively affect the paddy yield grown all over the world. The global average temperature has risen up to 0.5-0.6 C during previous century (Hansen et al., 2010). The process of reproduction was unsettling because paddy flowers become sterile due to high temperatures and the yield of paddy decreases up to 10-15%, It may cause a 32–37% increase in market price due to climate change (Nelson et al., 2009; Li, 2018). The plant's respiration has increased in response to the rise in temperature, which has led to an enhancement in carbon metabolism and a reduction in rice production (Zhao and Fitzgerald, 2013**).** Matthews et al (1997) reported that the average rice yield will reduce by 4% in different countries in Asia due to the negative impact of an increase in atmospheric CO_2. Vaghefi et al. (2011) predicted that model ORYZA 2000 model indicated that an increase in temperature 2°C (1999-2007) might reduce rice yields by 0.36 t ha^{-1} in Malaysia, which could cause significant financial and economic damage. Due to global warming, rice yield will reduce significantly at end of century (Matthews et al., 1997; Welch et al., 2010; Challinor et al., 2014). Due to climate change, some studies reported that rice yield increased 2.9 to 34%, which depends upon different scenarios in which high temperatures during night time and moving of production towards cooler climate areas now may increase their temperature due to changes in climate during 2050s and 2080s (Aggarwal and Mall, 2002; Lobel et al., 2011; Piao et al., 2010). Boonwichai et al. (2019) reported that rice yield will decline if the temperature will increase more 3°C to 2080 in the Thailand. During the last few years, the 0.3 to 0.6°C globally average temperature increased, thus respiration process increased causing maximum carbon losses due to which rice production declined (Hansen et al., 2010). Matthews et al. (1997) reported that due to air temperature increases at reproductive duration, pollen reduces their viability, and in Asia increased CO_2 atmospheric levels decreased rice production by up to 4%.

Table 3. Observed phenology trends of cereal crops in various zones in the world

Crop	Country	Period	Phenological stages (early/delay days/decade)				Phenological phases (reduction days/decade)			References
			Sowing	Emergence	Anthesis	Maturity	S-A	A-M	S-M	
Wheat	Pakistan	1980-2014	9.5 (D)	1.3 (D)	5.3 (E)	5.4 (E)	5.5	4.6	5.7	Ahmad et al. (2019)
Wheat	Australia	1995-2016	3.9 (E)	2.8 (E)	7.5 (E)	5.8 (E)	6.6	7.9	10.7	Luo et al. (2018)
Wheat	Germany	1952-2013	2.0 (E)	1.8 (E)	4.1 (E)	5.0 (E)	1.9	0.8	2.7	Rezaei et al. (2015)
Rice	Pakistan	1980-2014	7.9 (E)	6.6 (E)	5.0 (E)	5.0 (E)	1.4	4.1	6.4	Ahmad et al. (2019)
Rice	China	1981-2012	4.9 (D)	4.2 (D)	3.8 (D)	5.2 (D)	2.4	3.2	5.1	Hu et al. (2017)
Maize	Pakistan	1980-2014	3.0 (D)	1.9 (D)	2.8 (D)	4.4 (D)	5.5	2.2	7.8	Abbas et al. (2017)
Maize	USA	1981-2005	3.9 (E)	3.2 (E)	1.7 (E)	2.9 (E)	2.9	1.8	3.0	Sacks et al. (2011)
Maize	Germany	1961-2000	4.5 (E)	4.1 (E)	5.6 (E)	8.8 (E)	3.1	7.2	4.9	Chmielewski et al. (2004)
Maize	China	1992-2013	3.5 (D)	3.2 (D)	1.8 (D)	1.5 (D)	1.9	3.3	1.5	Mo et al. (2016); Wang et al. (2020)
Oat	Germany	1959-2009	1.1 (E)	1.8 (E)	9.7 (E)	10.7 (E)	7.9	13.9	9.4	Siebert and Evert (2012)
Oat	Germany	1951-2004	1.5 (E)	1.2 (E)	4.9 (E)	6.4 (E)	3.4	1.5	4.9	Estrella et al. (2007)
Barley	Lithuania	1961-2015	1.7 (E)	2.8 (E)	1.1 (E)	0.4 (E)	1.0	1.6	2.2	Sujetoviene et al. (2019)
Barley	Spain	1986-2008	2.8 (D)	1.9 (D)	2.7 (D)	3.5 (D)	1.6	2.1	3.7	Garcia-Mozo et al. (2010)
Rye	Poland	1957-2012	2.2 (D)	1.9 (D)	4.0 (D)	3.6 (D)	1.8	1.4	3.2	Blecharozyk et al. (2016)
Rye	Germany	1960-2013	1.0 (E)	1.2 (E)	1.8 (E)	1.6 (E)	2.9	3.1	4.5	Rezaei et al. (2018)

4.3. Maize

The growing period of maize was shortened such that flowering, and maturity was earlier 3 to 14 days due to increasing air temperature (Yang et al., 2021). A crop, maize that was sensitive to heat, would produce 30% less grain globally by the 2080s (Xiong et al**.** 2016). The maize yield might decline 3-25% between 2020 and 2099 in Texas, USA as a result of increased global warming (Chipanshi et al**.,** 2003; Chen et al**.,** 2019). Due to heat stress in maize, silking and anthesis duration increased, when the temperature was more than 42°C, and in a greenhouse, it was more than 52°C, and pollen viability was less in turn maize yield reduced (Lizaso et al., 2018). The duration of each growth stage and phenological phase in maize was negatively impacted by a temperature rise due to global warming. Variability in a crop's phenological phases and stages serve as important indications of changes in the climate (Meng et al., 2014; He et al., 2015). Climate changes negatively affected the phenology of autumn and spring maize crop reducing the S-A, A-M, and S-M phases 5.5, 2.2- and 7.8-days decade^{-1} and 2.4, 1.9- and 4.6-days decade^{-1}, respectively (Abbas et al., 2017). Hatfield and Prueger (2015) reported that maize grain yield was reduced to 90% when the crop reaches at reproductive stage due to extreme temperature, in which sterility of pollen occurs. In USA, maize crop phenological phase of sowing-anthesis, anthesis-maturity, and sowing-maturity was decreased by 2.9, 1.8-, and 3.0-days decade^{-1}, respectively during 1981-2005 (Sacks et al., 2011). In China, the phenological phase of maize crop S-A, A-M and S-M was decreased by 1.1, 2.0- and 3.0-days decade^{-1}, respectively during 1992-2013 (Mo et al., 2016). During 1961-2000, in Germany maize S, E, A and M phenological stages were 4.5, 4.1, 5.6-, and 8.8-days decades^{-1} earlier, respectively, while, sowing to maturity was decreased to 4.9 days decacde^{-1} (Chmielewski et al., 2004). In China, during 1981-2010 the phenological stages of maize were delayed 8.7, 6.9, 4.6- and 2.2-days decade^{-1} of S, E, A and M, respectively, while phenological phases were 4.6, 2.4- and 6.2-days decade^{-1} of S-A, A-M and S-M was extended (Liu et al., 2019; Wang et al., 2020). Phenological stages sowing, emergence, anthesis and maturity were delayed 5.0, 3.1, 4.0- and 6.7-days decade^{-1}, while phenological phases of S-A, A-M and S-M were reduced by 1.0, 2.7- and 3.5-days decade^{-1} (Liu et al., 2017; He et al., 2015). Msowoya et al. (2016) reported the model prediction that due to global warming maize crop production will decrease by 14% and

33% by mid and end of this century. In region of northeast China, model predicted that maize production may decline by 35%, as related to 2008 in 2030s in the increase of temperature 1.32° C due to global warming (Li et al., 2014). Between 1970-1999 in America, average maize production decreased by 2.5% with impact of increasing temperature and maize yield declined by 20-50% projected by the precipitation model that depend on current scenarios in 2050s (Leng and Haung, 2017). The availability of water is also essential for the growth of maize. According to studies, between 1999 to 2002, maize under irrigated areas had an average return (12.44 t ha^{-1}) that has been 16.5 percent, as a result, greater than maize cultivated under non-irrigated conditions (10.68 t ha^{-1}) (Nagy, 2003). In Africa, a 2°C temperature increase and a 20% decrease in rainfall have both been found to alter maize production. Under these circumstances, they claimed a 10% decrease in maize yields. According to historical data to understand how moisture affects maize production at harvest time. According to their findings, under both rain-fed and drought situations, a loss of between 1% and 1.7% was seen yield of maize for every day the crop is exposed to temperatures over 30°C. They demonstrated revealed maize's capacity to withstand the high temperatures that climate change has caused, depends critically on moisture (Lobel et al., 2011). The sensitivity of yield to temperature and atmospheric CO_2 was examined in a detailed study on variations in the productivity of maize that was reported in 2014. This study was conducted at four sites in Brazil, Tanzania, France, and USA to test 23 models. The results concluded that maize yield of 0.5 t ha^{-1} decreased with the increase of 1°C temperature but with the double of CO_2 concentration (360-720 ppm) in the atmosphere maize yield slightly increased (Bassu et al., 2014). Herrero et al. (1980) reported that the viability of maize pollen was reduced when the temperature goes up to 35°C, and cell tissues were also damaged by higher temperatures (Lobell et al., 2012).

4.4. Barley

Lobell and Field (2007) reported that barley yield of 2-3% decreased due to global warming from 1981-2002. In different regions of Africa, average global barley yield decreased in-between 3-17% due to geographical and climate conditions (Xie et al., 2018). Cammarano et al. (2019) global circulation models showed that 0.9 to 2.16 °C increase in temperature during growing period that impacted barley yield, which declined by 8 to 25%. Bento et al. (2021) reported that due to climate change used models RCP4.5 and RCP8.5 for analyzing previous data (1972-2000) and for future climatic conditions (2042-2070), in Iberian Peninsula. They reported that in southern areas the increase of maximum temperature in spring declined the yield drastically but yield increases in winter in northern areas due to early warming stimulating the growth. In Lithuania, during 1961-2015 the phenological stages of barley were reduced 1.7, 2.8, 1.1- and 0.4-days decade^{-1} of sowing, emergence, anthesis and maturity, respectively, while phenological phases were 1.0, 1.6- and 2.2-days decade^{-1} of S-A, A-M and S-M was reduced **(**Sujetovienė et al., 2019). In Spain, during 1986-2008 the phenological stages of barley were earlier 1.0, 1.2, 1.8- and 1.6-days decade^{-1} of S, E, A and M, respectively, while phenological phases were 1.6, 2.1- and 3.7-days decade^{-1} of S-A, A-M and S-M was reduced **(**García-Mozo et al., 2010). Photoperiod and rising global temperature influence the phenological growth of barley crops. Duration of specified phenological phases was reduced, due to which the growing period was shorter, and lower yield (Cammarano et al., 2020). Barley grain production declined 6-11% due to an increase in 2-8°C of air ambient temperature. The growing period of barley was shorter because of warming, and yield decreased (Araya et al., 2019). Fettell et al. (2010) reported the RCPs simulation results that a 3-98% reduction in the yield of traveller cultivar but EH-1943 cultivar recorded an increase (15%) and a decrease (98%) in barley production due to rising in 2°C, but in some areas, more than 4.5°C temperature may not affect the barley production in Ethiopia. Gardi et al. (2022) reported the prediction of two RCPs (4.5 and 8.5) and five GCMs. Due to the increase in temperature in future, EH-1493 and traveller cultivar yield declined to 63 and 98%, respectively.

4.5. Millet

Millet is the one of most drought-tolerant crops. It has a deep root system which enables it to grow in the water scarcity areas (Hadebe et al., 2017). Much research on millet revealed that the yield of millet increased with the increase in temperature. Cao et al. (2010) conducted a study and revealed that by an increase in the temperature in three different regions of China the yield of millet was increased by 30-121 kg ha^{-1}. A study stated that the yield of the millet was increased 6% by drought (lower limit of water availability) and 8% by an increase in temperature from 27-29°C. Both drought and increment in temperature showed an increase of 14% millet yield (Singh et al., 2017). However, the severe drought during the flowering and grain filling time resulted in a lowering of the millet yield (Gloria, 2013). The growth of plant occurs in post-flowering duration is very delicate to water deficiency (Mahalakshmi and Bidinger, 1985). So, post flowering drought is an important factor that can reduce the yield up to 70% (Gloria, 2013). Fusel et al. (1991) pointed out that terminal drought reduced the yield of grain by 40-49% with a great variation among the varieties. According to Gloria (2013) at flowering stage severe rainfall resulted in the complete failure of crop. It was observed that the yield of millet is reducing due to unpredicted and low rainfall, soil and atmosphere high temperature and other biotic stresses (Usaman et al., 2014). Africa is the largest millet-producing continent. But the yield is declining due to unpredicted and short rainy seasons with frequent dry periods, droughts, and reduction in soil fertility (Azare et al., 2020). The areas where other crops face difficulty to grow millet can grow easily like hilly areas.

4.6. Oat

The variations and changes caused by climate change are also affecting the growth and production of oat crops. The increase in temperature due to climate change is affecting the phenology of oat plants. In Germany, it was observed that the S, E, A and M days were prior by 1.1, 1.8, 9.7 and 10.7 days per decade and the growth phases S-A, A-M and S-M were declined 7.9, 13.9 and 9.4 days per decade (Siebert and Ewert, 2012). It is also reported that from 1951-2004 in Germany sowing, emergence, anthesis and maturity days were 1.5, 1.2, 4.9 and 6.4 days per decade earlier and the growth phases S-A, A-M and S-M were reduced by 3.4, 1.5 and 4.9 days per decade, respectively (Estrella et al., 2007). According to scientists, it is suggested that the increase in temperature, concentration of CO_2 and mild drought stress resulted in the increase of contamination of oat. Due to increase in temperature the precipitation pattern is also changed. Rainfall above 350 mm causes waterlogging which resulted in increased incidence of disease. This increased incidence of disease and waterlogging resulted in yield reduction (Vernon and Gool, 2006).

4.7. Sorghum

For sorghum, the average temperature ranges the required for germination of seeds, growth of vegetative parts, and reproductive are development 21–35°C, 26–34°C, and 25–28°C, respectively (Maiti, 1996). An increase in temperature rapid the growth and development of sorghum crop, which shortened the phenological phase and reduced yield (Attri and Rathore, 2003), shortened period of grain filling, which causes shrinking of seed size and decreased grain yield (Kiniry and Musser, 1988; Abrol and Ingran, 1996). In climate change, drought spells affect sorghum crops, and yield is reduced when dry spells at the vegetative stage of the crop in Africa (Elagib, 2015) and affect leaf area, leaf appearance rate, and plant height (Blum and Arkin, 1984; Assefa et al., 2010). Srivastava et al. (2010) reported that sorghum yield reduction up to 7% in 2020, with help of the simulation model InfoCrop-SORGHUM. Sultan et al. (2014) the effect of climate change by using a crop model on sorghum yield. They reported that projected yield reduction 16-20% due to pattern of rainfall change and the projected temperature of 2.8°C increase in 2031-2060, in West Africa. Misganaw and Mohammed (2021) reported that due to climate change used model RCP4.5 and RCP8.5 for future global conditions of 2030s and 2050s, in Ethiopia. In under RCP 4.5 and RCP 8.5 maximum average temperature was increased to 1.4°C and 1.9°C, 1.50°C and 2.50°C by 2030s and 2050s. Prediction of rainfall under RCP4.5 and 8.5 was increased 1.50% and 2.50% and increased 3.7% and 3.2% in 2030s to 2050s. Sorghum phenology decreased significantly in 2030s and 2050s. In scenarios of RCP8.5 prediction, grain yield was increased 5% and 12% of late maturing cultivars but yield decreases in early maturing cultivars. Miller et al. (2021) reported that sorghum is highly susceptible to temperature rises, with mild changes of 2 ºC temperature in the growing period resulting in a 24% loss in average yields. Sorghum yield declined significantly due to drought stress at the early stages of crop (Elagib, 2015).

4.8. Rye

In rye crop, the production and phenology are also disturbing due to climate change. According to the report of climate change and rye, high rainfall is a source of raising ground and surface water resulting in flooding and runoff causing the reduction or wastage of rye crop. Climate change also disturbed the growing season as in Finland, the growing seasons became more long and warmer especially at the start of season (Klein Tank et al., 2002; Carter, 1998; Kaukoranta and Hakala, 2008). Snow cover was the reason of injury to plant in the winter season (Be´langer et al., 2002). An increase in the projected precipitation of winter season causes the increase of cover to deeper snow which ultimately increases the attack of pathogens (Ho¨mmo¨ and Pulli, 1993; Serenius et al., 2005). The phenology stages of rye crop are shifted due to climate change. In Poland from 1957-2012 it was observed that S, E, A and M stages were delayed by 2.2, 1.9, 4.0 and 3.6 days per decade. For the same duration phenological phases which included S-A, A-M and S-M were reduced by 1.8, 1.44 and 3.2 days per decade respectively (Blecharczyk et al., 2016). It was also observed in Germany during the 63 years from 1960-2013 the S, E, A and M stages were delayed earlier by 1.0, 1.2, 1.8 and 1.6 days per decade, respectively. Same as during this period the phenological phases (S-A, A-M and S-M) were decreased by 2.9, 3.1 and 4.5 days per decade (Rezaei et al., 2018).

4.9. Quinoa

Due to climate change high CO_2 concentration, high temperature, drought (Ciccareli, 2008), frost, hail, and non-defined wind are occurring in quinoa sowing areas. Drought may occur at the start or end of the rainy season in highlands (Garcia et al., 2015). Drought at sowing time may resulted in the delayed sowing of quinoa in rain fed areas (Bonifacio, 2019). Delayed in emergence also cause the reputation or cancelation of sowing. Quinoa is good tolerant to frost at the early growth stage but becomes more sensitive to frost as it continues to grow especially at the flowering stage it is more sensitive to the frost. Flowering as well as grain filling or maturity stage are also sensitive to the hails (Garcia et al., 2015). At immature stages, hail also causes the breakage of stem, branches, and leaves. The damaged place is more sensitive and causes a fungal attack at that site. These necrotic and injured branches also break by wind. Almost the 30- years ago the wind occurs in well-defined season like in August in highlands. But due to climate change, the pattern and intensity of wind have also changed. The wind affects the quinoa crop at sowing stage by burying the seeds with sand and even at maturity by falling the ripened grain (Bonifacio, 2019).

5. SOLUTIONS TO CLIMATE CHANGE

To minimize the negative impact of climate change on crop production and to maximize the benefit and profit from it, the farmers, foresters, and other land managers should need to adopt advance adaptation measures. Some of these adaptations are quick and some need long term planning to mitigate the climate change impact. It is urgent need to take some actions to mitigate the impacts of climate change. It can be achieved by implementing climate smart agriculture system which is in line with FAO's vision of sustainable food and agriculture goals (Arora, 2019). It may include the development of resilient crop varieties which can tolerate abrupt stresses of temperature and precipitation, application of sustainable and biotic agriculture methods, for example, application of biofertilizers which include tolerant plant growth promoting rhizobacteria and their metabolites, and other methods of organic farming to promote the yield of the cereal crops in severe environmental conditions. It also includes the use of biopesticides and biofertilizers which minimize the dependence on chemical pesticides and fertilizers. This will result in the reduction of greenhouse gases emission (GHGs), water and soil pollution. It is also needed to develop new varieties of cereal crops which are better suited to the future climate and resilient to diseases, pests and other extreme factors. It is needed to grow the suitable cereal crop that can tolerate the climate changes and be an alternate to more affected crop especially in the arid and semi-arid regions globally. Millet is the cereal crop that can tolerate the increasing high temperature and can grow in low quality soils. Furthermore, the Millet crop emits less greenhouse gas so, it helps to mitigate climate change. It also requires less fertilizers and water which make it more favorable for environment. Adapting crop management practices will help to get benefit from warmer temperature and longer growing seasons like, by choosing different sowing and harvesting dates. Cultivation techniques such as mixed cropping system is also beneficial to mitigate the climate change impacts (Arora, 2019). It is also essential to improve the soil, water and crop management to reduce the erosion, compaction, flooding and soil organic carbon lost. It will also improve the water and fertilizer use efficiency. It also needs to improve the water supply for agriculture by increasing storage and capture capacity to mitigate the risk of the food insecurity it is required to enhance the production of food crops (Wang et al., 2018). Growers and researchers should develop variety of strategies based on the local conditions. This should be a part of strategy for obtaining food security in climate changing and population increasing conditions.

6. CONCLUSION

This chapter highlights the globally negative impact of climate change on the phenology and the production of cereal crops which will become severe and frequent in future. This change in the climate is threatening to the world food security due to consequences like, drought, heat and salinity stress. The effect of this change in climate can be mitigated by adopting some active measurements. It may include development of resilient new crop varieties which are tolerant to severe environmental conditions and can produce more yield. Farmers and researcher should make strategies to grow the crops which are more suitable for changing climate.

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CHAPTER 2

THE POSSIBLE EFFECT OF CLIMATE CHANGE ON FRUIT TREES

Prof.Dr. | Sezai ERCİŞLİ [1*]
Assoc. Prof. | Gürsel ÖZKAN [2]
Assoc. Prof. | Mehmet Ramazan BOZHÜYÜK [3]
Res. Assist. Ph.D.| Halil İbrahim SAĞBAŞ [4]

[1] Department of Horticulture, Faculty of Agriculture, Erzurum 25240, Turkey; sercisli@gmail.com, ORCID ID:0000-0001-5006-5687
[2] Department of Horticulture, Faculty of Agriculture, Erzurum 25240, Turkey; gozkan08@hotmail.com, ORCID ID:0000-0002-1229-411X
[3] Department of Plant and Animal Production, Vocational School of Technical Sciences, Igdir University, Igdir 76100, Turkey; mrbozhuyuk@gmail.com, ORCID ID: 0000-0001-5021-6019
[4] Department of Horticulture, Faculty of Agriculture, Erzurum 25240, Turkey; hibrahimsagbas@gmail.com, ORCID ID:0000-0002-1402-309X

INTRODUCTION

One of the most important branches of agriculture is fruit culture throughout the world. Temperate, subtropical and tropical fruit species are grown intensively in different continents in the world according to continental characteristics and they provide significant socioeconomic contributions to the growing countries. Fruits are very diverse groups including species, international cultivars, local cultivars, accessions, genotypes etc. and are an integral part of the diet in every culture from past to date.

The fruits are not consumed by humans and the other organisms including herbivorous and omnivorous animals, and birds as well dependent on fruits for their diet. Different fruit species exhibits high content of human health promoting substances and have distinct flavor and taste, excellent medicinal value and health care functions as well (Colak, 2019; Zivotic et al., 2019; Gecer et al., 2020; Sagbas et al., 2020). Adding them to daily diet is extremely beneficial as they can also help in chronic conditions like diabetes.

In the world from the 1950s to the present date fruit production shows increasing trends and also fruit consumption increased. For this development, the influential factors are;

1-Increased travel opportunities which resulted rediscover of exotic fruits in different continents

2-Better understanding and recognition human health promoting characteristics of fruits

3-Developing cold storage facilities to extend storage period of fruits

4-Improvements on the transportation network to shortening the delivering time

5-Improvements and discovering modern processing methods that the fruits will not deteriorate for a long time

6-Improvement on distribution system

7-Effective advertisement on fruits in developed social media

8-Increase knowledge on production systems and methods

9-Enormous developments of mechanization systems

10-Increased technological innovations used in smart agriculture

11-Developing different agricultural practices such as good agriculture, sustainable agriculture, organic agriculture etc.

12- Becoming a more income-generating workforce

13-Developments of fruit base agrotourism

For all these reasons, fruit growing is considered an indispensable branch of agriculture, especially for many fruit producing countries. As indicated in Figure 1, fruit production is steadily increase year by year in the world. It was 400 million metrics tons in 1990 and reached nearly 900 million metric tons in 2020.

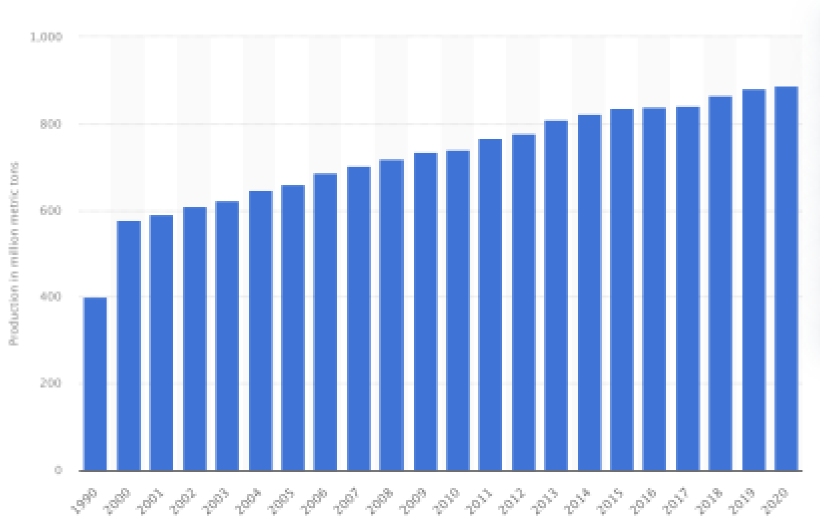

Figure 1. Global production of fresh fruits from 1990 to 2020

The countries that produce the most fruit in the world is China (242.79 million MT), and followed by India (105.97 million MT), Brazil (40 million MT), Türkiye (24.15 million MT), Mexico (23.84 million MT), USA (23.75 million MT), Indonesia (22.74 million MT), Spain (19.47 million MT), Iran (18.96 million MT) and Italy (17.83 million MT), respectively (Figure 2). Among these countries, especially Türkiye has different climatic regions and different fruit species grown in these regions and finally the country entered a very effective development period more recently both for production amounts and export level. In addition, the high income obtaining from fruit growing in the country has increased the orientation towards this sector and the sector has become the center of important investments.

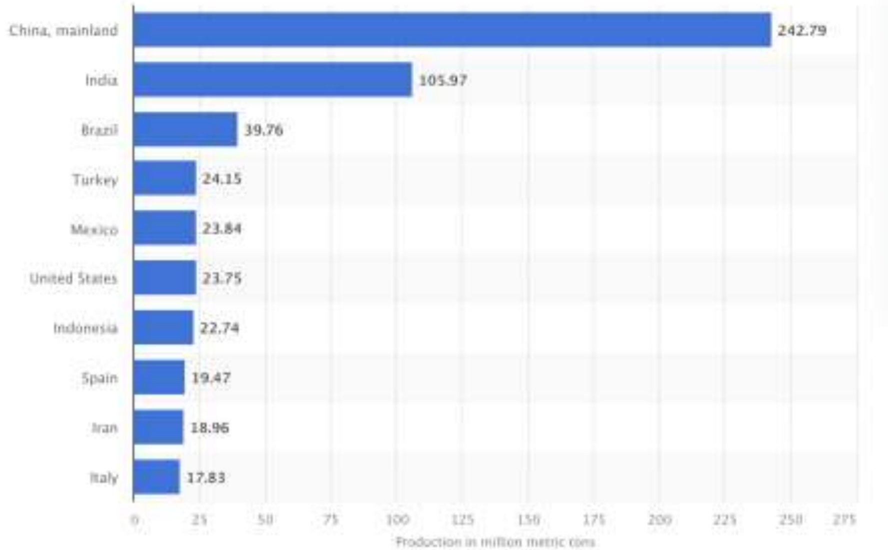

Figure 2. Main fruit producers in the world in 2020

The most produced horticultural plant in the world is banana (119.83 million MT), and followed by watermelons (101.62 million MT), apples (86.44 million MT), grapes (78.03 million MT) and oranges (75.46 million MT), respectively (Figure 3).

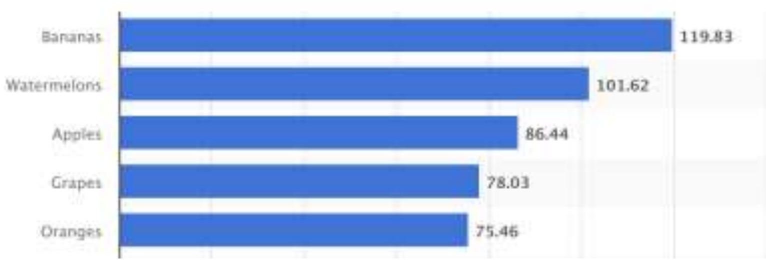

Figure 3. Main horticulture crops with production amount in 2020

1. WHAT IS CLIMATE CHANGE?

As a result of greenhouse gas emission, the increase in the temperature of the earth as a result of preventing the rays coming from the sun to go out of the atmosphere after being reflected from the earth is called climate change or global warming. In another word, climate change is the change of the Earth's climate due to the increase in the average temperatures measured in the land, sea and air throughout the year on Earth as a result of the greenhouse effect, which is thought to be caused by the greenhouse gases released into the atmosphere, which is formed by the increase of heat-trapping gases such as carbon dioxide in the atmosphere. Today, climate scientists (climatologists) agree on global warming (Santos and Bakhshoodeh, 2021). In this process, not only the temperature of the earth changes, but also other climatic elements such as humidity, precipitation, lighting and air movements. This situation is defined as climate change or global warming (Hisano et al., 2018).

Although the world climate has been changing for millions of years due to natural reasons, this change has accelerated with industrialization (Fawzy et al., 2020). Climate changes, which take a long time to occur, cannot be perceived clearly due to the shortness of human life. The meteorological findings from the past to the present show that there is a current change. During the last century, the world's surface temperature has increased by 0.3-0.6 oC, and the hottest 10 years of the 20th century have occurred in the last two decades. Snow cover in the northern hemisphere and glaciers at the poles decreased with climate change (Aguirre et al., 2018). Warming at 1 0C and its affects are shown in Figure 4.

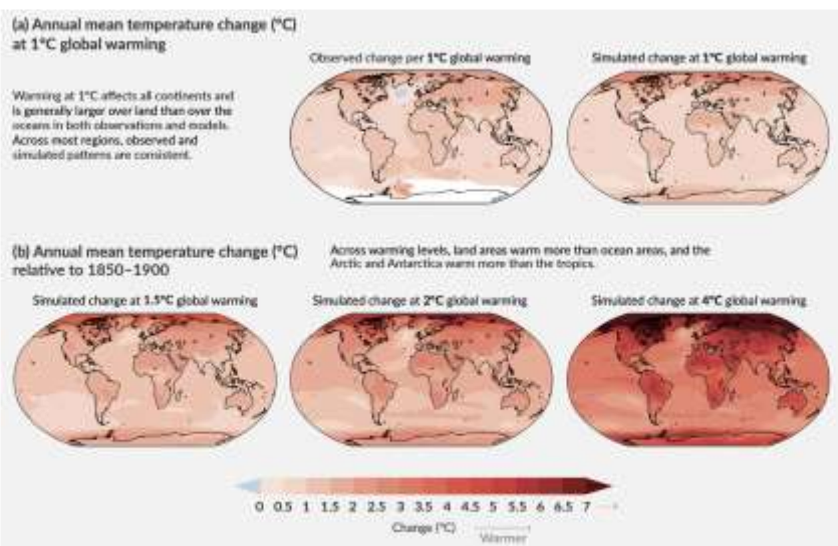

Figure 4. Annual temperature change scenario in the world

Along with temperature change, the CO_2 level, which was at the level of 280 ppm until the industrial revolution, has now surpassed the level of 400 ppm (Figure 5).

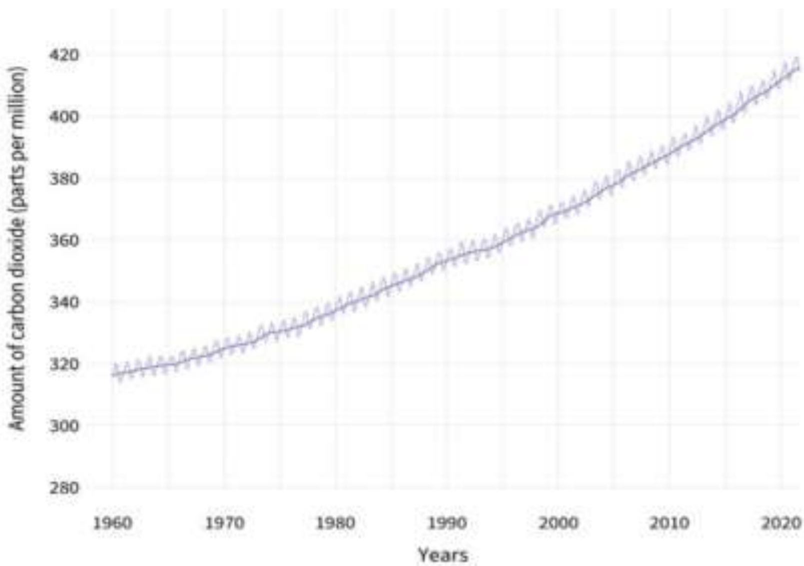

Figure 5. Atmospheric CO2 change in the world (1960-2021)

While the severity and frequency of hurricanes, and floods increase in some parts of the world due to climate change and global warming and long-term, severe droughts and desertification are effective in some regions (Ebi et al., 2021). Especially when compared to the year before 2000, it has been determined that winter temperatures have increased in the last two decades, spring comes early and autumn comes late (Beil et al., 2021).

It is documented that the most vulnerable sectors by climate change are water, food, ecosystem, health etc. With Paris agreement, efforts done to limit temperature increase to 1.5 °C until 2100 year (Gao et al., 2017). In the climate change scenario, the temperature increase is expected to be a few degrees higher in winter than in summer. A similar situation will be seen between night and day temperatures. The increase in nighttime temperatures will be greater than the increase in daytime temperatures. In this case, the lands will not have the opportunity to cool down at night as much as before. The riskiest region will be Africa in climate change scenario (Figure 6).

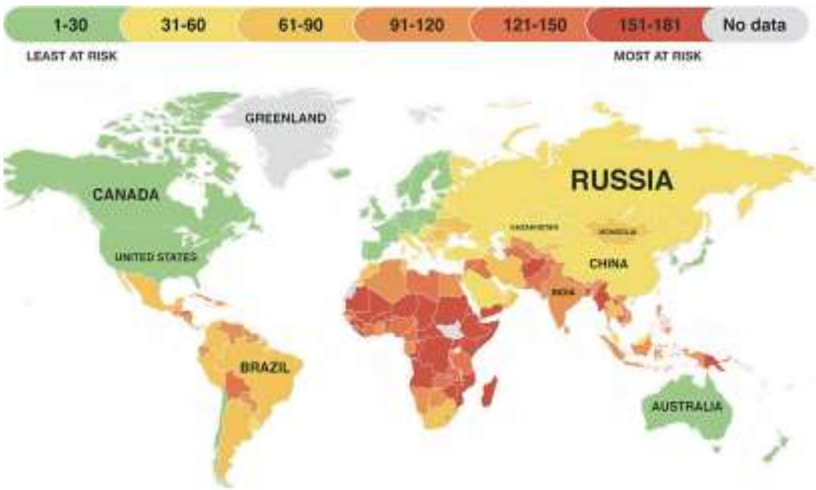

Figure 6. The countries most and least at risk against climate change (Shafqat et al., 2021)

2. CHARACTERISTICS OF FRUIT SPECIES IN THE CLIMATE CHANGE SCENARIO

Abiotic (temperature, irrigation, lighting, soil, nutrients etc.) and biotic (insects, fungi, diseases, animals etc.) stress factors are the most important factors limiting agriculture, especially fruit growing in the world. Each of these abiotic and biotic factors are essential for establishing, and sustaining a balanced ecosystem. It is well documented that fruit species are more vulnerable according to climate change than vegetables and field crops because of long living period which indicate difficult to adaptation in a short period (Kunz and Blanke, 2022). Shafqat et al. (2021) showed that drastic yield loss is evident for citrus trees because of abiotic stress including high temperature and low water. Under the abiotic stress conditions, citrus fruits show biochemical, anatomical, physiological, and genetic changes in plant structure and finally resulted defective growth, development, and reproduction. All these factors contribute economic yield lose. In particular during phenological stages, temperature and water scarcity increase leads to low fruit set, tends to smaller fruits, increase in fruit acidity and low yield. In addition, peel thickness decreases and pre-harvest fruit drop increase. High temperature reduces net carbon dioxide assimilation in citrus leaves and photosynthesis and CO2 assimilation decreased by water deficit and this lead mainly crop yield loss in citrus trees. To solve this important problem and mitigate climate change effects on citrus, smart and innovative agronomic practices, breeding strategies, and biotechnological approaches should be considered (Shafqat et al. (2021).

3. EFFECT OF CLIMATE CHANGE ON FRUIT TREE PHENOLOGY

3.1. Flowering Phenology

It is expecting that near future warming trends and spatial variability in rainfall regimes will potentially cause a serious imbalance between the physiological and biological rhythms of fruit species (Kaufman and Blanke, 2017). According to phenological clock of temperate fruit trees, the most effected periods of climate change including advanced flowering (rose), advanced and extended period of fruit development (flowering to harvest; green), earlier start of chilling and shorter time for chilling and forcing (blue) (Kunz and Blanke, 2022).

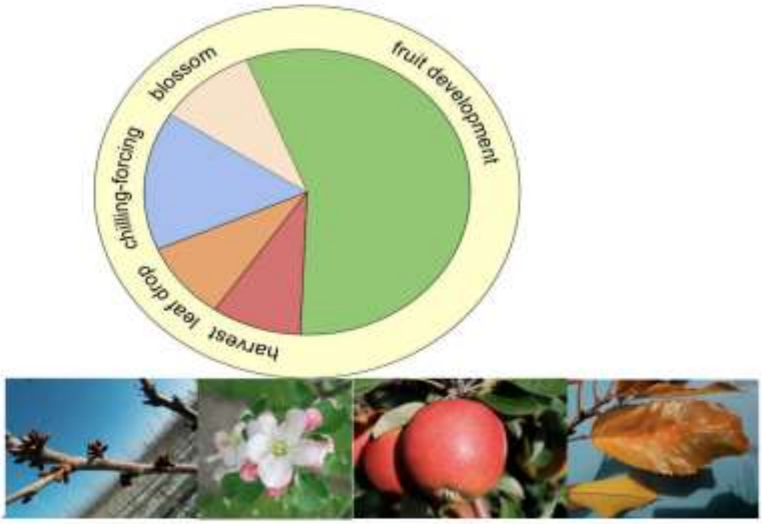

Figure 7. Phenology of temperate fruit trees (Kunz and Blanke, 2022)

In temperate climate conditions, in warmer spring months apple blossom occurs 11-14 days earlier harvest also were 4-15 days earlier due to climate change (Chmielewski et al., 2004). Previous studies conducted on different fruit species in different countries revealed that earlier flowering have occurred due to global warming (Legave and Clauzel 2006; Guédon and Legave, 2008; Woznicki et al., 2019; Tominaga et al., 2022).

In India, it is reported that temperature increase in year around in particular in growing and developing period resulted early flowering or delayed flowering, poor fruit set, reproductive bud transformation into vegetative ones etc. (Rajan et al., 2011). Increased CO2 level and temperature increase called as climate change resulted in yield reduction in strawberries (Sun et al., 2012). Extreme temperatures influence crops directly or indirectly like when the temperature is high the population of pollinating insects significantly decreased impacting the fruit set. In India, it is observed that higher temperatures resulted flower drop in female and hermaphrodite plants and also responsible for changes in sex in hermaphrodite plants (Reddy et al., 2017). In Mediterranean conditions increased temperature as a result of climate change resulted earlier flowering in olive (Aguilera et al., 2015).

3.2. Dormancy (Chilling Requirement Alteration)

It is well documented that climate change occurred in particular last two decades has resulted in warmer temperatures and in temperate regions warmer temperatures was evident from autumn to spring and has negatively affected dormancy progression, cold (de) acclimation, and cold tolerance in most of the temperate fruit trees. It is obvious that a clear decrease in chilling for all fruit growing regions in the world (Fraga and Santos, 2021).

This situation indicates leads to flowering and bud break disorder. Most of the scientists emerged this as a serious problem in the production of the pome and stone fruit tree productivity (Malagi et al., 2015; Fadon et al., 2020; Kunz and Blanke, 2022; Tominaga et al., 2022). Consequently, climate chance could affect varied rates of chilling and heat accumulation and may have influence the fulfillment of chilling and heat requirements which resulted advanced or delayed spring phenological events. In another study, it was found that at September–November smallest changes occurred (Luedeling et al., 2013). Inadequate chills can reduce pollination for cross-pollinated fruits such as pistachios and walnuts and thus reduces the crop yields (Chawla et al., 2021). A study conducted on olive trees showed that the higher temperature affected floral differentiation, favoring pistil abortion, and fertilization processes resulting fruit set reduction (Benlloch-González et al., 2018).

Temperate fruit trees are more sensitive to thermal conditions and the studies indicated that ongoing climate change affects fruit quality and productivity (Benmoussa et al., 2017; 2020; Buerkert et al., 2020; Fernandez et al., 2020). It is clear that considering and assessing present and future heat and chill accumulation in fruit species is vital to determine more suitable fruit species for a given site to success orchard management and profit and also lessen to detrimental impacts of climate change on fruit species (Fraga and Santos, 2021). Under global warming conditions, it is expected that winter chilling will be decreased at important fruit regions in warmer regions in different continent, in particular southern Europe and Mediterranean basin and this change will be more visible on high chill request fruit species including apple, pears, plums (Morais and Carbonieri, 2015). Along with south, the northern areas where apples grown will be exposed to chilling decrease and could be led flowering and fruit set abnormalities. In addition, a stronger inter-annual chill variability may produce to new problems (Ghrab et al., 2014). On the other hand, in warmer regions less chill or no chill demanding fruit species including oranges will not affected and will continue a normal flowering and fruit-set, and a more positive response to this warming is expected (Guo et al., 2015).

With global warming in particular warmer fruit growing areas, earlier bloom will be occurred and resulted spring frost damage on flowers. In addition, earlier flowering could be negatively affect pollination periods and enhance plant competition for nutrients and water (Woznicki et al., 2019; Lorite et al., 2020).

It is believed that, with global warming effect, the lower chilling required cultivars may increase in the near future to sustain this sector to increase adaptation for the most affected areas. In this scenario, in lower chilling conditions, some of cultivars will tend to migrate to other regions, depending on the regional climate conditions and in this case suitable cultivar selection for crop adaptation will be more important (Soloklui et al., 2017; Rodriguez et al., 2021). Considering all world fruit growing areas according to climate change scenario, climate change hotspot, Mediterranean basin, will have difficulties for fulfilling apple chilling requirements (Fernandez et al., 2020). Solution for this replacing cultivar may not have sufficient (Luedeling et al., 2011) and will lead to apply other options including to apply breaking dormancy agents, use rootstocks etc.

In warmer areas during spring-summer excessive heat are expected and deficit-irrigation strategies might be a suitable adaptation strategy for this (Lorite et al., 2020). The sunscreens, or certain types of shading system applications may have positive influence orchard microclimates (Lopez et al., 2018). In addition to this, heat-tolerant cultivars should be considered. Certain subtropical or tropical fruits are naturally adapted to warm climates and may replace some current temperate fruit trees currently grown in Mediterranean basin.

3.3. Fruit Maturation Time, Quality and Yield

Under climate change conditions, some visible changes occurred on growth and development of different fruit species and these changes including inadequate pollination, abnormal color development, advanced or delayed maturation, decrease fruit inner and external quality, low sugar content, low fruit set and low yield etc. In particular in warmer areas in the world such as India, Mediterranean regions etc. high-chilling needed apple cultivars like Royal Delicious have been replaced with low-chilling required cultivars or low-chilling needs fruit species including peach, kiwi, plum, pear etc. (Chawla et al., 2021). In addition, climatic change conditions a lot of abiotic factors are arises and consequently strongly affects fruit yield and quality of the several fruit crops and change their physiological, anatomical, morphological and bio-chemical parameters. Among the abiotic and biotic factors, rise temperature, drought, salinity, flooding, rise in CO2 concentration, and outbreak of insect-pests, have the greatest effect (Gora et al., 2019). In India, it is reported that temperature increase changes in the fruit maturity of mango (Rajan et al., 2011). Chen et al. (1997) showed that elevated CO2 increased yield and fruit quality of strawberry by increasing the total fruit number per plant, average fruit fresh weight, dry matter content, fruit total sugars and sugar/acid ratio. As temperate fruit crops, strawberries require much lower temperature and it is important to whether elevated CO2 will ameliorate the negative effects of the increased temperature on its reproductive development of strawberry. It is shown that high temperature conditions by climate change and low sunshine resulted apple's nutritional quality (Qu and Zhaou, 2016). Benlloch-González (2019) indicated that temperature in the Mediterranean Basin has been projected to rise drastically in the near future threatening olive production. They tested this hypothesis by using 'Picual' olive cultivar in simulating global warming conditions under field conditions. Results showed that 4 °C increase of ambient temperature based on 3 years average reduced fruit yield, strongly affects fruit traits and maturation. With temperature increase during development stage, smaller fruits, lower pulp/stone ratio, oil yield and anthocyanin contents were observed. The maturation period was forwarded and extended in some fruit species subjected to warmer temperatures. Temperature increases during fruit growing period has been revealed to reduces anthocyanins accumulation that affecting fruit color in olive (Benlloch-González, 2019). In addition, some studies revealed that higher temperatures during ripening may result in faster and unbalanced fruit maturity in temperate regions (Campoy et al., 2011; Luedeling et al., 2011; Ikinci et al., 2014). On the other hand in Norway, considering 30 years data, increasing March and April temperature revealed advanced blooming in plum and resulted growing season extension that increased fruit size due to extension of growing season. They suggested that ongoing climate warming may have positive or beneficial effect on plum in Nordic environment, but also earlier blooming brings spring frost risk because of continued warming (Woznicki et al., 2019).

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CHAPTER 3

CLIMATE CHANGE: EFFECTS ON VITICULTURE

Assoc. Prof. | Muhammed KÜPE[1]

[1]Department of Horticulture, Faculty of Agriculture, Atatürk University, Erzurum 25240, Turkey; muhammed.kupe@atauni.edu.tr, ORCID ID:0000-0002-7225-8065

INTRODUCTION

Agriculture is an indispensable sector in economy of most of the world countries because the sector feeding the any country's population, contributing to national income and employment, meeting the raw material needs of the industrial sector, transferring capital to the industry, and contributing directly and indirectly to exports (Redu et al., 2020; Beckman and Countryman, 2021).

Today, where the diversity of livestock and agricultural products is gradually decreasing, many countries support the issue of efficient and sustainable food security, which they see as an important dimension of agriculture in order to preserve the sector more strongly (Arulbalachandran et al., 2017; Vågsholm et al., 2020).

Türkiye has a serious comparative advantage in agriculture, which is seen as a national security issue and requires strategic policies to be produced in this direction (Serin and Civan, 2008; Sahinli, 2014).

While Türkiye's geographical structure offers great advantages for a rich and productive agricultural production, its geopolitical position serves as an important bridge for world agriculture. With its position among the top ten countries in the world in terms of agricultural production value, Turkey needs to take serious steps against its structure that may be vulnerable to possible climate change in order to get better (Esitken et al., 2009; Caglar and Yenal, 2011; Aksoy and Oz, 2020).

A guiding state policy should be brought to the fore both in strategic production and product diversification, with a breakthrough move to be made against the effects of possible climate change. Turkey is in an advantageous position in the agricultural sector in terms of comparative advantages. If it can implement the right policies that will support product diversity and appropriate production pattern on the basis of regions against possible climate change and increase the efficiency of products, it will both increase the added value of agricultural exports and minimize the input dependence on imports (Kanat and Keskin, 2018; Bozoglu et al., 2019).

Global warming and climate change are important issues that are closely related to the world in terms of their effects and consequences and are on the agenda of all countries. With the negative effects caused by the intensive production process to the environment and atmosphere, global warming and climate change are now felt severely in all sectors (Kanat and Keskin, 2018).

This increase in greenhouse gas directly triggers temperature. According to the 6th Assessment Report of the Climate Change Panel (IPCC), from the industrial revolution to the present, world average temperature has increased 1.1 °C. Paris Climate Change, which was approved by Türkiye and entered into force the long-term goal of the agreement is declared to keep this temperature rise below 2 °C and, if possible, decreased to limit to 1.5 °C (IPCC, 2022).

When we look at the table in Türkiye; due to global warming and climate change, changes in precipitation regime produce excessive precipitation and flooding in some agricultural regions, drought and water cycle vulnerabilities in some regions and in some region, it can be seen as big forest fires as well.

As a result of global warming, climate change has manifested itself with varying effects in different areas. Climate change cause vital problems such as; epidemics, drought, erosion, desertification, displacement of climate zones, increase in severe weather events, rise in sea level, deterioration of natural balance, damage to wildlife species and deterioration of human health (SPatz et al., 2012; Sena and Ebi, 2020).

The climate factor created the risk for the agricultural sector because of the unknowns involved is very high. Temperature increases, precipitation differences and extreme weather events form climate changes in most regions of the world is expected to cause adversely effects on crop and animal production systems (Ladrera and Cagasan, 2022).

1. VITICULTURE IN THE ANATOLIA

The one of the origin centers of grape (*Vitis* spp.) is Anatolia, and the history of the viticulture goes back to 3500 BC. During the Hittites period (1800-1600 BC), in Alişar (Yozgat, Sorgun) from the same dates wine and drinking vessels in the form of bunches of grapes, golden wine glasses from king tombs in Çorum Alacahöyük (3200 BC) On the relief of Tarhu, a bunch of grapes in his right hand as a symbol of fertility, the god of fertility, in Trabzon (410 BC), in Tarsus (378-374 BC), Bergama district of Izmir a relief from the 3rd century BC in the finding a ceramic artifact showing the wine god Dionysus in his hand and wine is included on the coins found in Karaburun, Seferihisar and Cesme are important evidence to support hypothesis that one of the origin of grape is Anatolia (Taskesenlioglu et al., 2022).

2. VITICULTURE IN THE WORLD

The grape can be found in every continental in the world and shows relatively high adaptative capacity on different climate and soil conditions and also propagated easily by grafting. It is one of the most common cultivated plants in the world. The geological and archaeological researches carried out in the 20th century showed that the plant have different origin centers including Caucasia, south of the Caspian Sea and North East Anatolia regions. The grape was grown in many parts of the world even about 60 million years ago (Mc Govern et al., 2017; Maghradze et al., 2021).

Grape growing around the world is located in the northern hemisphere between 20^0-52^0 and in the southern hemisphere is spread between 20^0-40^0 degrees of latitude due to temperature. In the world, more than half of the grape production is carried out in the European continent. According to FAO (2022), China ranks first in world grape production with around 14.770 million tons and followed by Italy with 8.220 million tons, Spain with 6.817 million tons, France with 5.884 million tons, USA with 5.388 million tons and Türkiye with 4.210 million tons, respectively. The estimated total world production for grapes in 2020 was 78.034 million tonnes, up to 1.3% from 77.800 tonnes in 2019.

Main grape producers distributed different continent in the world. (Figure 1 and 2).

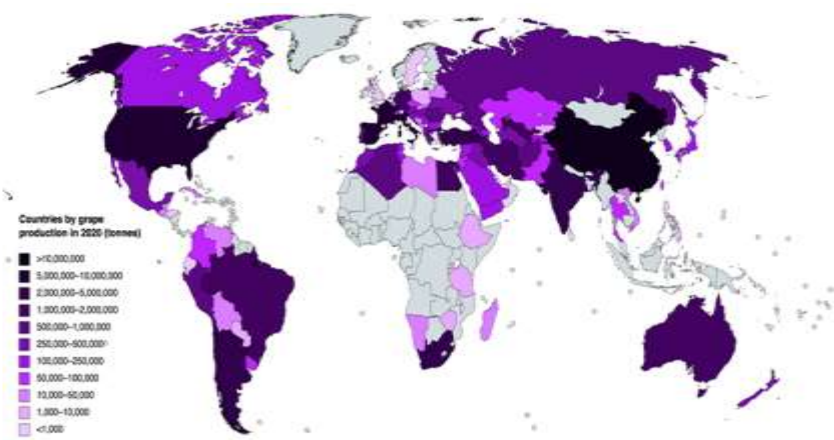

Figure 1. Countries by grape production in 2020

Turkey ranks 5th in world grape production in terms of vineyard areas and 6th in terms of production amount.

77.8 million tons of grapes are produced in the world, of which 57% is evaluated for wine and must (292 million liters), 36% for table (27.3 million tons), and 7% for drying (1.3 million tons). According to the data of OIV (International Vineyard and Wine Organization), grape production in the world is increasing despite fluctuations.

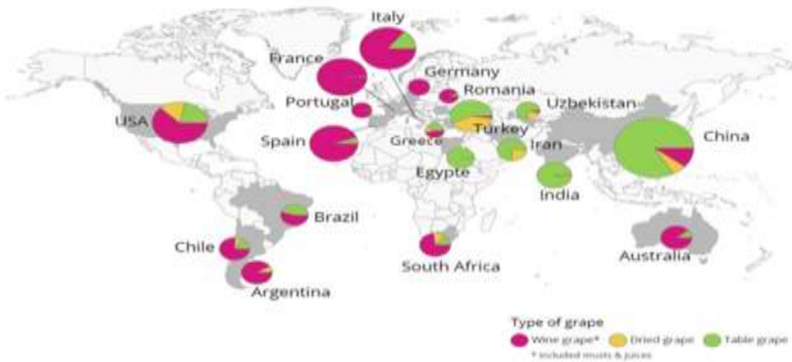

Figure 2. Main grape producing countries in the world

According to the data of OIV (International Vineyard and Wine Organization), world vineyard areas decreased from 7.8 million hectares to 7.4 million hectares between 2000-2018. The record years are 2002-2003 when the world vineyard acreage reached over 7.8 million hectares. We have lost about 6% of vineyards since then. The top five of the vine growing countries – Spain, France, China, Italy, Turkey – represent 50% of the world surface area.

According to OIV (International Vine and Wine Organization) 2018 data, world vineyard areas are given in the map below. Turkey is in the group of 400.000-650.000 ha in terms of vineyard area (Figure 3 and 4).

Within the EU vineyard plantings are subject to government controls (planting authorizations), the EU countries have agreed to limit growth to 1% per year.

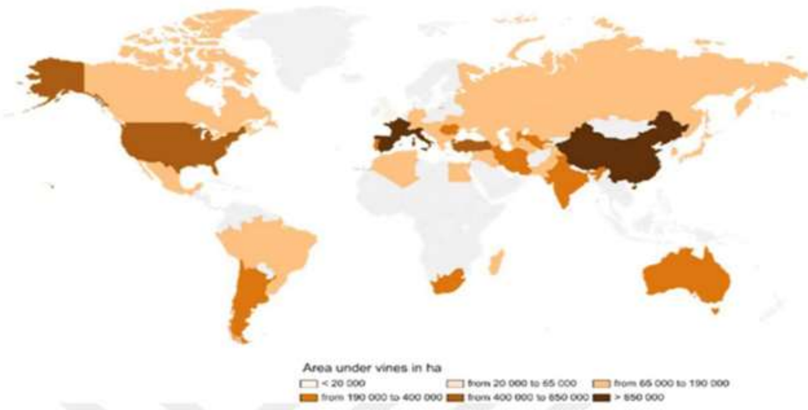

Figure 3. Vine growing areas in the world

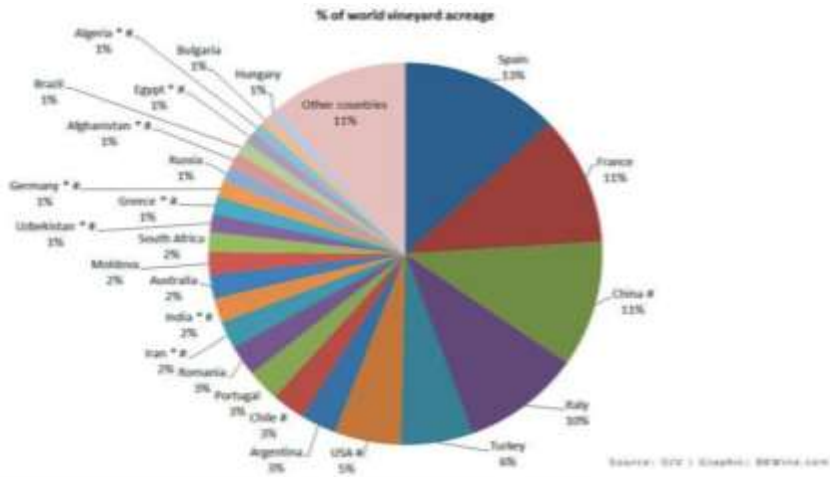

Figure 3. Vine growing areas according to countries in the world

3. CLIMATE CHANGE AND POSSIBLE EFFECTS ON VITICULTURE

Climate is an important forcing factor on grapevine (*Vitis vinifera* L.) physiological development (Keller, 2010), vegetative growth (Van Leeuwen et al., 2004), phenology (Costa et al., 2019), production, and consequently on wine quality. Climatic factors also determine the geographical location of vineyards (Fraga et al., 2019) and the variability in the weather parameters, such as air temperatures, precipitation, and solar radiation, leads to annual changes in productivity (Jones et al., 2000; Fraga et al., 2017). Weather extremes are also known to have detrimental impacts on grapevine productivity and quality, namely hail, late frost spells, and excessive rainfall (Mosedale et al., 2015).

The viticulture sector is an important sector especially in the economies of OIV member and developing countries. Global warming, which has made its impact felt in recent years, triggers many changes in vineyard areas, especially productivity, and opens opportunities for researching adaptation strategies and developing viticulture in new agricultural regions.

It is well documented that variations in temperature, relative humidity, water availability, and UV radiation, among others, may affect vine physiology, productivity and berry quality in vine growing areas. In addition, viticultural practices and edaphoclimatic conditions affect grape and wine quality, and their understanding may provide us valuable information for vineyard management and to define harvesting time (Costa et al., 2019; Fraga et al., 2019).

Climate change is an anticipated challenge that winegrowers will have to deal with in the next decades. During the 20th century, significant changes in temperatures were found, including increases from 2 to 5 °C in Europe (Christensen et al., 2007), which is home to world-renowned wine regions. Moreover, decreases in the precipitations over southern Europe (Christensen et al., 2007) were also found. According to the latest report of the ***International Panel on Climate Change*** (IPCC), following different representative concentration pathways (RCP), global temperature is expected to rise between 1 °C (RCP2.6—least severe scenario) and 5 °C (RCP8.5—most severe scenario), over the 21st century (IPPC, 2013).

Given the projected modification to climatic conditions, it is expected that climate change will generally have a negative impact on grapevines and wine production. Grapevines will be strongly affected by the higher temperatures during the growing season. As temperatures are a major driver of the grapevine development stages (Parker et al., 2013), significant warming is expected to lead to earlier phenological events. The advance of the flowering stage may also have a strong impact on management practices. Moreover, a warming during the maturation period will most likely change wine quality attributes and typicity. Extreme heat during this period may abruptly reduce vine metabolism, affecting wine quality attributes. Higher sugar and lower acidity levels should be expected, potentially increasing the risk of wine spoilage (Orduna, 2010), threatening wine production and quality. Furthermore, extreme heat and water stress, under future climates, may threaten final yields and productivity (Fraga et al., 2018).

Temperature increases, which started to become evident towards the end of the 20th century in cold climate regions where wine grapes are grown, such as the Mosel and Rhine valleys of Germany, reduced regional ecological risks in grape growing and provided significant benefits in increasing wine quality (Jones et al., 2004). They also indicated that from last 50 years period (1950-1999) when consider the highest quality wine-growing regions in the world, experienced warming trends in particular at growing periods of vine grapes. All wine-making regions in the world, the growers increased significantly their knowledge about wine-making, vintage quality and vine grape cultivations. It is evident that climate have a significant role in quality variations. England is accepted one of the world's highest quality wine producing countries and studies conducted from 1950 to 1999 showed that commercial vineyard regions in the country during vegetation period temperatures increase of 1.26 °C compared with the temperature data until 1950 (Jones et al., 2004). In another study carried out on Merlot in Australia, it was determined that bud burst, flowering and fruit ripening times were delayed due to climate change and increasing temperatures (Jackson and Lambord, 1993). It was previously showed that, with increasing temperatures, organic acid content, especially malic acid percentage decreases rapidly during grape ripening, while sugar concentration, phenolic compounds and potassium ratios increase rapidly (Coombe, 1987; Adams, 2006). In a study conducted on vines in Alsace, France, it was found that the number of days above 10 °C in 2002 was 33 days more than the data in 1972, and the harvest was delayed 2 weeks earlier (Duchene and Schneider, 2005). In another study carried out on the Pinot Noir grape variety in Baden, Germany, it was determined that the annual average temperature increased by 1.2 °C from 1976 to 2005, and this shifted the maturity start time and harvest 2 weeks ahead (Sigler, 2008).

It has been determined that the activity and role of Arbuscular mycorrhizal fungi, which play an important role in the creation of vineyards and the cultivation of vines, the introduction of nutrients to the plant and the resistance to drought, increase with temperature and CO_2 increases due to climate changes (Fitter et al., 2000). Ollat et al., (2002) revealed that during the vegetative development of the vine, the potassium ratio in the fruit components and the pH of the must increase with the effect of increasing temperatures due to climatic changes.

The factors affecting global warming are the mainly temperature and the increase in the CO_2 concentration in the atmosphere. It is known that an increase in atmospheric CO_2 concentration directly increases net photosynthesis, biomass, plant yield, light assimilation and water use efficiency in vines as in many other plant species (Bindi et al., 1996).

In a study carried out in a 20-year-old Sangiovese vineyard, between bud burst and harvest period, CO_2 values were increased from 370 ppm to 550 ppm, resulting in 35% of leaf area, 49% of vegetative dry weight and 21% of generative dry weight within a few months. Negative results have been observed in vines exposed to high concentration (700 ppm) CO_2 for a long time (Bindi et al., 1996).

In another study by Bindi et al., (2001), it was determined that the changes in the CO_2 concentration during fruit formation in Sangiovese vineyards were more effective on the berry components, which in turn affected the eating quality of table grapes and wine quality and lifespan in wine grapes.

In studies on vines, it has been determined that photosynthesis and adequate water intake are stimulated with a certain increase in CO_2 concentration in a short time. With the increasing CO_2 concentration, it is thought that the plants will be less affected by water shortage in viticulture in arid regions such as Spain (Schultz, 2000).

Aerosols, which have been released into the atmosphere in recent years, significantly reduce the ozone density. The decrease in the ozone density to such an extent that it cannot do its job of absorbing ultraviolet rays has increased the intensity of ultraviolet (UV) rays on earth, which adversely affects all living beings, natural resources and agricultural products. (Fergusson, 2001). The observed atmospheric warning and temperature increase trends and potential future changes influence vine production viability due to changes in winter hardening potential, frost occurrence, and growing season lengths (Nemani et al., 2001; Moonen et al., 2002). A long history of grape growing has resulted in the finest wines being associated with geographically distinct viticulture regions (Johnson, 1985; Penning-Rowsell, 1989; Unwin, 1991) found in the Mediterranean climates around the world (Figure 5).

Figure 5. Wine region centroids used to extract the appropriate grid cells for both the 0.5◦ × 0.5◦ 1950-1999 observed climatology data and the 2.5◦ ×3.75◦ 1950–2049 HadCM3 climate model data.

In a study conducted in England, it was determined that UV-B radiations cause some differences in coloration, aroma and taste formation in wines with the accumulation of phenolic compounds, which play a very important role in protecting the vine from light (Caldwell et al., 2007).

Although it has been determined that the drought, which occurs especially in the hot climate regions with the global climate change, causes some positive and negative morphological, physiological and chemical changes on the vines, the changes that negatively affect the growth and development are caused by cultural practices (irrigation, fertilization, soil cultivation, etc.) may be considered tolerable to a certain extent.

Many studies have been carried out based on different levels of water stress and irrigation practices at different growth stages of vine grain. Although most of the studies have shown that water stress has some beneficial effects on grain quality (anthocyanin and polyphenol concentrations and increase in water-soluble dry matter content) during the vegetation period (Carbonneau and Bahar, 2009), water deficiency in the period between flowering and first maturation causes the grapes to grow. It has been determined that the grain size is reduced (Matthews et al., 1987).

In the projections made from 2000 to 2100, it is estimated that there will be a temperature increase of 0.18-0.58 ^{o}C every 10 years in the regions where viticulture is made (Jones et al., 2004). When all these projections are evaluated, it is estimated that the highest warming will be in Portugal and the lowest warming will be in South Africa, and it is thought that this increase will be 2 ^{o}C on average for the vine growing regions (Anonymous, 2011). In addition to researches on determination of vine species/cultivars resistant to drought stress, clarification of tolerance mechanisms, protection and transfer of gene resources of drought-resistant vines, which emerged with the significant decrease in vegetation period precipitation in many regions where viticulture is carried out, especially in the Southern Hemisphere, with global climate change, it is thought that it is possible to reduce the damage caused by drought with some measures to be taken in cultural practices (Baloglu et al., 2010).

With the possible increase in temperature and the change in precipitation conditions, there will be a wide change in the agricultural areas of Türkiye. In this respect, important changes will be inevitable in the general vegetation distribution of Türkiye and the Eastern Anatolia Region. There will be expansions in the microclimates, which are very important in terms of horticultural production in the region, and new ones will be added to the plant species and variety richness. It is thought that insect populations, which are indispensable for flowering plants, will be affected by this change, and the existing diseases and pests of plant species will also get their share from this change.

Due to the global climate change, it is estimated that the loss of the protective effect of the snow cover in the traditional viticulture vineyards with the significant reduction in snowfall in relatively high-altitude regions will negatively affect viticulture in these regions in the near future.

As a result; In the light of these studies and evaluations, it is thought that the economically viticulture areas in the 20^{o}-40^{o} North and South latitudes will shift to the north in the Northern Hemisphere, and to the south in the Southern Hemisphere and towards the inner parts with higher altitudes. According to the studies carried out in this direction, it has been agreed that the least climate change will occur in the regions closest to the equator and that the probable changes expected in the Northern Hemisphere will be more than in the Southern Hemisphere. With these changes, it is thought that this risk will disappear in the areas where low temperatures limit viticulture in European vineyards in the Northern Hemisphere, while the problem of quality losses in world-renowned wines has come to the fore. As a result of this, although new areas suitable for viticulture have emerged with climate change, high-quality grape varieties grown in limited areas will have difficulty maintaining their quality in the regions they are in due to climate change, perhaps they will be replaced by other varieties.

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CHAPTER 4

USAGE OPPORTUNITIES OF WATER HYACINTH FOR REUSE OF WASTEWATER

MSc Student | Berna KELES [1]
Assoc. Prof | Hakan KELES [2]

[1] Department of Horticulture, Kırşehir Ahi Evran Univercity, Kırşehir, Türkiye, bernacetinel@gmail.com, ORCID ID: 0000-0002-6723-283X
[2] Department of Horticulture, Yozgat Bozok Univercity, Yozgat, Türkiye, hakan.keles@yobu.edu.tr, ORCID ID: 0000-0002-8225-931X

INTRODUCTION

Global warming and water scarcity are among the most significant problems of today and future generations. The global climate change is considered the most dangerous natural disaster due to the difficulty in solving the problem, (Kadıoğlu, 2001). Drought was examined under different titles and defined in 4 ways. The drought types, defined as meteorological, agricultural, hydrological, socioeconomic, and agricultural drought, which affects agricultural production and indirectly human nutrition, confront humanity as an important problem (Öner, 2013; Wilhite and Glantz, 1987). While 97.4% of the total water resources in the world are saltwater, only 2.6% of the resources are freshwater resources, and 0.8% of these freshwater resources can be used by humans (Samsunlu, 2006). 70% of fresh water is used for irrigation in agricultural areas. (Madakbaş et al. 2014; Kaya, 2018).

While desertification in the world is increasing day by day, more than 1 billion of the world's population currently lives in regions at risk of desertification. The increasing need for water due to the growing population and technology daily causes more people to face the risk of drought (Madakbaş et al. 2014). In developed countries where education and income levels are higher, attention is paid to the production and consumption of recyclable products, that are eco-friendly, contribute to the natural balance, do not have toxic effects on humans and the environment against risks threatening humanity such as global warming, water scarcity, and drought, etc. In recent years, many studies have been designed to serve these purposes and some measures can be taken against global warming, water scarcity, and desertification (Dursun et al., 2019; Kodaş 2011; Ozyazıcı et al., 2010). For example, research on the development and use of organic plant nutrition products (vermicompost, humic acid, seaweed, hydrogel, etc.) and containing microorganisms (pgpr, mycorrhiza, etc.), studied the ability of protecting the balance in soil ecology, not polluting groundwater unlike artificial fertilizers, and thus protecting both water resources and the natural balance in the soil (Ertürk et al., 2021; Balcı et al., 2020; Koc et al., 2016). In addition to the clean use of soil and water resources, the economical use of water and the reuse of wastewater is also important. Studies on the wastewater recycling also appear as one of the most important solutions against water scarcity and drought.

In recent years, rather than releasing used water to nature in an uncontrolled way, rehabilitating these waters and reusing them for various purposes became a good tool for better management of water resources (Salgot, 2006). In different countries, various projects are conducted in order to recycle wastewater for reuse, especially water that serves agricultural purposes (Friedler, 2000). Although the recycling and use of wastewater are considered fundamental ways to solve the problem of water scarcity, only a few countries, including the USA, Western Europe, Australia, and Israel have carried out this method (Miller, 2005; Salgot, 2006).

Besides many technological systems in wastewater, recycling some phytoremediation technologies can be used in addition to these systems. In this study, the water hyacinth (*Eichhornia crassipies*) plant, which is frequently mentioned in herbal healing technologies, will be emphasized.

1. WATER HYACINTH (*Eichhornia crassipies* (MART.) SOLMS.)

It was first described as an Indian ornamental plant by researchers in Brazil in 1896 (Rao, 1988, Chillers, 1991). *Eichornia crassipes*, belonging to the Pontederiaceae family, was once depicted as "a lavender symphony that adorned the world with beauty" (Poling ve Barr, 1965). Also called "lilac devil", "million-dollar grass" and commonly "water hyacinth" by different researchers (Edwards and Musil, 1975).

Figure 1. Water hyacinth (*Eichornia crassipes*) blossoms (Anonymous 2022a,b)

Water hyacinth is spread over 2 million hectares of water surface in India and it has been noted that it is relatively abundant on the Thamirabarani River surface (Murugesan et al., 2002; Murugesan et al., 2005). Originating from South America, water hyacinth is widespread in stagnant or slightly flowing waters in tropical, subtropical, and temperate climatic regions. It is also a native plant of Central America, North America, Africa, Asia, and Australia (Agunbiade et al.., 2009; Gülgün et al., 2010). Thanks to its intriguing flowers and leaves, it has been transported to more than 80 countries in the last 100 years by botanists and plant collectors (Jafari, 2010).

Water hyacinth, a perennial plant, can double its size in an average of 7 days when it finds suitable ecological conditions. It can produce 50,000 plants quickly from the mother plant (Gülgün et al., 2010). Due to its rapid reproduction feature, it is known as a harmful aquatic pla the water hyacinths may densely cover water areas and, therefore cause problems such as blocking water transport; blocking the inlets of irrigation, hydroelectric, and water supply systems; forming microhabitats for various disease vectors; increased evapotranspiration, fish mortality and reduction of aquatic biodiversity in the water caused by depletion of oxygen (Chaudhuri et al., 2008; Malik, 2007). Some techniques have been developed for the controlled growth of water hyacinths. Some methods include physical or mechanical cleaning by hand, biological removal using water hyacinth-consuming insects, and chemical cleaning using herbicides (Gopal, 1989; Hong et al., 2005).

Figure 2. Water hyacinth on the water (*Eichornia crassipes)* with its blossoms (Anonymous, 2022c, d)

Apart from the application of water hyacinth as an ornamental plant, it is used in many other areas effectively. Therefore, in cases of increased population, it can be evaluated in areas such as rope and furniture production, mixing with soil or using it as a mulch cover on the soil, fish or animal feed, basket production, paper and fiber production, biogas production.

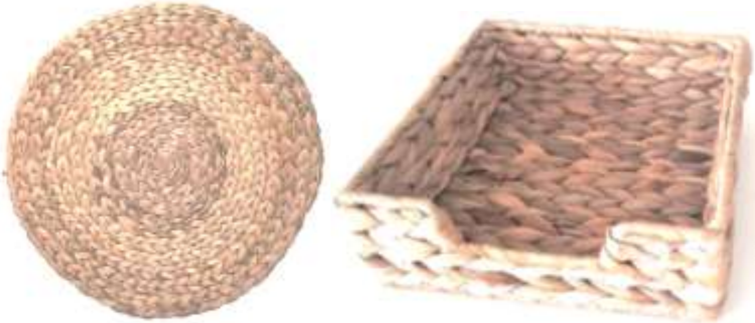

Figure 3. Some uses of Water Hyacinth (*Eichornia crassipes)/*(Photo by: Hakan KELES)

However, wastewater treatment is considered the most useful and proising way of problem solving. Baraach ve Singh, 1984; Almoustapha et al., 2009; Ajayi ve Atoke, 2012). Moreover, water hyacinth can be evaluated in the producing of renewable fuels and chemicals through pyrolysis of bio-oil detected compounds such as phenols, alcohols, carboxylic acids, ketones, alkenes, alkanes, aldehydes, and aromatic. This property may solve the problems of uncontrolled growth in freshwater (Wauton and Ogbeide, 2022). Water hyacinth contains several phytochemicals, including alkaloids, flavonoids, terpenoids, tannin, phenolic compounds, sterols, etc (Zarifikhosroshahi et al., 2022; Jha and Namdeo, 2022). High level of such compounds leads water hyacinth to have pharmacological activities, such as antibacterial, antifungal, antioxidant, anti-inflammatory, immunomodulatory, and cytotoxicity effects (Valenzuela et al., 2013; Lavecchia et al 2012). However, the unique nature of water hyacinth causes its potential application for developing various products in the industry, such as the construction of various supercapacitors, the production of ethanol, and improving the immune resistance of plants and animals (Guna et al., 2017).

2. THE APPLICATION OF WATER HYACINTH (*Eichhornia crassipies* (Mart.) Solms.) IN PHYTOREMEDIATION AND RELATED STUDIES

Phytoremediation has been defined as the direct use of plants and their natural metabolic and hydraulic properties to remove, decompose or trap a contaminant (Cheremisinoff, 1996). While water hyacinths show positive properties in phytoremediation, they exhibit significant potential in wastewater treatment. Brundu et al., (2013) reported that water hyacinths are evaluated in two ways, based on ornamental plant characteristics and the properties of being a phytoremediation plant. Thanks to their fibrous roots, water hyacinths form dense felt on the water surface, making it easier for water pollutants to reach plant roots. At the same time, they can tolerate high concentrations of heavy metal accumulation due to their large leaves. These properties show their potential for use in water treatment systems (Soltan and Rashed, 2003; Harun et al., 2008). Studies on water hyacinths have determined that plants improve wastewater from integrated treatment plants and oxidation ponds, and significantly reduce inorganic nitrogen and phosphorus found in household, sewage, industrial and municipal wastewater (Polprasert and Khatiwade, 1998; Liao and Chang, 2004; Jayaweera et al., 2008; Nesir, 2010). Keith et al., (2008) reported that water hyacinths convert sewage waste into relatively clean water by absorbing and digesting pollutants in wastewater. The same researchers have also used water hyacinth to clean wastewater in small-scale sewers.

Nesir (2010) studied the potential of water hyacinths in wastewater treatment in Serbia and reported that they removed suspended solids in domestic wastewater. Recurrently, in a study on the treatment of textile factory wastewater, it was reported that when water hyacinths are used in secondary treatment, they reduce the biochemical oxygen demand of water and remove suspended solids (Gamage and Yapa, 2001).

3. CONCLUSION

Plants play an essential role in every aspect of human life with their many beneficial properties. Although water hyacinths are seen as invasive and dangerous plants in some aspects, they have a very high potential to be used in different areas with the proper methods.

Although drought threatens humanity, many methods are being tried to overcome this issue. Many studies have been conducted on the evaluation of water hyacinths on this subject, and positive results have been obtained in the studies. Turkey is among the water-poor countries. For this reason, it is very important to use the available water more effectively. The use of water hyacinths, which develop well in subtropical and temperate climatic conditions, can be evaluated in suitable regions of Turkey as the main or substitutional element in water treatment facilities, in the treatment of domestic or municipal wastewater. These processes can contribute to more sustainable use of water to be supplied for the increasing population.

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CHAPTER 5

DROUGHT STRESS IN PLANTS

Assoc. Prof. | Emine Sema ÇETİN [1]

[1] Yozgat Bozok University, Faculty of Agriculture, Department of Horticulture, Yozgat, Turkey, esema.cetin@yobu.edu.tr, ORCID ID:0000-0001-7601-8491

INTRODUCTION

Plants play an important role in the ecological cycle. They primarily take on a highly complex and efficient task, photosynthesis, but also critical functions such as preventing erosion, contributing organic matter to the soil, providing temperature control, and becoming raw materials for different industrial areas. Despite these extremely important roles in the ecological cycle, plants are known to be facing numerous negative factors. Plants may be affected by these unsuitable conditions, and in response, they exhibit signs of damage ranging in severity depending on their sensitivity. This condition, called stress, is initially referred to as a downturn event that manifests itself with retrogression in growth and development, resulting in a low crop. In short, the conditions that prevents the plant from adapting in any way, which make it difficult for it to survive and reproduce, are defined as a stressful environment (Hawkesford and Buchner, 2001). The ability of a plant to survive in unsuitable conditions is called "stress tolerance" (Levitt, 1980).

Biotic and abiotic environmental factors cause stress in plants. Abiotic stresses are classified as physical (drought, salinity, temperature, plant nutrients, air pollution, pesticides, toxins, soil PH, mechanical effects,) stresses. Biotic stresses are caused by diseases, animals, microorganisms, wild plants, and pests.

The most fundamental factor determining the best way for plants to grow in different ecologies is their response to stresses. Stresses caused by abiotic factors are common in many parts of the world (Asraf and Ali, 2007).

Any stressor can cause damage to an organism's various functions. Damage can be reversible if stress is eliminated or a tolerance to stress is developed. Whether the response given by plants is reversible (elastic) or irreversible (plastic) varies depending on the plant's genetic potential, duration, and severity of the stress (Korkmaz and Durmaz, 2017). However, in any case, if the stress lasts for a long time, its severity increases, or tolerance cannot be kept during this process, developmental retardation begins in the plant, which can cause permanent damage to the plant, such as impaired metabolism, low crop yield, and genetic changes (Zaidi et al., 2014; Bhat et al., 2020).

Losses in crop yield under different adverse conditions create the basis for social and economic problems, especially for developing countries (Ashraf and Iram, 2005; Kalefetoğlu and Ekmekçi, 2005; Daşgan et al., 2009).

Our world population is increasing rapidly. It is estimated that the world's population will be more than 9.7 billion by 2050. More than 65% of this consists of a population that lives solely on agriculture. It is thought that this rate will rise to over 90% in developing countries (Castañeda et al., 2016). As a result, not only the economy of a country but also its food supply will depend heavily on agriculture. However, agricultural practices face numerous challenges, particularly a scarcity of water resources (Ahluwalia et al., 2021).

The most important cause of crop loss in agriculture worldwide is abiotic stress, which threatens the future of agricultural production by causing about 50% losses in major agricultural products (Mahajan and Tuteja, 2005). Among the abiotic stresses, drought stress is the biggest source of stress (%26) in our age (Figure 1) and climate changes are exacerbating this situation more and more (Kalefatoğlu and Ekmekçi, 2005; Kahil et al., 2015).

Figure 1. Shares of plant stress in usable lands around the world

Irrigable agricultural areas are limited worldwide (Wang et al., 2003), and it is known that these areas are decreasing every day with changing climatic conditions. The freshwater needed for the continuity of the ecosystem is becoming more and more insufficient, which creates a serious problem (Khanna Chopra and Selote, 2007; Balint et al., 2013). According to the United Nations World Water Development Report, an estimated 55 million people worldwide are affected by drought. It has been stated that about 700 million people will be at risk by 2030 due to drought (Anonymous, 2018). By 2040, an estimated one in four children will live in areas with severe drought conditions (Figure 2). (Anonymous, 2022).

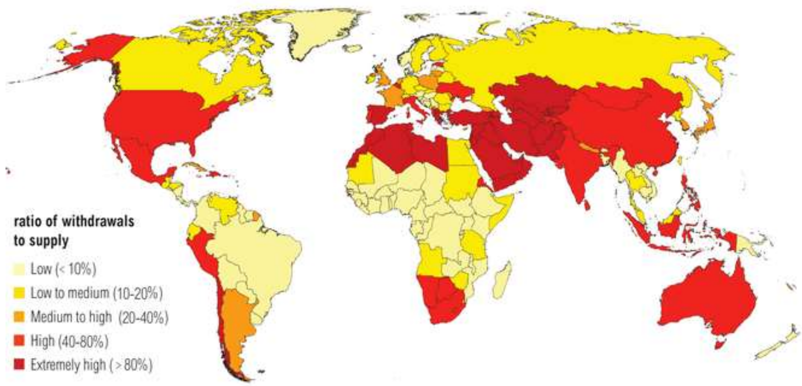

Figure 2. Water stress by country: 2040 (Anonymous, 2022).

Drought affects food production, as well as causes groundwater levels to decrease, water quality to deteriorate, soil erosion to increase and other negative consequences that can eventually result in disasters such as fire, flood, and the spread of pandemics (Ahluwalia et al., 2021).

Despite the increasing population, our agricultural areas cannot be enhanced, on the contrary, the mentioned problems are present, which make it mandatory to increase the amount of yield received from the unit area. In this case, the selections of stress-resistant species and varieties, and approaches that will give the plant strength are crucial.

1. TYPES OF DROUGHTS

Drought is classified into four categories.

-Meteorological drought: It is a drought that occurs in dry weather.

-Hydrological drought: It occurs especially at the surface and underground water levels, in situations of low, insufficient water supply and a few months after a meteorological drought.

-Agricultural drought: It is a drought that is usually associated with decreasing soil water levels and, accordingly, decreases in crop yields, severely affecting food production all over the world.

-Socio-economic drought: It is associated with problems in the supply and demand of various products due to droughts (Heim, 2002; Ahluwalia et al., 2021).

2. AGRICULTURAL DROUGHT

Agricultural drought usually occurs when water is scarce in the habitat. This drought is also described as a physical drought. In some cases, although there is water in the soil, plants cannot benefit from this water. It's not about the lack of water it's about the inability to use it. This condition, defined as physiological drought (Korkmaz and Durmaz, 2017), is a condition in which the water in the soil cannot be taken because it is frozen, or high osmotic pressure is created in the soil by keeping water molecules in the ions of dissociating molecules, and therefore it cannot be taken. Regardless of the origin, stress occurs when the water lost by transpiration in plants over certain of time exceeds the amount of water taken from the environment. Water intake competition begins between plant tissues following low water intake. Thus, the water between plant tissues is imbalanced.

3. THE EFFECTS OF DROUGHT ON PLANTS

If plants cannot benefit from the water in the environment, several damages occur according to the severity, duration, and tolerance of the drought. In addition, drought often also occurs in combination with other stresses, such as salinity, metal toxicity, unfavorable temperatures, pathogens, or a lack of nutrients. Adaptation to this type of stress is more demanding for the plant, and their effect is more destructive than the stress caused by drought alone (Ahluwalia et al., 2021). The general disadvantages caused by drought in plants are stated below.

3.1. Plant Development and Productivity

One of the effects of drought is the inhibition of germination (Harris et al., 2002; Kaya et al., 2006). In a study conducted on peas, drought stress prevented the germination and seedling development of five tested varieties (Okcu et al., 2005). In alfalfa (*Medicago sativa*), germination power, hypocotyl length, fresh and dry shoots, and root weight decreased, but root length increased (Zeid and Shedeed, 2006).

One of the most sensitive physiological processes in the drought process is the inhibition of cell growth depending on a decrease in turgor (Taiz and Zeiger, 2006). Cell enlargement may be inhibited due to scarce water flow from the xylem (Fernández-de-Uña et al., 2017). Plant height, leaf area, and quantity of product decrease in arid conditions (Kaya et al., 2006; Hussain et al., 2008).

Many physiological processes that determine yield in plants are affected by drought stress. In drought stress, the severity, duration, and time of stress and the reactions of plants after stress relief and the interaction between stress and other factors are important (Plaut, 2003). For example, in triticale genotypes, drought conditions shortened the flowering time before flowering, as well as shortened grain filling time after anthesis (Estrada-Campuzano et al., 2008). Water scarcity reduced grain yield by diminishing the number of seeds, spikes, grains per plant, and grain weight in barley. Drought stress after anthesis damages grain yields, regardless of the severity of the stress (Samarah, 2005).

Many species have been detected to yield low product depending on the severity and duration of the drought. In conditions of drought stress in corn, the number of grains per plant decreased, especially in relation to spike and grain count (Cattivelli et al., 2008). Drought stress reduced the total seed yield in soybeans (Frederick et al. 2001).

Drought stress during the flowering period often results in infertility. The most important reason for this is that the flow of nutrients, which is necessary for optimal development, is reduced (Yadav et al., 2004). Lint yields decreased in cotton (*Gossypium hirsutum*) during the drought (Pettigrew, 2004).

Drought stress reduced seed yield by 40-55% in chickpeas (Nam et al., 2001). Water stress naturally accelerates the activation and flow of pre-stored carbohydrate reserves into the grain in rice (Yang et al., 2001).

3.2. Crop Yield

There are three main reasons for crop yield decline depending on the lack of water in the soil. The decrease in photosynthetically active radiation, the decrease in radiation utilization efficiency, and the reduced harvest index (Earl and Davis, 2003).

3.3. Relative Water Content

In response to drought stress, the relative water content of plants is changed. Total water content decreased by approximately 57% in *Opuntia ficus*. The water-storing parenchyma cells lost more water from the sclerenchyma and therefore showed a lower turgor potential (Nerd and Nobel, 1991).

Relative water quantity, leaf water potential, stomatal tolerance, transpiration velocity, and leaf temperature are important features that affect plant-water relationships. The relative water content of wheat leaves is initially higher during leaf development, which decreases as dry matter accumulates and the leaf matures. The relative water content in wheat and rice crops under drought stress is lower than in non-stressed ones. Leaf water potential, relative water quantity and transpiration velocity are significantly reduced in stress conditions (Siddique et al., 2001).

In terms of water use efficiency, which is defined as the ratio between produced dry matter and the amount of consumed water (Monclus et al., 2006), plants under stress exhibit a variety of reactions. Lazaridou et al. (2003) reported that alfalfa grown under water scarcity had greater water use efficiency than under irrigated conditions. Abbate et al. (2004) also concluded that the water use efficiency of wheat in the case of limited water is higher than in well-irrigated conditions. Researchers have attributed this to the plant closing its stomata to reduce transpiration. In another study on alfalfa, water use efficiency increased under drought stress, primarily due to reduced transpiration velocity and leaf area (Lazaridou and Koutroubas, 2004). In a study conducted on *Hibiscus rosa*, Egilla et al. (2005) stated that transpiration, stomata conductance and water use efficiency decreased under drought stress.

3.4. Nutrient Intake

The limited availability of water decreases under drought, leading to limited nutrient intake. The decrease in absorption of inorganic nutrients is also depending on decreased transpiration (Garg, 2003). However, under drought conditions, mineral intake varies depending on the plant and the type of consumed nutrient. It is stated that the effect of drought on plant nutrition may be related to limited energy use or NO_3^-, NH_4^+, PO_4^{-3}, and SO_4^{-2} assimilation, also it is emphasized that these ions can be used in plant growth and development before being converted into energy-dependent processes (Grossman and Takahashi, 2001). In a study, it was stated that drought affects transpiration, but this does not change food intake in the same way (Peuke et al., 2002). In a different study, it was indicated that drought stress increased nitrogen, decreased phosphorus significantly, and had no definite effect on potassium (Garg, 2003).

3.5. Photosynthesis

A major effect of drought is a decrease in photosynthesis, disruption of the photosynthesis mechanism, and early leaf senescence (PLS) caused by a decrease in leaf expansion (Wahid and Rasul, 2005).

The first reaction of almost all plants to drought is to close their stomata to prevent water loss through transpiration (Zhanshuai et al., 2022). This reduces the entry of CO_2 into the leaves and allocates more electrons for the formation of reactive oxygen species (ROS).

Drought stress causes changes in photosynthetic pigments (Anjum et al., 2003), damaged photosynthetic apparatus (Fu and Huang, 2001), and decreased activity of Calvin cycle enzymes (Monakhova and Chernyadev, 2002). Indeed, CO_2 concentration in the protoplasm of mesophyte plants exposed to mitigated drought stress remains at a high level. This is depending on reduced CO_2 consumption and suggests that photosynthesis is inhibited. In general, several photosynthetic enzymes and other metabolic activities in mesophytes are directly affected by stress. Severe drought conditions limit photosynthesis owing to a decrease in Rubisco activity (Bota et al., 2004). Dehydration causes cell shrinkage and, therefore, a decrease in cell volume. This makes the cellular content more viscous. Therefore, an increase in the likelihood of protein-protein interactions leads to their aggregation and denaturation. The increased concentration of solutes, which leads to an increase in the viscosity of the cytoplasm, can become toxic and be harmful to the functioning of enzymes, including those that act in photosynthesis (Hoekstra et al., 2001).

3.6. Dry Matter Accumulation

Drought stress often increases the accumulation of dry matter in the roots (Leport et al., 2006). Drought stress during pod filling resulted in a significant increase in the contents of trehalose, sucrose and starch but glucose was decreased (Hlahla et al., 2022). Drought stress reduces the velocity of photosynthesis, reduces the level of sucrose in the leaves, and disrupts carbohydrate metabolism. This is owing to the increased activity of acid invertase following drought stress (Kim et al., 2000). Limited photosynthesis and accumulation of sucrose in the leaves can interfere with the correct delivery of sucrose to the organs of consumption and ultimately block reproductive development.

3.7. Respiration

Carbohydrates lost through respiration determine the plant metabolism (Davidson et al., 2000). The root is an important consumer of carbon and uses it in growth and development (Lambers et al., 1996). The rapidity of photosynthesis usually limits plant growth when soil water decreases (Huang and Fu, 2000). More than 50% of the daily photosynthesis products in wheat are transported to the root and approximately 60% of them are used in respiration (Lambers et al., 1996). The drought-sensitive wheat genotype (Longchun, 8139-2) spends a relatively high amount of glucose to absorb water under severe drought stress (Liu et al., 2004). In severe drought situations, shoot and root biomass, photosynthesis, and root respiration velocity are reduced. A lack of water causes an increased root respiration velocity, resulting in an imbalance in the use of carbon resources, enhanced production of ROS (Farooq et al., 2009).

3.8. Oxidative Damage

Plants produce ROS (superoxide anion radicals, hydrogen peroxide (H_2O_2), hydroxyl radicals, and singlet oxygen) that damage membrane components in stress conditions (Blokhina et al., 2003; Munné-Bosch and Penuelas, 2003). ROS production can occur in many components of the cell. The stimulated pigments in thylacoid membranes can interact with O_2 to form powerful oxidants (Reddy et al., 2004). The interaction of O_2 with reduced components of the electron transport chain in the mitochondria can lead to the formation of ROS (Möller, 2001) and peroxisomes produce H_2O_2 when glycolate is oxidized to glyoxylic acid during photorespiration (Fazeli et al., 2007). ROS can react with lipids, proteins, and DNA, causing oxidative damage (Foyer and Fletcher, 2001).

ROS production in biological systems can occur through enzymatic/non-enzymatic reactions (Apel and Hirt, 2004). Peroxidases and catalases play an important role in the regulation of ROS (Sairam et al., 2005).

4. DROUGHT TOLERANCE MECHANISM

While the responses of plants to drought are generally known, it is not easy to discern the reactions of plants resulting from multiple stress situations. In particular, some stress factors such as drought, excessive light, and heat stress occur together (Zhou et al., 2007). Plants classified as xerophyte and mesophyte should be evaluated separately in terms of their reactions to drought. Because, the plants of both groups try to survive and continue their generations by expressing different reactions from each other (Korkmaz and Durmaz, 2017).

4.1. Mechanism in Xerophytes

Plants in regions where water is extremely scarce, such as deserts, are developing different strategies to adapt. These strategies occur in 4 different types; drought avoidance, drought escape, drought tolerance, and drought recovery against insufficient water stress (Levitt, 1980).

4.1.1. Drought avoidance

Drought avoidance consists of mechanisms that reduce water loss from plants through stoma control and maintain water intake through an effective root system (Turner et al., 2001; Kavar et al., 2007). Root characters such as intensity, biomass, length, and depth are the main characteristics that contribute to crop yields in these plants in arid conditions (Turner et al., 2001). A deep and thick root system helps to extract water from the deep (Kavar et al., 2007). Yellowing of the leaves or waxy layer on the leaves helps maintain tissue water potential (Jun et al., 2016). Xerophytes that live in deserts and have developed an "avoidance" response to the stress of water scarcity have a wide range of protoplasmic water potential. Palms develop their roots rapidly in the desert and reach the water layer in the soil. Plants such as *Prosopis glandulosa* and *Medicago sativa*, which can rapidly extend their roots up to 7-10 meters deep into the soil, never experience a "negative water potential" in their cells (Korkmaz and Durmaz, 2017).

4.1.2. Drought escape

Plants with these characteristics "escape" from dry periods, which can cause "negative water potential" in their protoplasm (Salisbury and Ross, 1992). Here, matching the growth time of plants to the time when water is present in the soil is critical for high seed yield (Siddique et al., 2003). Escape from drought occurs when the phenological development of the plant harmoniously coincides with periods of moisture in the soil.

It is a mechanism that allows the plant to reproduce before the environment dries out, expressed by a shortened life cycle or a short growing season (Araus et al., 2002). These plants are annual, short-lived plants, and their metabolism is quite different. Plants, which express a strategy of escaping, escape from water scarcity by remaining in seed form during the drought season. Their seeds germinate during periods when the soil is wetted by rains and they complete their vegetation cycles in a short time by forming flowers, fruits, and seeds before the soil loses moisture (Korkmaz and Durmaz, 2017). In this system, flowering time is critical (Araus et al., 2002). The time of flowering is an important feature of the adaptation to the environment. However, yield is often associated with the duration of crop yield under favorable growing conditions, and any decrease below optimal reduces yield in this process (Turner et al., 2001).

4.1.3. Drought tolerance

Plants that store water in their tissues, such as cacti, are succulent plants with "Crrassulace Acid Metabolism" (CAM). They develop a response to drought in the form of tolerance.

CO_2 assimilation in CAM plants occurs through Crassulacean acid metabolism, which is why these plants are called CAM (Crassulacean Acid Metabolism) plants. This name was given because CO_2 assimilation was first detected in plants belonging to the Crassulaceae family, and later it was found that the same metabolic pathway was followed in plants in some other families. Today, it is known that this metabolism exists in 26 different Ferns and Angiosperm families, such as Cactaceae, Orchidaceae, Bromeliaceae, Liliaceae, and Euphorbiaceae.

These plants grow in arid areas or where water is difficult to get from. Extreme climatic conditions such as extremely hot days and extremely cool nights such as desert climates, very high light intensity, and drought often cause

CAM plants to thrive. The cuticle layer on the leaf surface of CAM plants is very thick, and the palisade parenchyma (mesophyll) is usually not well developed, it photosynthesizes with sponge parenchyma cells. These cells have few cytoplasms and very large vacuoles. Most CAM plants have a succulent structure. CAM plants also have bundle sheath cells around the vascular bundles, but they are not as well developed as in C4 plants. Structurally, they are more similar to mesophyll cells. The most important feature of these plants is that their stomata are closed during the day and open at night. In this way, the loss of water in the form of steam through the stomata is minimal during the day. When the stomata are opened at night, the water loss by stomatal transpiration is very low compared to the absorbed CO_2. For example, *Agave americana* L. keeps its stomata close during the day, preventing water loss during the hot and drought period. Some cacti have a "broad superficial root system" and can collect soil surface moisture immediately after precipitation and store it in succulent tissues, thus resisting drought stress. Some species that are periodically exposed to drought open their stomata throughout the day during periods when the water reaches sufficient potential, returning from CAM to "C3 photosynthesis". For example, *Clusia rosea* is a tree that begins its life as an epiphyte in the rainforest. During drought periods between rainy seasons, especially young epiphytes are subject to the stress of water scarcity, as their aerial roots are not yet sufficiently developed. During these periods, plants turn to CAM photosynthesis via the C3 pathway in response to rapidly decreasing humidity (Levitt, 1980).

4.1.4. Drought recovery

Although these plants lose excess water from their protoplasm, they do not die, as they tolerate the effect of dehydration. Because, unlike others, in addition to having some xerophytic adaptations, their protoplasm retains its vitality even when they are exposed to excessive negative water potential (Korkmaz and Durmaz, 2017). For example, even for many xerophyte species, a protoplasm water potential below 75-50% is fatal, while *Larrea divaricata* Cav. can maintain its vitality despite the water potential in its protoplasm being as low as 30%. Many species of mosses and ferns are also included in this group (Levitt, 1980).

4.2. Mechanism in Mesophytes

Mesophytes, which prefer more humid environments than xerophytes, have also developed many responses to water stress. The impact of drought on the plant varies from morphological to molecular levels and is observed in all phenological phases of the plant (Farooq et al., 2009).

4.2.1. Morphological strategies

Changes such as increases in deeper penetration or elongation of root systems, surface-reducing changes in leaf and stem shapes, reduction and fragmentation of leaf areas in various sizes, curling or rolling of leaves to protect stomatal surfaces, changes in the number of hairs on the leaf and stem, changes in the cuticle and wax layers on the epidermis, increase in the thickness of the cuticle and wax layers on the epidermis, the deeper embedded stomata, the shedding of leaves, the photosynthetic function of some stems are among the morphological changes.

One of the first influences of stress in plants is restricted growth, and there is a lot of research reporting that growth is adversely affected under stress conditions, especially in susceptible plants (Abdelmoneim et al., 2014; Zhang et al., 2020a; Mareri et al., 2022). The decrease in cell growth is the most sensitive response that mesophytes have developed to water stress. Turgor pressure is an important factor in cell growth (Le Gall et al., 2015). A low turgor pressure leads to a reduction of cell extensibility and cell expansion (Tardieu et al., 2011). Plants exposed to drought display morphological changes. In winter triticale, water deficit induced leaf rolling (Hura et al., 2012).

In laboratory studies, although the negative water potential in the range of -0.3 to -0.8 Mega Pascal (MPa) is considered moderate, it has been seen that from -0.3 MPa onwards, direct, or indirect internal responses begin to occur in cell metabolism.

In some species, for example, where the negative water potential is within this range, the amount of cytokine hormone in the leaves, which promotes cell division and contributes to plant growth, decreases. In more negative water potentials, the amino acid proline in the cell protoplasm expressed a sudden increase, sometimes even accounting for 1% of the dry weight of the tissue (Salisbury and Ross, 1992). It has been observed that if mesophytic plants are irrigated during periods when negative water stress is -

1.0 to -2.0 MPa, they return to their former state. This indicates that despite the severity of water scarcity stress, some of the responses are reversible.

Plant growth is greatly affected by the shortage of water. At the morphological level, shoots and roots are the most affected, and both are essential components of the plant's adaptation to drought. Plants often limit the number and area of leaves to reduce water use in response to drought stress (Skelton et al., 2015; McDowell et al., 2020).

Roots are the essential organ for drought adaptation. Root growth, density, proliferation, and size are key plant responses to drought stress, as roots are the sole source for obtaining water from the soil. Having a deep and thick root structure allows access to water deep in the soil and this is important in gaining tolerance (Kavar et al., 2007).

Researchers emphasized that the structure and distribution of roots are important, not the number of roots, and the drought tolerance of tea, onion, and cotton is increased with improved root development. Nayyar and Gupta (2006) also conducted studies to determine the effects of drought stress on wheat and corn crops and noted that the decrease in growth is remarkable in wheat plants susceptible to stress. Drought stress reduces shoot and root dry weight (Wu and Zou, 2009a; Wu and Zou, 2009b), decreases root hairs, weakens branching, changes root morphology, and decreases the transition of nutrients to the roots, so plant growth slows down (Nahar and Gretzmacher, 2002).

Drought rhizogenesis is an adaptive strategy that occurs during drought stress. The formation of short, tuberous, hairless roots in the Brassicaceae family is an example of this. These roots can withstand a long period of drought (Vartanian et al., 1994).

Tolerant plants with small and needle leaves survive very well under drought, but their growth rate and biomass are quite low (Abobatta, 2019). Leaf hair is a xeromorphic feature that helps protect leaves from heat overload. Hair on the leaves reduces leaf temperatures and transpiration (Sandquist and Ehleringer, 2003). Hairs are formations created against arid conditions, which are most clearly seen on both leaves and some stems. Other duties of hairs are to distribute the rays coming on the plant or to break the rays reflected from the soil, to protect the plant from the attacks of pests such as flies and insects, and to contribute to the cooling of the leaf surface. Under the stress of high temperature and radiation, hairiness increases light reflection and minimizes water loss by increasing the boundary layer resistance of the leaf against transpiration.

The accumulation of a wax layer on the leaf surface, which leads to the formation of a thicker cuticle, reduces water loss from the epidermis. This also reduces carbon dioxide uptake but does not affect leaf photosynthesis. Because the epidermal cells under the cuticle are not photosynthetic.

4.2.2. Physiological strategies

Responsibilities related to stomata, regulations related to photosynthesis, osmotic adjustment, the emergence of protective solutions in leaves, changes in the amount of protein, oil, and carbohydrates in the membrane, increases in protective plant surface lipids, changes in the storage lipid quantity, presence of water stress proteins are physiological changes.

4.2.2.1. Stomatal closure

In mesophytes, a common response to water scarcity stress is the closure of the stomata, thereby reducing transpiration and photosynthesis. The closure of the stomata has a significant effect on reducing transpiration. However, stomata are known to close faster in partially drought-tolerant plants than in less tolerant plants. It is thought that early closure of the stomata is a reaction to the drying of the soil, which can help establish the ideal water balance depending on the transpiration velocity of the leaf.

4.2.2.2. Osmoregulation

Osmotic adaptation is recognized as one of the most important processes in drought adaptation as it helps maintain plant metabolic activity (Kaur and Asthir, 2017). One of the most common tolerance efforts in plants is the production of organic compounds (Serraj and Sinclair, 2002). Amino acids (proline, aspartic acid, and glutamic acid), glycine betaine, sugars (fructans and sucrose), and cyclitols (mannitol and pinitol) are produced. These are generally non-toxic compounds even at high concentrations.

Maintaining high tissue water potential with osmotic regulation is effective against drought stress (Turner et al., 2001). Osmotic regulation is an important feature in delaying dehydrative damage in water-restricted environments (Taiz and Zeiger, 2006). They usually protect plants from stress by different means, such as osmotic adjustment, ROS detoxification, stabilization of the membrane structure, and natural structures of enzymes and proteins. Osmotic regulation maintains water relationships under stress. Under a shortage of water and as a result of its solute accumulation, the osmotic potential of the cell is reduced, which attracts water to the cell and helps maintain turgor (Subbarao et al., 2000).

Proline is known to be the most important osmoprotectant (Hu et al., 2015). Proline accumulation is used not only as a drought parameter but also as a tolerance parameter to stresses such as temperature and nutrient deficiency (Abdul Jaleel et al., 2007). Osmotic regulation contributes to the accumulation of carbohydrates before flowering during grain filling in cereals. Higher turgor leads to higher photosynthetic velocity and growth (Subbarao et al., 2000). Drought stress leads to the accumulation of citrulline, glutamate, and arginine in wild watermelon leaves (Yokota et al., 2002).

Exposure of mesophytes to excess negative water potential leads to inhibition in protochlorophyllide synthesis. Terzi and Kadıoğlu (2006) reported that while chlorophyll and carotenoid content and chlorophyll stability index decreased in the early period of drought stress, these values increased in later periods. In addition, they reported that the synthesis of phenylalanine, amino ligase, and some other enzymes decreased because of increased water scarcity stress, while the activity of alpha-amylase and ribonuclease enzymes increased. In this case, hydrolytic enzymes are thought to break down the starch and other compounds, making the osmotic potential in the protoplasm more negative and allowing resistance to water scarcity through a kind of osmoregulation.

Polyamines are known to have significant effects on plant growth and development. Polyamines have been previously reported to be involved in drought tolerance (Seifikalhor et al., 2020; Zhang et al., 2020b). Since they are cationic, polyamines combine with anionic components of the membrane, such as phospholipids, to protect the membrane from stress (Rudolphi-Szydło et al., 2020). Many genes of enzymes involved in polyamine metabolism have been cloned from several species, and their expression under various stress conditions has been analyzed. The apple spermidine synthase gene codes high levels of spermidine synthase when overexpressed, which significantly increases tolerance to abiotic stress (Wen et al., 2007). Among various polyamines, an increase in the level of putrescence is usually depending on an increased arginine decarboxylase activity (Fortes et al., 2019). Compared to sensitive plants, stress-tolerant plants generally have a higher capacity to synthesize polyamine in response to stress (Kasukabe et al., 2004). Recent studies have shown that rice has a great capacity to increase the biosynthesis of polyamine in early response to drought stress, including spermidine and spermine in free form and putrescine in insoluble conjugated form. This was considered an important physiological feature of drought tolerance in rice (Yang et al., 2007).

Plants under stress produce not only osmotic regulation but also different biochemicals to cope with stress. For example, secondary metabolites play an important role in the adaptation of plants to disuniform environmental conditions and overcome the stress effects (Edreva et al., 2008). Phenolic compounds are a promising group for inducing stress tolerance (Celeste Varela et al., 2016; Parvin et al., 2022). Ayaz et al. (2000) reported that the increase in phenolic acid in the leaves may be owing to the increased level of amino acid synthesis stimulated by drought in *Ctenanthe setosa*. Celeste Varela et al. (2016) stated that flavonoid production and accumulation could be a useful indicator of drought tolerance in native species. Similarly, Sarker and Oba (2018) studied the nutritional and bioactive compounds of amaranth under drought stress and they determined that the increments of all these components were more preponderant at moderate and severe stress conditions and drought stress enhanced the nutritional and bioactive compounds.

4.2.2.3. Conservation of water in cells and tissues

Sensitive pea genotypes are more affected by drought than tolerant ones owing to a relative water content decrease (Upreti et al., 2000). The water content in the leaves in the morning and afternoon was reported to be useful in determining drought tolerance in chickpeas (Pannu et al., 1993). There are also studies reporting that leaf water potential is not very suitable for distinguishing between sensitive genotypes and tolerant ones, this water potential is not a determinant, but a tolerance property (Riccardi et al., 2001).

4.2.2.4. Antioxidant defense

The antioxidant defense system in the plant cell consists of enzymatic and non-enzymatic components. Enzymatic components include superoxide dismutase (SOD), catalase (CAT), peroxidase (POX), ascorbate peroxidase (APX), and glutathione reductase (GR). Non-enzymatic components include cysteine, reduced glutathione, and ascorbic acid (Gong et al., 2005).

The high activity of antioxidant enzymes and the high content of non-enzymatic components are important in stress tolerance such as drought. ROS in plants is scavenged by various antioxidant enzymes and/or scavenger molecules that dissolve in oil and water (Hasegawa et al., 2000). The most effective mechanisms against oxidative stress are antioxidant enzymes (Farooq et al., 2008).

SOD is the first step in systems of scavenging ROS and plays an important role in the enzymatic mechanisms that catalyze the dismutation of two superoxide molecules into O_2 and H_2O_2.

APX is a key antioxidant enzyme in plants. GR has a central role in maintaining reduced glutathione during stress (Pastori et al., 2000).

Lima et al. (2002), in a study in which they used two clones of *Coffea canephora*, suggested that drought tolerance may be associated with increased antioxidant enzyme activity.

Transcription of certain antioxidant genes has been detected at higher levels during the recovery period after drought stress, suggesting that these enzymes play a role in protecting against damage to ROS (Ratnayaka et al., 2003). These metalloenzymes form an important primary line of defense of cells against superoxide free radicals produced under stress conditions. Therefore, increased SOD activity is known to provide oxidative stress tolerance (Pan et al., 2006).

Due to the decrease in the activity of the nitrogen reductase enzyme following water scarcity in mesophytes, nitrogen fixation and reduction are also subdued, and even cell division is inhibited as a result of decreases in enzyme activity (Salisbury and Ross, 1992).

4.2.2.5. Cell membrane stability

It is generally accepted that maintaining the integrity and stability of membranes under drought stress is an important process of drought tolerance in plants (Bajji et al., 2002). Membrane stability in response to cell membrane damage is used in the assessment of drought tolerance (Wang et al., 2022). There are also studies indicating that this trait is related to genetic structure (Tripathy et al., 2000; Dhanda et al., 2004). In Holm oak seedlings, hardening reduced osmotic potential and stomatal regulation, increasing drought tolerance, developing new stem growth capacity, and increasing cell membrane stability. Fluctuation in stability of cell membrane, stomatal regulation, and stem growth capacity is negatively associated with osmotic regulation (Villar-Salvador et al., 2004).

4.2.2.6. Plant hormones

Phytohormones play a vital role in the drought tolerance of plants. Auxins, gibberellins, cytokinins, ethylene, and abscisic acid are the most well-known plant hormones. While xerophytes generally developed irreversible adaptive responses, mesophytes developed hormonal reversible responses to water stress. One of the common reversible responses is observed in abscisic acid (ABA) metabolism.

Auxins induce new root formation by breaking the apical dominance of the root induced by cytokinins. The exogenous application of indole-3-acetic acid increased net photosynthesis and stomatal conductance in cotton (Kumar et al., 2001). ABA application increases the synthesis of indole-3-butyric acid in corn under drought stress. In the GA5, biosynthetic mutant of GA was also found gibberellic acid to contribute to the formation of short, softened, hairless roots seen in drought rhizogenesis (Vartanian et al., 1994).

ABA is a growth inhibitor and is produced under a wide range of environmental stresses. ABA prevents transpiration by closing the stomata, which saves water. It reduces the development of the apex organs of the plant and allows water to be used in the root system so that the root can go deep and reach more water.

Although reactions are seen in all plant species in water scarcity, their severity varies. While the amount of ABA increases 40-fold in the leaves during the stress process, this increase is less in other organs, including the root (Abdul Jaleel et al., 2007).

It has been suggested that ABA and cytokinin have opposite roles in drought stress. An increase in the amount of ABA and a decrease in cytokinin levels facilitate the closure of the stomata and limit water loss through transpiration under water stress (Sah Saroj et al., 2016; Huang et al., 2018). When plants wilt, ABA levels typically rise as a result of increased synthesis. By its effect on closing the stomata, ABA can control the velocity of transpiration and, to some extent, be involved in the mechanism that provides drought tolerance in plants. The increased concentration of ABA leads to many changes in development, physiology, and growth. ABA alters growth rates in different plant parts, such as an increase in the root-shoot dry weight ratio, inhibition of leaf area development, and deep root production. This triggers the formation of a complex series of events that lead to stoma closure, which is an important water conservation response (Turner et al., 2001).

Ethylene has been considered a growth inhibitor hormone for many years (Taiz and Zeiger, 2006). The response of cereals to drought includes the loss of leaf function and the onset of early senescence in leaves. Ethylene is effective in drought-induced aging, regulating leaf performance and determining the onset of natural aging (Young et al., 2004). In addition, endogenous ethylene production in plants is influenced by several biotic and abiotic factors (Chen et al., 2022).

Salicylic acid, a plant growth hormone, is also emphasized to be effective in the formation of tolerance to various abiotic stresses. Salicylic acid has been found to enhance the formation of ROS in the photosynthetic tissues of *Arabidopsis thaliana* during osmotic stress (Borsani et al., 2001).

4.2.3. Molecular strategies

Under drought stress, several changes occur in gene expression in the plant. At the transcriptional level, various genes are stimulated in response to drought and these genes are effective in drought tolerance (Kavar et al., 2007). Gene expression may be triggered directly by stress conditions or may result from secondary stresses and/or injury responses. It is known that drought tolerance is a complex mechanism involving many genes (Agarwal et al., 2006; Cattivelli et al., 2008).

Aquaporins can facilitate and regulate passive water exchange between membranes. They belong to the family of fundamental internal membrane proteins (Tyerman et al., 2002).

In plants, aquaporins are abundant in the plasma membrane and vacuolar membrane. Aquaporins are thought to regulate the hydraulic conductance of membranes and provide a 10-20-fold increase in water permeability (Maurel and Chrispeels, 2001).

The synthesis of stress proteins is one of the responses of plants to cope with stress in drought stress, as in other stresses. Most stress proteins are water-soluble and therefore contribute to stress tolerance through the hydration of cellular structures (Wahid et al., 2007). The synthesis of various transcription factors and stress proteins is particularly relevant to drought tolerance (Taiz and Zeiger, 2006).

Membrane-stabilizing proteins are another important group of proteins that are effective in drought tolerance. These are proteins called dehydrins. They also play an important role in retaining ions, which are concentrated during cellular dehydration (Gorantla et al., 2006).

General responses to stress include the stress detection signal through the redox system, checkpoints that cease the cell cycle, and DNA repair processes that are stimulated in response to DNA damage.

Chemical signals, such as ROS, calcium, and plant hormones, act through transduction cascades, play a role in inducing stress tolerance and activate genomic reprogramming (Joyce et al., 2003).

5. APPLICATIONS IN DROUGHT STRESS

As the drought problem is becoming more and more severe, it has led to studies on the use of some practices to reduce the effects of this stress on agricultural production. These include sustainable farming techniques and efforts to transform unproductive land into arable land. Recent research has focused on drought resistance to alleviate the effects of this stress with the use of nanoparticles (Saxena et al., 2016), the use of superabsorbent hydrogels and biochar (Saha et al., 2020; Zhang et al., 2020c), and plant growth-promoting rhizobacteria (Chiappero et al., 2019). In addition, studies are being carried out on the development of drought-resistant plants (Nuccio et al., 2018).

5.1. Ensuring Drought Resistance -Nanoparticles

Nanoparticles (NPs) have versatile physicochemical properties such as large surface area, high activity, and adjustable pore size (Saxena et al., 2016). The mechanism of action of NPs in inducing drought tolerance is complex and mostly unknown. However, different studies have reported that NPs regulate aquaporins, which are water channel proteins, provide better water and nutrient supply to germinating seeds and thus increase germination rates even under drought stress conditions (Khodakovskaya et al., 2011; Li et al., 2020).

TiO_2 is the most studied NPs. They can improve the velocity of photosynthesis with their characteristic photo-catalytic activity, in which a load transfer takes place between the light-harvesting complex II and TiO_2 NP (Ahluwalia et al., 2021).

The use of NP in drought resistance is quite successful. Silicon, silver, zinc, titanium, and iron NPs are effective in improving the photosynthesis velocity, reducing the MDA content, increasing the proportional water content, and improving the root and shoot system, in short, supporting plant growth and development (Ashkavand et al., 2018).

NPs also help in the production of enzymatic and non-enzymatic antioxidants, increasing the levels of antioxidant systems and in some cases even mimicking the role of ROS scavengers (Zaimenko et al., 2014; Ashkavand et al., 2018). Sun et al. (2021) found that the application of ZnO NPs in drought-affected corn plants improved the net velocity of photosynthesis, aided stomata movement, increased water and chlorophyll content, and also improved the activities of enzymes involved in starch and sucrose biosynthesis, as well as glucose metabolism in the leaves of plants. Despite these advantages, there are many disadvantages associated with using NPs as an ingredient in sustainable agriculture. NPs can cause cytotoxic effects on the plants with which they interact (Martínez-Fernández et al., 2016; Rawat et al., 2018). Furthermore, the precise impact of NPs on the environment has not yet been recognized. It may be possible that their regular use may lead to long-term adverse effects that cannot be detected immediately (Moulick et al., 2020).

5.2. Use of Superabsorbent Hydrogels and Biochar

Super absorbent hydrogels (SAHs) are a new strategy that aims to promote drought tolerance by introducing changes in the soil. Hydrogels are a thin layer with a high cross-link, 3-dimensional, 60 cm wide, and 0.06 mm thick layer with the ability to absorb and retain water and soluble molecules in high quantities (Batista et al., 2019). The materials used to create these hydrogels are non-toxic, biodegradable, biocompatible, and cost-effective (Ahmed, 2015; Saha et al., 2020).

By applying this method, a large number of crops can be grown even in deserts and concrete (Mori, 2013). However, this technique is still not very popular because it is both time-consuming, requires intensive labor, is not economical, requires large areas, and the installation of a greenhouse (Sardare and Admane, 2013).

It has been established that when super absorbent hydrogels are applied to various soils, they increase the efficiency of water use, improve soil permeability, and reduce surface runoff and the frequency of soil erosion. It has also been determined that SAHs also improve the beneficial water content of the plant (Narjary et al., 2012; Yang et al., 2014).

Superabsorbent hydrogels present in the soil absorb water during periods of precipitation and release water for uptake by plants in the case of drought (Feng et al., 2014; Tomášková et al., 2020).

Biochar is a carbon-rich product. It is important as a plant stress reducer because of its properties of increasing soil fertility, promoting nutrient uptake and development, and improving water capacity in plants under stress (Semida et al., 2019; Haider et al., 2020). The implementation of biochar as a soil improvement technique depends on the type of used raw material, and its physical and chemical composition, including specific surface area and porosity (Afshar et al., 2016; Zhang et al., 2020c). When biochar is added to soil, it affects the soil's surface area, porosity, water-holding capacity, and many other chemical and biological events (Durukan et al., 2020; Zhang et al., 2020c). Plant growth and development are supported in arid conditions in soil with increased productivity. Biochar absorbs and retains nutrients directly in the soil, and plant roots reach the water without having to dig deeper for water intake. Studies have shown that the application of biochar has a positive effect on the photosynthetic ratios of the plant, xylem water potential, chlorophyll content, phytohormone production, intake of essential nutrients, and plant growth (Ali et al., 2017; Semida et al., 2019). The production of biochar is a boring and expensive process for farmers.

5.3. Drought Tolerance by Plant Growth-Promoting Rhizobacteria

Plant growth-promoting rhizobacteria are microorganisms present in the rhizosphere and show activity with root secretions (Woźniak and Gałazka, 2019; Xiong et al., 2020). These bacteria are usually beneficial and act as biostimulants, being directly or indirectly involved in promoting plant growth and production. *Pseudomonas, Bacillus, Rhizobium, Bradyrhizobium, Pantoea, Azospirillum, Acetobacter* and *Burkholderia* are among this group of bacteria (Timmusk et al., 2014; Chiappero et al., 2019; Pathania et al., 2020). These PGPRs provide growth-promoting benefits in the plant by colonizing the roots (Kabiraj et al., 2020; Pathania et al., 2020). PGPRs develop symbiotically or non-symbiotically in the rhizosphere. Many of them can penetrate plant roots and express endophytic relationships in the stem, leaves, and other parts of the plant (Wozńiak and Gałazka, 2019; Kabiraj et al., 2020). The most prominent functions of PGPRs include nitrogen fixation, phosphate solubility, phytohormone production, maintenance of soil composition, biological decontamination of polluted soil, resistance to pests, insects, and fungal pathogens, and reduction of abiotic stresses such as drought and salinity (Novo et al., 2018; Pathania et al., 2020). PGPRs cause physical, chemical, and biological modifications to plants to help them survive and thrive in stressful conditions such as drought. In addition, their implementation requires less labor (Vurukonda et al., 2016; Etesami and Maheshwari, 2018).

5.4. Development of Drought-Resistant Plants

5.4.1. Selection and breeding

Conventional breeding requires the selection of superior ones in terms of yield (Atlin and Lafitte, 2002) but it is not a very correct approach, since yield is a quantitative characteristic, depending not only on genotype but also on the interaction of genotype × environment (Babu et al., 2003).

5.4.2. Seed priming

One of the short-term and most effective approaches for alleviating/reducing drought stress is seed priming. Seed priming is a technique in which seeds are partially hydrated to a point where metabolic processes related to germination begin, but root formation does not occur (Farooq et al., 2006). These pre-treated seeds usually have a higher germination rate, higher germination uniformity, and sometimes a higher total germination percentage (Kaya et al., 2006; Farooq et al., 2007).

5.4.3. Use of osmoprotectants

Osmoprotectants are involved in the signaling and regulation of plant responses to multiple stresses, which may be part of the plant's adaptation to stress. Common osmoprotectants in plants are proline, trehalose, fructan, mannitol, glycin betaine, and others (Zhu, 2002). They play an important role in mediating osmotic regulation and protecting cellular structures in stressed plants. However, not all plants accumulate these compounds in sufficient quantities to prevent the negative effects of drought stress (Penna, 2003).

5.4.4. Use of plant growth regulators

Foliar application of hormones or plant growth regulators has been beneficial in improving plant growth against various abiotic stresses. While drought stress alone prevented increases in hypocotyl length and fresh weight, the exogen application of GA reversed this effect. In this case, GA partially increased the water condition of the seedlings and partially maintained protein synthesis (Taiz and Zeiger, 2006). GA increased the net photosynthesis velocity, stomatal conductance, and transpiration velocity in cotton (Kumar et al., 2001).

The application of 1-aminocyclopropane-1-carboxylic acid also delays senescence and improves drought tolerance (Todd et al., 2004). Exogen uniconazole, brassinolide, and ABA applications increased soybean yields in both well-watered and water-deficient conditions. In conditions of water stress, regulatory applications for plant growth significantly increased the water potential and increased chlorophyll content (Zhang et al., 2004).

Jasmonates play an important role in the signaling pathway by triggering the expression of plant defense genes in response to various stresses (Kumari and Singh, 2022; Moradi et al., 2022). Jasmonic acid applied externally to pears increased betaine levels, leading to drought tolerance (Gao et al., 2004). Benzyladenine is an active cytokine that can increase the drought resistance of different plants (Shang, 2000).

5.4.5. Molecular and genomic approaches

It has been stated that transgenic plants have higher yield values and tolerate abiotic stresses (Rastogi Verma, 2013; Fita et al., 2015; Nuccio et al., 2018). Tolerance can be improved in plants with modifications of some proteins, increased production of phytohormones, and adjustments in osmotic regulations (Hu and Xiong, 2014). However, there are several disadvantages to using transgenic plants in combating drought stress. This approach is time-consuming, requires labor, and can lead to the loss of some useful properties of the plant. Genetically modified plants can also make the use of herbicides mandatory, create superweeds, cause uncontrolled population growth of insects and lead to antibiotic resistance (Key et al., 2008). Furthermore, genetic manipulation for drought resistance is difficult, as the biochemical and molecular basis of drought signal detection, signal transduction, and stress adaptation are still not fully known (Hu and Xiong, 2014).

Drought tolerance is a genetically controlled condition. For this reason, many quantitative characteristics and other associated genes that ensure membrane stability have been characterized using bioinformatic tools (Tripathy et al., 2000; Fu et al., 2007).

Molecular and biochemical studies have identified many genes that are sensitive to ABA and stress (Buchanan et al., 2005; Poroyko et al., 2005). The expression of some stress-regulated genes has resulted in increased tolerance to drought and other stresses. But the enhanced expression of these genes is most often associated with the regression of growth in the plant, which limits practical applications.

New-generation drought-resistant plants obtained by breeding or bioengineering require a better understanding of the molecular and genetic basis of drought resistance (Xiong et al., 2006). Therefore, rice as an aquatic plant is an excellent model for a precise understanding of the phenomenon of drought tolerance. Studies are reporting that rice shows morphological changes after exposure to drought at various stages of growth (Manikavelu et al., 2006).

6. CONCLUSION

Plants in nature are constantly exposed to various biotic and abiotic stresses. Of these stresses, drought stress is one of the most negative factors on plant growth and productivity and is considered a serious threat to sustainable crop production in changing climatic conditions. Drought affects food production, as well as causes a decrease in groundwater levels, deterioration of water quality, increased soil erosion, and other adversities that can eventually result in disasters such as fires, floods, and the spread of epidemics. Therefore, studies aimed at preventing drought and the effects of drought are crucial. First, it is necessary to use water resources efficiently and to carry out applications to improve the soil structure.

Drought triggers a wide range of plant responses, from cellular metabolism to changes in growth rates and crop yields. Understanding the biochemical and molecular responses of plants to drought is essential for a holistic perception of plant resistance mechanisms to stress. It is important to select and develop drought-resistant varieties through traditional and modern engineering techniques. Developing varieties that yield crops in a short time, ensuring early ripening, helps the crop avoid a period of stress, so it is an effective strategy to minimize yield loss due to drought. Moreover, healthy survival in the arid period can be achieved by implementations to enhance tolerance in plants and retain the amount of moisture in the soil.

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CHAPTER 6

THE POLYPLOIDY MECHANISM AS RESPONSE TO GLOBAL CLIMATE CHANGE

Prof. Dr. | Halil Erhan EROĞLU [1]

[1] Yozgat Bozok University, Faculty of Science and Art, Biology Department, Yozgat, Türkiye, herhan.eroglu@bozok.edu.tr, ORCID ID: 0000-0002-4509-4712

1. GLOBAL CLIMATE CHANGE

The climate system is a complex and interactive system that includes the atmosphere, land surfaces, snow and ice, oceans and other of waters, and living things. This system gradually changes over time, under the influence of its internal dynamics or depending on external factors. External factors can occur naturally or by human influence as burning of fossil fuels, land use changes, deforestation, and industry. These factors will absolutely have positive or negative consequences for organism diversity (Naghiloo and Vamosi, 2021; MGM, 2022). In short, the natural and human environment that lived in the glacial and interglacial periods, when the earth was covered with glaciers, has been greatly affected in the period from the beginning of human history to the present. It is certain that human influences have also contributed to these changes, which are related to natural factors, since the middle of the 19th century (Öztürk, 2002).

There are three main ways disturbed radiation balance which is the power source of the climate system and changes the climate: changes in the incoming solar radiation, changes in the reflected part of the solar radiation, and changes in the long-wave radiation sent back from the earth to space due to the greenhouse gas effect. The climate change is defined as changes in the mean state and/or variability of the climate, regardless of the cause over a period of decades or more. Climate changes in geological periods not only changed the world geography, but also caused permanent changes in ecological systems, especially through glacial movements and changes in sea level. Especially, the growth and resilience of the organisms can be greatly influenced by climate changes (Naghiloo and Vamosi, 2021; MGM, 2022).

The plants and other organisms may generally respond to global climate changes through expansion and contraction in their geographical areas. In addition, it is very important to understand the mechanisms of plants' responses to global climate change (Naghiloo and Vamosi, 2021). One of the most important of these mechanisms is the polyploidy mechanism, also known as whole genome duplication. Although studies on polyploidy have been carried out on existing taxa for many years, the focus on ancestors has increased with phylogenetic approaches. The mechanism of polyploidy in response to global climate change will form the basis of this chapter.

2. POLIPLOIDY

The polyploidy is the presence of more than two sets of chromosomes in somatic cells. In organisms, there may be a single set of chromosomes (monoploidy), two normal sets of chromosomes (diploidy), or multiple sets of chromosomes (polyploidy). Polyploidy is determined by the number of extra chromosomes sets and is expressed as three chromosome sets triploidy, four chromosome sets tetraploidy, five chromosome sets pentaploidy, and six chromosome sets hexaploidy (Figure 1).

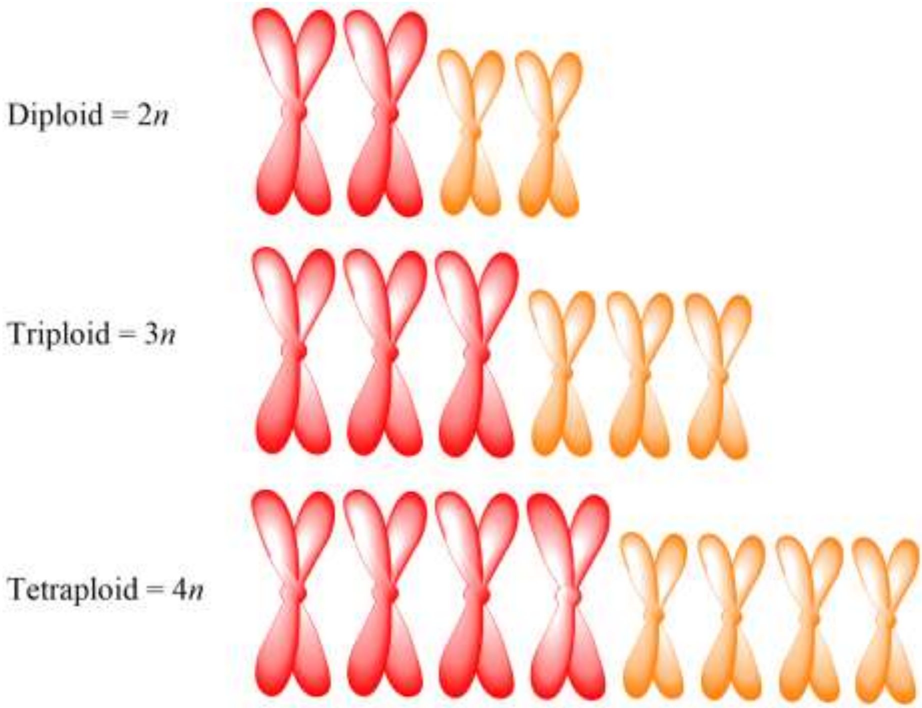

Figure 1. The diploid refers to a normal pair of homologous chromosomes (upper). Triploid contains three of each chromosome (middle) and tetraploid contains four of each chromosome (lower).

Here, it would be useful to mention the concept of basic chromosome number as well as haploid chromosome number. The basic chromosome number is expressed with the symbol "x". Since gamete cells are haploid, haploid number of chromosomes also gives the basic number ($n = x$). This set of chromosomes is referred to as haploid or monoploid. In diploid cells, both the haploid chromosome number and the basic chromosome number double ($2n = 2x$). If we consider the situation with respect to the chromosomes of the model organism *Arabipodsis thaliana*, the equations $n = x = 5$ and $2n = 2x = 10$ are obtained.

Polyploids can occur naturally (Figure 2) or as a result of artificial induction. Natural polyploids have arisen spontaneously in nature through various influences and have been a slow and gradual process that has driven speciation for centuries (Wood et al., 2009).

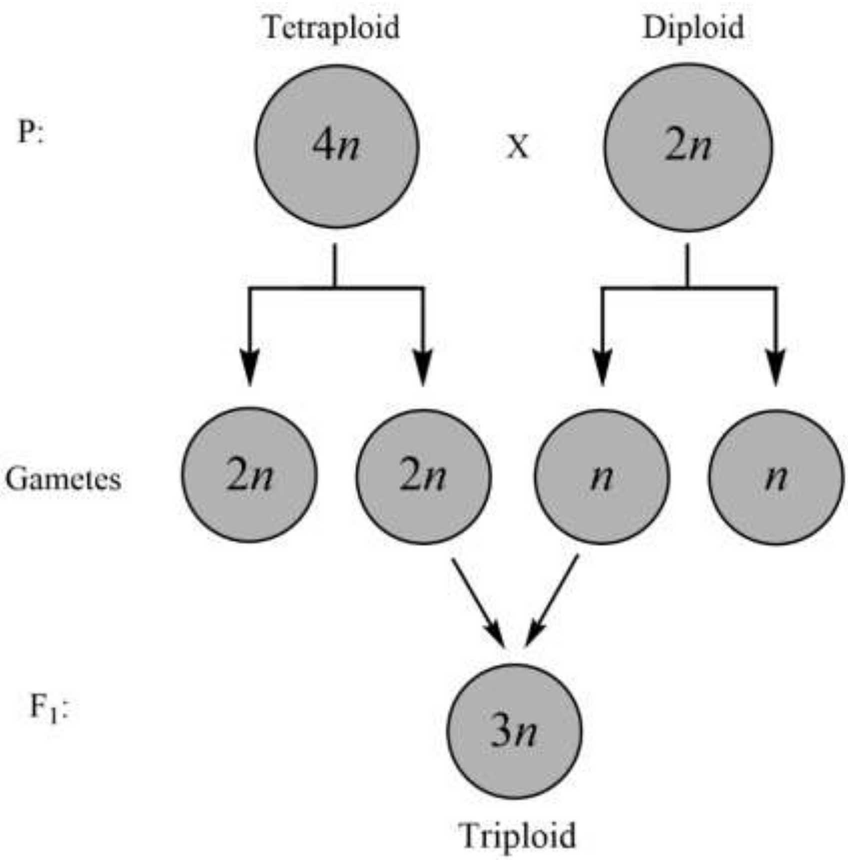

Figure 2. Representation of naturally occurring polyploidy in the population. Tetraploid cell produces diploid gametes while diploid cell produces haploid gametes. As a result of the pairing of these gametes, a triploid cell is formed.

2.1. Autopolyploidy and Allopolyploidy

The exponential increase in the number of genomes within a species is defined as autopolyploidy, and the folding of the genomes of different species together is defined as allopolyploidy. In nature, the mechanism of polyploidization has led to the emergence of many cultivated plant species. Plants such as wheat, cotton, potatoes, clover can be given as examples (Şehirali and Özgen, 2010).

Autopolyploids do not carry any new genetic information different from their diploid relatives, while allopolyploids contain chromosomes of both species.

2.2. Characteristics of Polyploid Plants

Polyploidy is one of the main mechanisms effective in the evolutionary process in both wild and cultivated plants. Polyploid organisms often show higher vigor than their diploid relatives, and in some cases show superior qualities in terms of different characteristics. This remarkable advantage of polyploids has recently been the main target of many plant breeders who promote polyploidy by natural or synthetic means to enable the development of plant varieties. The important advantages of polyploids in plant breeding are the size of the plant organs, protection from harmful mutations and increased heterozygosity. In addition, polyploid plants may have advantages such as high yield, increase in product quality, increased tolerance to biotic and abiotic stresses. With polyploidy breeding, it is possible to produce seedless varieties. In addition, sterility in interspecies hybrid individuals can be repaired by genome folding and fertile interspecies hybrid plants can be obtained (Sattler et al., 2016).

As the level of polyploidy increases, there is usually a growth in cells and organs in plants, and as a result, an increase in dry matter yield. This is called "giga" effects, in which cells increase in size as a result of chromosome doubling (Sattler et al., 2016). Generally, the cells, cell nuclei and plant organs of polyploid plants are larger than those of diploid ones. Features of polyploid plants such as tolerance to biotic and abiotic stress conditions and increase in product quality are also reported (Dhooghe et al., 2011; Sattler et al., 2016; Manzoor et al., 2019).

2.3. Artificial Polyploids

Due to the positive characteristics of polyploid species, artificial polyploid production in economically important plants has been highly preferred by plant breeders (Dhooghe et al., 2011). Eng and Ho (2019) reprted that there are more than 3.000 recorded mutant cultivars as of 2018, and about 50 of them are artificial polyploid cultivars produced with colchicine. Polyploids can be formed by mitotic or meiotic polyploidization mechanisms (Dhooghe et al., 2011). In mitotic polyploidization, doubling of the chromosome number takes place in somatic cells. Somatic chromosome numbers of plants can be multiplied by physical (such as heat shocks) or chemical applications (colchicine, oryzalin, trifluralin, pronamide and amiproposmethyl) (Sattler et al. 2016; Dabkeviciene et al. 2017).

Antimitotic agents are used to ensure chromosome folding in obtaining polyploid plants. These substances prevent the formation of spindle fibers during mitosis and double the number of chromosomes in the cell. The most commonly used chemical agent for this purpose is colchicine (Figure 3).

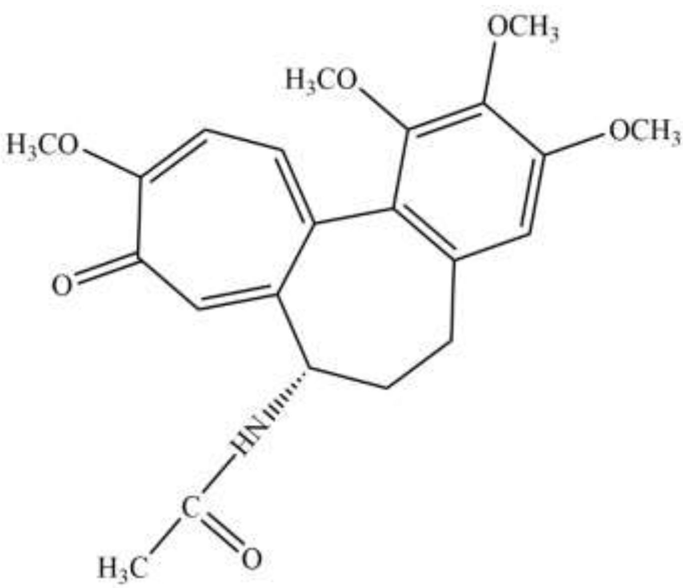

Figure 3. The chemical structure of colchicine

This alkoloid substance is obtained from the roots of *Colchicum automnale* L. (autumn crocus), which colorless, soluble in alcohol, chloroform and cold water, insoluble in hot water and ether, is a strong poison. Colchicine stops microtubule synthesis in the metaphase of mitosis. At this time, the number of chromosomes doubles, since it is not possible for the doubled chromosomes to be pulled to the poles (Amanah et al., 2016).

3. PLANT RESPONSES TO CLIMATE CHANGE

Polyploidy is recognized as one of the most important mechanisms for speciation and species diversity. Even the fastest patterns of plant speciation, such as crops, do not happen in a short time. In addition, natural speciation may require tens of thousands of years. On the contrary, individual or mass extinctions can occur in a very short time (by natural factors or human influence) (Gao, 2019). Polyploidy is quite common in the plant kingdom. Currently, it is estimated that more than 50% of seed plants have polyploid. For easy understanding, the chromosome numbers and ploidy levels of Turkish *Paronychia* taxa are summarized in Table 1. It is clearly seen in the table that polyploidy is quite common in the genus. In addition to the fact that polyploidy is so common in the plants, the occurrence of genome duplications over very long periods of time suggests that it is related to global climate changes. The ability of polyploid species to evolve in more challenging climatic and environmental conditions than their diploid relatives seems to have emerged as a defense mechanism against periods of mass extinction or global climate change of whole genome copies (Van de Peer et al., 2021).

Major climate change occurred at the end of the Cretaceous period, and the majority of genomic copies coincide with this period (Jiao et al., 2011). In addition, the transition from Paleocene to Eocene and late Miocene are also important periods of global climate change (Zachos et al., 2008). Especially during these periods, an increase in the number of plant chromosomes and an increase in new polyploid species occurred as a response to global climate change or as a survival strategy. The duplicated genome provides quite a few mechanisms for the adaptation of these new species to climate change. It will now be useful to take a look at some examples from the plant kingdom regarding climate change and polyploidization.

Table 1. The chromosome numbers and ploidy levels of Turkish *Paronychia* taxa

Taxa (alphabetically)	**Chromosome Number**	**Ploidy Levels**	**References**
P. adalia	36	4*x*	Eroğlu et al., 2017
P. amani	36	4*x*	Eroğlu et al., 2021
P. aksoyii	36	4*x*	Eroğlu et al., 2020
P. anatolica subsp. *anatolica*	18	2*x*	Eroğlu and Budak, 2020
P. anatolica subsp. *balansae*	36	4*x*	Eroğlu et al., 2020
P. angorensis	36	4*x*	Eroğlu et al., 2020
P. argentea	28, 36, 56	4*x*, 8*x*	Blackburn and Morton, 1957; Lorenzo Andreu and Garcia Sanz, 1950
P. argyroloba	36	4*x*	Eroğlu et al., 2020
P. beauverdii	36	4*x*	Eroğlu et al., 2020
P. carica	36	4*x*	Eroğlu et al., 2020
P. cataonica	54	6*x*	Eroğlu et al., 2020
P. cephalotes	36	4*x*	Fedorov, 1974
P. chionaea subsp. *chionaea*	36, 72	4*x*, 8*x*	Eroğlu et al., 2020
P. chionaea subsp. *kemaliya*	52, 104	4*x*, 8*x*	Eroğlu et al., 2020
P. condensata	36	4*x*	Eroğlu et al., 2020
P. davrazensis	36	4*x*	Eroğlu et al., 2020
P. echinulata	10, 14, 28	2*x*, 4*x*	Runemark, 1996; Diosdado and Pastor, 1994; Blackburn and Morton, 1957
P. galatica	36	4*x*	Eroğlu et al., 2020
P. kapela	18, 36	2*x*, 4*x*	Löve, 1975
P. kurdica subsp. *hausknechtii*	18	2*x*	Küpfer, 1980 Eroğlu et al., 2020
P. kurdica subsp. *montis-munzur*	18	2*x*	Küpfer, 1980 Eroğlu et al., 2020
P. macrosepala	18	2*x*	Runemark, 1996
P. polygonifolia	14, 56	2*x*, 8*x*	Blackburn and Morton, 1957
P. saxatilis	36	4*x*	Eroğlu et al., 2020
P. turcica	36	4*x*	Eroğlu et al., 2020

The triploid *Butomus umbellatus* (Eurasian wetland grass) is more resistant to plant pathogens in laboratory trials than its diploid relatives (Harms et al., 2020). Li et al. (2020) reported that the plant-pathogen relationship may change with climate change, as well as the pathogen ploidy level.

Polyploid *Fosterella* is distributed in regions with colder and wider temperature ranges than its diploid relatives. This is due to the fact that the polyploid species of the genus use the polyploid mechanism as a response to global climate change, and these polyploids can survive in more unfavorable climatic conditions (Paule et al., 2017).

As a contrasting example to the above cold climatic conditions, *Themeda triandra* (kangaroo grass) polyploids are generally distributed in hot and dry areas (Ahrens et al., 2020). This supports the possible link between global warming and polyploidy.

Naghiloo and Vamosi (2021), in their study to understand the mechanism of polyploidy in response to global climate change, exposed *Crataegus* (hawthorn) species to increasingly severe environments. They reported a negative correlation between polyploidy and distribution areas as a response to climate change. As a result, while polyploid speciation is more common in more negative conditions, diploid speciation is more common in more positive conditions.

After stating that we can increase the examples listed above much more, it would be appropriate to mention a very important review article. In this review article, Levin (2019) reported that with the accelerating global climate change, polyploidization and especially autopolyploid-induced speciation in plants will accelerate in the next 500 years. Anyone who studies speciation and interspecies relationships must understand the importance and consequences of polyploidy processes (Stebbins, 1940).

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CHAPTER 7

POSSIBLE EFFECTS OF GLOBAL CLIMATE CHANGE ON TURKEY'S PLANT DIVERSITY

Prof. Dr. | Ümit BUDAK [1]

[1] Yozgat Bozok University, Faculty of Science and Art, Biology Department, Yozgat, Türkiye, umit.budak@bozok.edu.tr, ORCID ID: 0000-0002-7517-7092

1. GLOBAL CLIMATE CHANGE AND TURKEY'S IMPACT

Climate change can be defined as statistically significant changes in the climate over many years (Türkeş, 2008). Climate change can occur alongside natural processes and due to human action (anthropogenic) changes in the composition of the atmosphere or changes in land use. The variability of the climate due to human influence, that is, by unnatural means, causes deviations from the average situation and the emergence of extreme events. BC of the last ice age it is known that it ended in 8000 BC and the interglacial period has prevailed in the world since that day. Unlike this situation, which is a natural process, it is possible to talk about climate changes on a global scale as a result of the rapid increase in industrialization since the 19th century and the increase in greenhouse gases. Volcanic eruptions and changes in the sun's activities, etc. events can be evaluated in the natural process. However, especially towards the end of the 20th century, due to the increase in the emission of greenhouse gases and aerosols, the natural process has deteriorated, and global warming has begun to manifest itself in a much greater amount than the normal process. In the measurements made at the Mauna Loa observatory in Hawaii in 1958, the amount of CO_2 from greenhouse gases; It has been revealed that before industrialization, it was 280 ppmv (one molecule in a million volume or one part per million), 315 ppmv in 1958 and 400 ppmv in 2013. Natural CO_2 accumulation in the past 700 thousand years of CO_2 accumulation in the atmosphere varies between about 180-300 ppmv. Therefore, when the figures are considered, it should not be overlooked that this increase is due to the anthropogenic effect (industrialization, deforestation, agricultural activities and the increased use of fossil fuels) and how significant this increase is. As a result, it is forced to warm the world as a result of human effects. In other words, the world is in an unnatural warming trend (Türkeş, 2012).

Surface temperatures on Earth began to warm in the late 19th century and have increased even more since the 1980s. It has been revealed that the linear increase of 100 years reached 0.74 ^{0}C, especially between 1906 and 2005 (Solomon et al., 2007). However, 1998 was the year with the highest increase with + 0.548 ^{0}C. This was followed by + 0.482 ^{0}C in 2005 and + 0.478 ^{0}C in 2010. Accordingly, as a result of the excessive melting of the glaciers, the sea level rose by 0.17 m (IPCC, 2001; 2007). During the same period, precipitation increased by about 0.5% to 1% per decade in the mid- and high-latitude regions of the northern hemisphere and decreased by about 3% per decade in the subtropical belt, including the Mediterranean basin. In Turkey, on the other hand, there is a significant decrease in total precipitation in winter, and accordingly, aridification is observed. In Turkey, especially since the 1990s, the decrease in frosty and snowy days (Erlat and Turkes, 2008, Kartum et al., 2011), the increase in the lowest night and daytime air temperatures (Turkes et al., 2002; Turkes and Sumer, 2004; Kuglitsch et al., 2010), in other words, it makes itself felt in the form of strengthening of the frequency and intensity of heat waves. However, when we look at the measurements of the last 50 years, the warming trends observed in our country, especially in the Marmara, Aegean, Mediterranean, Eastern Anatolia and Southeastern Anatolia regions, have been revealed. Therefore, it can be said that there are warming trends throughout the country. Apart from the warming, it is observed that there is a significant decreasing trend (aridity) in the winter and spring precipitations throughout the country in the Marmara, Aegean, Mediterranean and Southeastern Anatolian regions and in the inner and southern parts of the Central and Eastern Anatolian regions. In addition, a part of the Marmara, the Black Sea region, the northern parts of the Central and Eastern Anatolia regions, the increase in precipitation is striking (Türkeş, 2012). From here, the following conclusion can be drawn; It can be concluded that approximately 2/3 of Turkey has become dry in the North-South line, especially in the parts where 36^0-40^0 north latitudes are located, while approximately 1/3 of Turkey is faced with excess precipitation in 40^0-42^0 latitudes. (Figure 1). As a result, in addition to the temperature increase observed in the whole country, the decrease in precipitation and drought in most of the country, especially in the south of 40^0 north latitude, results in the fact that these regions are much more affected by global climate change.

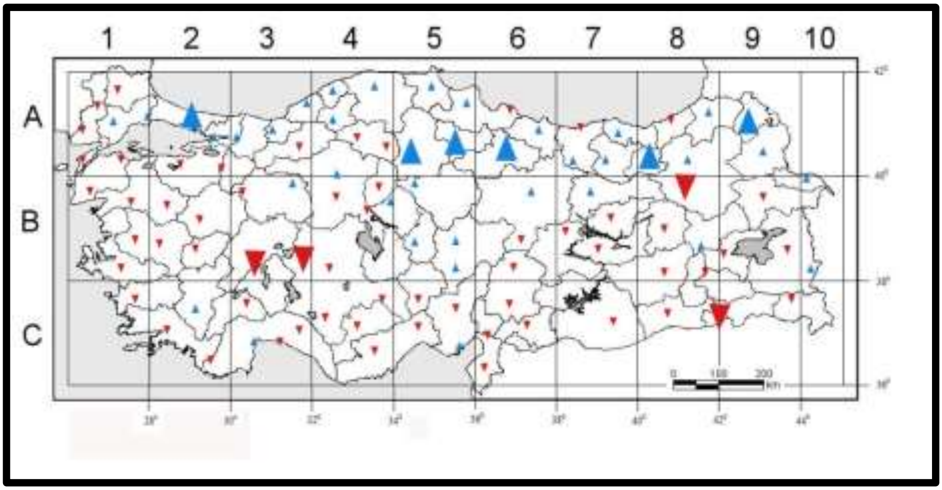

Figure 1. The status of the average precipitation amounts according to the 50-year observation results of Turkey (▲ Significant increases in precipitation amount, ▼ significant decreases in precipitation amount.) (Modified from Türkeş, 2012).

2. IMPORTANCE OF TURKEY FOR PLANT BIODIVERSITY

Although our country covers 0.6% of the world's land surface, our country has 2.5% of the world's plants. Turkey is the country with the highest plant biodiversity in both Europe and the Middle East. The reasons for this are climatic differences, geological and geomorphological diversity, rich water resources, great height differences ranging from 0-5000 m, the existence of a wide variety of habitat types, if the Anatolian diagonal is accepted as the border, there are ecological differences between its east and west and three different plant geographies. (Mediterranean, Iran-Turan and Europe-Siberia) can be shown to be one of the rare countries at the intersection. For these reasons, it has almost as much plant biodiversity as a continent. With the latest publications, the current number of taxa in Turkey is 12,345, of which 4,157 taxa are endemic and the endemism rate is 33.7% (Güner et al. 2012; Öztahay et al. 2022). This endemism rate shows that Turkey is at a very high level when compared to countries in Europe such as Spain (18%), Greece (15%), France (3%) and Poland (0.1%). A great responsibility is placed in Turkey, especially in terms of ensuring the protection of endemic species without extinction.

Turkey is in the area where two important gene centers overlap. It is also a gene center where many genera such as *Verbascum* L. are diversified. The gene center of many economically important cultural plants is Turkey. Among the cereals, 25 wild relatives of wheat, 8 of barley, 5 of rye and 8 of oats are distributed in our country. Turkey is also rich in wild relatives of edible legumes and fodder crops. There are 4 species of lentils, 10 species of chickpeas, 104 (11 endemic) species of clover, 34 species of clover, 42 species of sainfoin and 60 (6 endemic) species of vetch in our country.

Turkey is also the center of gene and diversity for apricot, peach, almond, pear, melon, cucumber, pumpkin, apple, pistachio, plum, pomegranate and vine species. It is known that wheat farming started in Anatolia (fertile crescent) for the first time in history and spread all over the world from there. In addition, our country is the homeland of many fruit species such as apple, pear, quince, hazelnut, pistachio, sour cherry, cherry, plum, walnut, almond, chestnut, fig, grape and pomegranate, which have an important place in fruit growing culture.

High levels of endemism in Turkey are concentrated in certain areas such as Amanos Mountains, Ilgaz Mountain, Central Taurus Mountains, Taşeli Plateau, Bolkar and Aladağlar, Kazdağları, Uludağ, the mountains between Gümüşhane and Erzincan, Munzur Mountains, Salt Lake and salty steppes. Especially the protection of areas with high endemism rate becomes very important.

After the plant biodiversity was revealed, many measures were taken to protect this diversity. There are 48 national parks, 31 nature protection areas, 262 nature parks and 113 natural monuments in Turkey. In addition, there are 95 wetlands, of which 14 are Ramsar Areas, 59 Wetlands of National Importance, and 22 Wetlands of Local Importance (https://www.tarimorman.gov.tr/DKMP). In addition to these, there are 122 Important Plant Areas (IPA) (Özhatay et al. 2008). Of these, 31 IPAs are located north of 40^0 north latitudes. There are 91 IPAs south of this latitude. Therefore, it is obvious that a large part of the IPA will be more affected by global climate change.

3. THE RESPONSES OF PLANTS TO DROUGHT, TEMPERATURE AND SALINITY STRESS

Stress is one of the environmental factors that can have a negative effect on plants. Stress tolerance is the plant's potential to cope with unsuitable environmental conditions. If a plant has increased tolerance to this stress as a result of being exposed to any stress, it can be said that this plant has become accustomed to this stress or its resistance to stress has increased. Adaptation, on the other hand, is an expression of resistance gained as a result of exposure to stress over generations and accordingly selection. Adaptation and adaptation to environmental stresses can occur at all organizational levels, including morphological, anatomical, physiological, cellular, biochemical, and molecular levels.

3.1. Drought stress

Plants can develop mechanisms of resistance to drought stress. These mechanisms are;

a) Delayed drying (able to conserve water)

b) Tolerance to desiccation (fulfillment of metabolic functions despite water loss)

c) It appears in the form of escaping from drought (completion of life cycle before drought).

In many regions of Turkey, where the Mediterranean climate prevails, most of the plants tend to grow rapidly by consuming water in the rainy spring months and to form fruits and seeds in the dry summer months and avoid drought. The responses of plants to water scarcity are explained below in articles.

1. The first step in responding to water scarcity is the limitation of leaf area. As the water content in the plants decreases, the cells undergo plasmolysis, that is, they shrink. In addition, with the decrease in turgor pressure in the cells, leaf expansion and root elongation inhibition occur depending on turgor. Both situations appear as factors sensitive to water scarcity. In addition, with the decrease in turgor, it is possible that the growth will decrease or even stop. Since it reduces leaf area as a result of stopping leaf expansion in the early stages of water scarcity, it reduces water loss by transplantation, thus effectively conserving the limited amount of water in the soil for a long time. Therefore,

the decrease in leaf area appears as the first line of defense developed by the plant against water shortage. In limitless growing plants, as a result of water scarcity, there is a decrease in the number of leaves as well as the limitation of the leaf area, and as a result, negative situations such as decrease in growth, stagnation and regression occur.

The total leaf area of a plant is determined by multiplying the number of leaves and the surface area of each leaf. If they are exposed to water stress after the total leaf area is formed, the leaves turn yellow and fall off. This arrangement of the total leaf area in a plant exposed to water stress is an important long-term change that increases the adaptation of the plant to this situation.

2. If there is water in every part of the soil, there is no need for the root to develop into the depths. However, depending on the water scarcity, the upper parts of the soil dry up first and the moist soil where the water is located is drawn deeper. Accordingly, the subsoil growth of plants is increased during water scarcity, encouraging roots to extend into deeper moist areas. In this way, it appears as a second line of defense against water scarcity by increasing the root/stem ratio of plants. In order to increase root growth, photosynthesis products produced in the leaves must be transferred to the roots. This is evident during the vegetative growth of the plant. However, if the plant has started to grow reproductively, i.e., to form fruit, and is faced with water shortage, then a competition begins between the fruits and the roots for the products of photosynthesis. For these reasons, it turns out that plants are more sensitive to water stress during reproduction.

3. Stoma should close in plants exposed to water scarcity. This appears to be a third mechanism. Closure of stomata is a quick and effective method of conserving available water in the early stages of exposure to water scarcity. The closure of stomata occurs hydro-passively due to the decrease in turgor in the cells or hydroactive ways as a result of water loss in both leaves and roots. In addition, the increase in ABA (Apsisic acid) secretion also supports this situation.

4. As a result of water scarcity, photosynthesis should be limited. Decreased photosynthesis does not manifest itself as much as leaf expansion due to turgor reduction, especially in the early stages of water scarcity.

However, as a result of moderate water shortage, stomata are closed and thus photosynthesis is inhibited.

5. The water balance in plants is maintained as a result of osmotic regulation. The increase in solute concentration due to the decrease in turgor in plants allows an increase in osmotic potential. Especially due to the decrease in water in the leaves, osmotic regulation manifests itself in the form of increasing osmotic pressure as a result of the dissolution of inorganic substances such as sugars, organic acids, and K^+. The same is done in the roots, increasing the osmotic pressure of the stem cells. As a result, the ability of plants to absorb water from the soil is increased and it leads to water supply from the soil against stress.

6. Water scarcity increases resistance to liquid water flow. This situation both affects the flow of water in liquid form, which decreases in the soil, and a similar situation arises in the xylem elements of the plant. Therefore, a situation arises that prevents the flow of water in liquid form.

7. Water scarcity increases the waxy layer on the leaf surface. As a measure of the waterproofing of plants, the thickness of the cuticle increases due to water scarcity. As a result of covering the cuticle with wax, it reduces the water loss of the plants and prevents the unnecessary loss of limited water. In addition, increasing the thickness of the cuticle reduces the permeability of CO_2. In addition, transpiration by the cuticle varies between 5-10% of total transpiration. Therefore, transpiration by the cuticle occurs when the stress is too severe, or the cuticle is damaged.

8. The scarcity of water prevents the distribution of energy by the leaves. Plants cool down by giving the heat energy in the leaves to the air by transpiration. In this way, even if the air temperature is very high, the internal temperatures of the plants can be lower than the environment. When transpiration is reduced by water scarcity, this heat transfer is also prevented. Therefore, other ways of lowering the internal temperature of the plant will be introduced. With the water shortage, the angles of the leaves facing the sun are changed to prevent further warming. In addition, as a result of the energy-reflecting effects of the waxy layer and hairs on the leaf surface, the absorption of heat is prevented.

9. Water scarcity promotes CAM metabolism in some facultative plants. CAM metabolism is mostly seen in desert plants that open their stomata at night

to minimize water loss in plants. However, there are some plants that can switch between facultative C3 and CAM, such as *Sedum* and *Sempervivum*, which also live in Turkey. These plants prefer rock cracks where water is limited as habitat. It has been shown that these plants use the C3 pathway in the presence of water, while they use the CAM metabolic pathway when water is limited (Castillo, 1996; Earnshaw et al. 1985). In addition, some C4 plants such as *Portulaca oleracea* can also use the CAM metabolic pathway in water stress (Ferrari et al. 2020). In this way, they reduce water loss by opening their stomata at night.

10. Osmotic stress alters the expression of many genes. In particular, it has been revealed that some genes encoding enzymes responsible for osmotic regulation are turned on under the influence of stress (Buchanan et al. 2000). Genes regulated by osmotic stress encode proteins that regulate transport across the membrane (Maggio and Joly 1995). In addition, stress also stimulates some protease genes and provides osmoregulation by breaking down proteins whose structure is disrupted by the enzymes involved. It led to the discovery of a large group of genes that synthesize a protein called LEA, which is regulated by osmotic stress during seed maturation. LEA proteins are synthesized under osmotic stress and accumulate in vegetative tissues. These proteins are hydrophilic and can bind water strongly. Therefore, these proteins provide protection to the plant by preventing water conservation in case of water loss and the crystallization of other proteins in the cell. It has been shown that the expression of many genes changes after plants are exposed to stress (Kawasaki et al. 2001).

As can be seen, plants develop many different arrangements under drought stress. In general, drought stress causes shortening of plants, reduction of leaf area, and increase in root/stem ratio, thickening and waxing of the cuticle on the leaf surface, burying the stomata deeper, and covering the leaf surface with more hairs.

3.2. Temperature Stress

Actively growing tissues of advanced plants do not survive long above 45°C. Water and temperature stresses are in a close relationship with each other. While the plants do not have any problems with water, the rise in temperature does not appear to be a big problem. Because with the increase in temperature, plants lose water by transpiration and cool their tissues. In this way, especially

C3 and C4 plants can keep the temperature in their tissues below 45°C even if the air temperature is high. Under water stress, it is expected that the temperature in the tissues will increase as transpiration will decrease. Regarding this;

1. High leaf temperature and water scarcity cause heat stress. Many CAM plants such as *Ananas* and *Sempervivum* have adapted to high temperatures due to their succulent (water storage) properties. The body temperatures of this type of plants can even withstand tissue temperatures of 60-65°C. Since the stoma of CAM plants are closed during the daytime, they cannot be cooled by transpiration. Instead, they radiate heat from the sun by reflecting infrared rays; however, they lose heat by conduction (radiating heat) and convection (radiating heat between liquids).

2. At high temperatures, the photosynthesis of plants is inhibited earlier than respiration. The temperature at which the amount of CO_2 fixed by photosynthesis is equal to the amount of CO_2 exhaled at a certain temperature is defined as the temperature compensation point. At temperatures above this point, plants prefer the respiratory tract to obtain energy and reduce the organic compounds in the stores.

3. Temperature stress reduces the stability of the membrane structure. The stability of the structure of cell membranes is an important phenomenon at high temperatures as well as at low temperatures. The excessive fluidity of cell membrane lipids at high temperatures indicates the loss of the physiological functions of the membrane. For this reason, some plants such as *Nerium oleander* are able to resist high temperatures by increasing the amount of saturated fatty acids in the membrane structure, reducing the fluidity of the membrane (Raison et al. 1982). Damage to the membrane can inhibit metabolic events such as photosynthesis and respiration, as they depend on electron carriers and enzyme activity.

4. Plants produce heat shock proteins under heat stress. Plants secrete heat shock proteins (HSPS) in response to a sudden 5-10°C increase in air temperature. Heat stress causes misfolding of many proteins in cells. As a result, the structure and activities of enzymes are disrupted. Many of these HSPS compounds act as chaperones to correct these misfolded proteins. The secretion of these compounds increases the temperature tolerance of the cells in heat stress and enables plants to withstand lethal heat. Some of the heat shock

proteins are not unique to high temperature stress. Water stress, ABA application, injury, low temperature and salt stress can also stimulate the secretion of such HSPS.

3.3. Salinity stress

High plants living in the interior of the land, natural salt seeps from geological marine deposits transform those areas into salty soils unsuitable for agriculture. Salt accumulation in irrigation water is a more common problem encountered in agriculture. Salt concentration increases. In this way, it results that salt-sensitive species are affected by salt. It has been calculated that one third of the irrigated fields worldwide are affected by salinization. It is known that as a result of salt accumulation in the soil, the structure of the soil is deteriorated, and many agricultural plants cannot fulfill their functions. Excess salt in the soil suppresses photosynthesis and growth in salt-sensitive species. Except for halophytes (salt resistant), it is not possible for other plants to grow in saline soils. For this reason, it is known that glycophyte (salt sensitive) plants are prevented from growing in salty soils. Cotton is moderately tolerant, although some crops such as maize, lettuce, beans and lemons are highly sensitive to salt. Sugar beet, on the other hand, is more tolerant to salt. Halophytes, on the other hand, have adapted to these areas as they have chosen only salty soils as habitat. Halophyte plants have developed different strategies to eliminate salt damage.

Halophytes have developed an adaptation by switching from the apoplastic way to the symplastic pathway through their cell membranes in order not to absorb salt while taking water from the soil. In this way, the water taken into the roots is filtered as it passes through the cell membranes and excessive passage of salt to other organs is prevented. Thus, halophytes tend to expel harmful ions.

Na^+ ions in the soil can enter the roots passively. Stem cells, on the other hand, give the excess Na^+ ions to the soil by active transport. Since the cell membranes of stem cells are less permeable to Cl^- ions, they keep these ions out. In addition, as a result of the absorption of Na^+ ions in the xylem during the transport from the root to the leaves, the transport of these ions to the leaves is reduced.

Many halophytes have salt-secreting glands in their leaves. These plants do not expel salt ions. The imported salt ions are transferred to the salt glands in the leaves, crystallized and given out. In this way, they protect themselves from the harmful effects of salt.

Many halophytes can achieve optimum growth at moderate salt concentrations. Optimum growth in these plants is related to the storage capacity of salt in the vacuole. While these ions do not harm even salt-sensitive enzymes, they contribute to the osmotic potential of the cells.

Mechanisms such as reduction of leaf area or abscission (leaf shedding) are similar in salt stress as in water stress. In addition, changes in gene expression due to osmotic stress are also associated with salinity stress. However, halophytes must cope with the stress caused by high ion concentrations as well as xerophytes.

High ion concentrations in the cells of halophytes are toxic to many enzymes. To prevent this, ions in the cytoplasm must be deposited in the vacuole to reduce their toxic concentration. For this, by expending energy through active transport, especially excess Na^+ ions in the environment are transported to the vacuole. In addition, the excretion of Na^+ ions through the plasma membrane is mediated by the gene product of the SOS1 (salt hypersensitive) gene. In this way, it is possible to reduce Na^+ ions in the cytosol.

4. POSSIBLE EFFECT OF TURKISH PLANT DIVERSITY FROM GLOBAL CLIMATE CHANGE

It was stated that the temperatures in Turkey increased due to the effects of global warming. In addition, it is estimated that 2/3 of the country will be more affected by global climate change as a result of decreasing trends in precipitation especially in the south of 400 north latitude.

It is likely that the wetlands will be severely affected due to the decrease in precipitation and the wetland will begin to dry out due to the reduced water supply in the wetland. As a result, it can be said that many plants and animals benefiting from that wetland will be directly affected by this situation and will have to migrate. Especially the hydrophytes may disappear completely with the drying of the wetland.

All plants have the potential to resist stress and survive to a certain degree. Resistance to stress can also vary according to the growth and development of plants. While it is tolerant to stress in one of these developmental stages, it may be sensitive to the same stress in another stage. Stress resistance comes in two forms. One is stress avoidance and the other is tolerance. Avoidance is to provide an indoor environment that does not stress the cells of the plant despite the stress in the environment. Many xerophytes may not transcribe when the plants are under drought stress to protect themselves from the ambient temperature and to cool off. These avoidance events can also manifest themselves in the morphology of the plant. On the other hand, in tolerance, plants tend to maintain their vitality to a certain extent under stress conditions and thus to withstand stress. Both of these two types of resistance can develop on the same plant.

Drought is the most important and most common type of stress in terrestrial plant life. It usually manifests itself in the form of not raining over a long period of time. With drought, avoidance and tolerance mechanisms appear in all plants. With water stress, plants often try to avoid this stress by trying to use the scarce water sparingly. For this, they try to make them lose less water by curling their leaves and changing their angle. With this change in the leaves, they provide fewer surfaces for light absorption. The same situation manifests itself in the form of folding due to turgor loss in the middle veins in grass plants. With the leaf surface being flat and oriented to light, the leaf will heat up more and this heat will be tried to be reduced by transpiration. Likewise, senescence of old leaves can be observed in plants exposed to drought stress in order to reduce the total leaf area and thus transpiration. Again, some of the plants struggling with drought stress will be able to benefit from deeper water by increasing root growth.

Habitat selection in plants is inherited. That is, a natural plant adapted to a habitat can only reveal itself in that habitat, or in other words, a plant adapted to a habitat can find a place for itself only in that habitat. Precipitation, temperature, soil characteristics and sun exposure in the habitat where the plant exists make that habitat special for that plant. This type of climate change directly affects the habitats. Glycophyte plants will be affected the most by this situation at latitudes 360-420 and may result in the complete disappearance of many glycophyte plants. As a result of this effect from glycophytes, some of them will have to migrate to more suitable and similar habitats in the north, and in cases where this migration does not occur, it will result in the extinction of the species.

Xerophytic tolerance will be tested in natural plants with xerophytic characteristics and the probability of species loss from these plants will be high.

Most saline areas are located below 400 north latitudes. Halophytes adapted to these regions will be more affected by these adverse conditions due to both the increase in temperature and the critical decrease in precipitation. Naturally, these plants will be able to take and store less water depending on the decreasing amount of precipitation. This will adversely affect their ability to survive, bloom and seed due to xerophytic tolerance.

As can be seen, plants develop many different arrangements under drought, temperature, and salinity stresses. In general, drought stress causes shortening of plants, reduction of leaf area, increase in root/stem ratio, thickening and waxing of the cuticle on the leaf surface, burying the stomata deeper, and covering the leaf surface with more hairs. Therefore, with the increasing global climate change, the possibility of morphological changes such as shorter stature, growth disorders, more hairy, thick and small leaves will increase due to the way that plants keep the vegetative growth short and switch to reproductive growth as soon as possible. Salt fields in Turkey are located especially in the south of 400 north latitude. It was revealed that the temperature increased, and the precipitation decreased in these areas. Accordingly, halophytes will have to increase their osmotic pressure more with increasing temperature and drought. Those who keep up with this situation will continue their lives in a position that is becoming more and more efficient, or those who cannot resist it will perish.

Depending on the decrease in precipitation, it is expected that there will be a decrease in the number of cloudy days. For this reason, it is predicted that plants will be exposed to more UV radiation.

It is likely that there will be an increase in forest fires with increasing temperature and decreasing humidity. As a result of this, it is obvious that there is a decrease in natural plants again.

For these reasons, it is recommended that especially endemic taxa be protected by in situ or ex situ methods.

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CHAPTER 8

EFFECT OF DROUGHT STRESS ON SECONDER METABOLITE PRODUCTION OF SOME MEDICINAL AND AROMATIC PLANTS

Assoc. Prof. | Hülya DOĞAN [1*]
Assoc. Prof. |Hatice BAŞ[2]

[1] Yozgat Bozok University, Department of Seed Science, Yozgat, Turkey. hulya.dogan@bozok.edu.tr, Orcid ID: 0000-0003-1970-4123
[2] Yozgat Bozok University, Faculty of Arts and Sciences, Department of Biology Yozgat, Turkey hatice.bas@bozok.edu.tr, Orcid ID: 0000-0001-8296-0360

INTRODUCTION

These days, industrialization, technological developments, increasing urbanization and the increasing of the population have caused global warming to be felt more. Global warming affects the world; It has affected the climatic factors and disrupted the natural balance, threatening the existence of water, which is the basic resource necessary for life (Çöp and Akat, 2021; Karık et al., 2016; Dogan, 2020). Changes in precipitation regimes, prolonged drought and an increase in air temperatures will both adversely affect water resources and cause an increase in water demand (Metin and Koçan, 2020). Water deficit or drought stress is considered one of the most restrictive factors in agricultural plant growth and yield in many areas of the world (García-Caparrós et al., 2019; Emrahi et al., 2021; Yazici and Yılmaz, 2021). Drought is the systematic precipitation deficit that occurs as a result of the precipitation in a region falling below the long-term average or normal precipitation values (Mansori et al., 2019). Drought stress is one of the important stress factors affecting plant growth. Many metabolic activities that take place within the plant occur thanks to water. Drought stress, which occurs for various reasons, reduces the water potential and turgor pressure in plant cells and creates changes in their concentration. The resulting changes can affect many vital activities such as gas and ion exchange, carbon assimilation, respiration, photosynthesis, hormone balance, fat synthesis, protein synthesis. For this reason, drought stress in the crop plant damages the plant and even causes the death of the crop plant (Yurdcu, 2019).

Turkey will be affected by the predicted negative aspects of global warming, especially the weakening of water resources, forest fires, drought and desertification, and ecological deterioration due to these, and is among the risk group countries in terms of the potential effects of global warming. A climate change that may occur in the coming years due to the increase in greenhouse gas accumulations in the atmosphere will add to the water resources problems in the arid and semi-arid areas of Turkey. Thus, in addition to the expansion of arid and semi-arid areas, increases in the duration and intensity of summer drought will support desertification processes, salinization, and erosion (Yaldiz and Şekeroğlu, 2013).

In studies on medicinal and aromatic plants, it is thought that genetic characteristics of the plant, anatomical and morphological development stages, as well as stress factors, play a role in the formation of its phytochemical composition, unlike traditional plant products (Lakušić et al., 2013). Because stress-related metabolism greatly affects all other metabolic events, it also affects the synthesis and accumulation of secondary metabolites (Selmar and Kleinwächter, 2013). For this reason, evaluating and examining the effects of different stress factors on plants (medical and economic importance) is of great importance in terms of obtaining resistant varieties in plant breeding (Yazici and Yılmaz, 2022).

The effects of global warming on agriculture are in the form of low productivity, especially in arid regions due to extreme temperatures. In regions where irrigated agriculture is made, the number of irrigations increases due to extreme temperatures, and this situation causes the excessive use of underground and surface water resources (Türkeş, 2008). Considering that hotter and drier conditions await our country in the future, it is necessary to determine agricultural plant varieties that are resistant to drought and suitable for hot conditions.

The negative effects of drought on agriculture and farmers will force many producers to change their products according to new seasonal characteristics (Yaldiz and Şekeroğlu, 2013). Despite the increase in importance and usage areas in recent years, it is important to cultivate medicinal and aromatic plants (which are still mostly collected from natural flora in Turkey) under cultural conditions in suitable ecologies of Turkey. For this reason, our study, it is aimed to give information about some medicinal and aromatic plants with the high economic return, which can be an alternative product that is drought resistant and adaptable to hot conditions.

1. DROUGHT STRESS ON SECONDARY METABOLITE PRODUCTION IN MEDICINAL PLANTS

Secondary metabolites in plants are important biochemicals for the pharmaceutical industry and food industry. Environmental factors such as light intensity, humidity, water, temperature, drought, minerals, and CO_2 effect of plants growth and production of secondary metabolites (Mishra, 2016). Many studies have been carried out effects of drought on the content of secondary metabolites in plants. For example, terpenoids, phenolics, alkaloids, glucosinolates, and cyanogenic glucosides in water-stressed conditions, were observed and plants accumulate more secondary metabolites (Gupta et al., 2019). *Salvia officinalis*, which is defined as medicinal sage, is a species that has many uses in aromatherapy, perfumery, cosmetics industry, spice, herbal dye and food preservative (Elmas and Elmas, 2021). An average of 1-2.5% essential oil is obtained from the leaves of the plant, usually by hydrodistillation method. The main chemical composition of essential oils in *Salvia officinalis* are monoterpenes (borneol, bornyl acetate, α-pinene, β-pinene, α-thujon, β-thujon, camphor), diterpenes (carnosol) and triterpenes (oleanolic, ursolic acid) (Elmas, 2021). Radwan et al. (2017), reported a strong increase in the monoterpenes of sage due to drought stress. Whereas bornyl and sabinene synthases are up-regulated, cineole synthases are down by drought stress. An experiment was conducted on *Origanum vulgare*, the content of essential oil per plant remained constant, while the concentration of metabolites increased in drought conditions (Ninou et al., 2017).

2. SOME DROUGHT RESISTANT MEDICINAL PLANTS IN TURKEY

***Salvia* spp.**

Drought resistant Salvia species could also be valuable for use on extensive type urban green roofs, where certain species of Salvia with culinary or medicinal uses could simultaneously serve urban agriculture (Papafotiou et al., 2021).

***Salvia fruticosa* Mill.**

S. fruticosa known as Anatolian sage in Turkey is found in the Balkans, Italy, Cyrenaica, Sicily, and in the west of Syria; In Turkey, it spreads naturally in Western Anatolia (İzmir), Northwestern Anatolia (Balıkesir, Tekirdağ) and Southwestern Anatolia (Antalya, Aydın, Muğla). *S. fruticosa*, a perennial plant, is a species that can reach up to 160 cm in height, growing mainly in bushy rocky areas, often on coastal cliffs, at altitudes, 1–700 m, bloom in March-May, its branches are covered with grayish green hairs. Its leaves of it have a high oil content. The essential oil rate can vary between 0.9-5.15%. It is widely used for the preparation of herbal tea (Elmas, 2021; Papafotiou et al., 2021).

***Salvia officinalis* L.**

S. officinalis is a perennial and semi-bush herb with a length of 60-100 cm, white, blue, or purple flowers, silvery leaves, and hairy and simple (Elmas, 2021). Its seeds are round, brown, and the weight of a thousand grains is 7.6 grams. Its essential oil is between 1-2.5% and is in the thujone group according to its main components. *S. officinalis* has an important place in international trade. In studies conducted with *S. officinalis*, it has been stated that the plant exhibits many therapeutic properties such as antioxidant, antimicrobial, anti-cancer, anti-stress, antidepressant, antidiabetic, anti-inflammatory effects (Miraj and Kiani, 2016).

This species, known as medical sage, does not show the natural distribution in Turkey, but it spreads naturally in the southern and middle parts of Europe and the Western Balkans, especially in Dalmatia and Macedonia. This species is cultivated in Turkey as well as in Germany, Southern France, Hungary, Russia and South and North America. Both the above species are used in xeriscaping, however *S. fruticosa* although it grows naturally in southern areas compared to *S. officinalis*, often faces survival problems that are attributed to limited water supply, particularly on extensive green roofs, to the contrary of *S. officinalis* that shows a higher drought resistance (Elmas, 2021; Papafotiou et al., 2021).

Studies conducted on *S. officinalis* against drought stress showed that it responds by creating physiological and metabolic changes in the structure. According to studies, *S. officinalis* plant has been defined as a moderate drought-tolerant plant (Taarit et al., 2010). In addition, plants exposed to moderate drought stress had higher essential oil content, essential oil yields, and higher terpene concentrations compared to the control groups (Sönmez, 2015; Yurdcu, 2019). The increase of essential oil content under drought conditions may be related to a higher density of oil glands, mainly due to the reduction in leaf area as a consequence of the stress generated by the water deficit (García-Caparrós et al., 2019). Regarding the increase in essential oil content of *S officinalis* under drought stress, it has been reported that the drought tolerance of the aerial parts is related to the rich polyphenol content of the leaves. For this reason, polyphenol accumulation capacity of this species contributes to drought tolerance by creating a balance between growth and defense (Selmar and Kleinwächter, 2013; Govahi et al., 2015). The excess of monoterpene synthesis induced by drought stress suggests that the high reducing power in stressed leaves pushes biosynthesis towards highly reduced compounds and may thus represent only a symptom of this physiological condition (Nowak et al., 2010). Reactive oxygen species such as superoxide radicals, hydrogen peroxide, and hydroxyl radicals, which accumulate under stress conditions, are a natural by-product of cell metabolism. However, their excessive accumulation causes cell damage or cell death by causing membrane and lipid peroxidation, protein oxidation, enzyme inhibition, chlorophyll degradation, and deterioration in structures such as RNA and DNA in the plant cell (Anjum et al., 2011; Öztürk, 2015). Reduction and inhibition of these reactive oxygen compounds that cause oxidative stress in plants, enzymatic (superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT), glutathione reductase (GR), peroxidase (POD), monodehydroxyascorbate reductase (MDAR), dehydroxyascorbate reductase (DHAR) and glutathione peroxidase (GPX)) or non-enzymatic (ascorbate, glutathione (GSH), αtocopherols, carotenoids and phenolic compounds) low molecular weight antioxidant compounds. In stressful conditions, enzymatic oxidant molecules from these antioxidants reduce reactive oxygen compounds and prevent their accumulation. However, non-enzymatic antioxidant molecules are responsible for the protection of photosynthetic membranes (Dolferus, 2014; Öztürk, 2015). According to the studies, it has been reported that the carotene and lutein carotenoid levels are significantly reduced during the drought-induced leaf senescence of *S. officinalis* (Abreu ve Munné-Bosch, 2008).

***Salvia sclarea* L.**

Salvia sclarea L. (clary sage or clear eye) is a perennial plant native to southern Europe and central Asia. It is a shrub that grows up to 60–100 cm with large hairy leaves and small blue, white, or purple flowers. It is widely valued for its aromatic and medicinal properties (García-Caparrós et.al., 2019).

S. sclarea L., is an important medicinal plant its oil has been evaluated as antioxidant, antibacterial, antifungal, anti-inflammatory, antimalarial, anticholinesterase and antiviral agent. The yield of plants is influenced by environmental and agricultural management factors such as drought stress and nutrition (Abbaszadeh et.al., 2017).

Gonceariuc et al. (2018), used Dacia 99, V. Junior, Victor, and Nataly Clary stated that clary sage varieties are drought resistant. The high amount of essential oil was obtained from these varieties. The efficiency of *S. sclarea* varieties ranges between 2.7 and 3.6 kg/t of essential oil per tonnes of raw material.

Figure 1. Some *Salvia* spp. grown under drought conditions in Yozgat.

***Thymus* L.**

They are small shrubs or perennial herbaceous plants. The plant, which is resistant to heat and drought, does not have a clear soil selectivity. In Turkey, there are 37-40 species, 14 of which are endemic. These species are distributed in places up to an altitude of 1500 m. Thyme species are in the xeric plant class and have determined the possibilities of use in erosion prevention and especially species such as *Thymus fallax*. They are also plants that play an important role in preventing erosion (Yaldiz and Şekeroğlu, 2013).

There is a great deal of literature on essential oil components of thyme. However, piece of information in the studies is that the essential oil components of thyme differ according to the place where it is grown. This situation shows that regional differences can occur in different ratios of components on the same species. It is known that environmental factors (such as temperature, precipitation, duration and intensity of light, altitude, aspect, drought, salinity, soil nutrients, and soil structure) have a great impact on the synthesis and accumulation of active substances (Baydar, 2020).

This difference also explains the wide range of antioxidant activity values of thyme oil in the literature. For example, the major component in some

Thymus species was thymol, while in others it was determined to be carvacrol (Yazıcı et al., 2020).

***Rosmarinus officinalis* L.**

It is a shrubby plant. It has been stated that the plant has lignified roots with many branches and is resistant to drought stress. In Europe, rosemary is used not only in the food industry, but also in the pharmaceutical industry and aromatherapy. Rosemary essential oil, which has a significant consumption, is used in shampoos, body lotions, colognes and creams in cosmetic products as well as used to disinfect the room air (Yaldiz and Şekeroğlu, 2013). In a study conducted with different water levels, it was stated that plants exposed to water stress showed a strong adaptation on an anatomical and cellular basis (Olmos et.al., 2007).

In the literature, another factor affecting the composition of rosemary essential oil components is drought stress. It has been revealed that the percentage of essential oil components alpha-pinene, β-myrcene and camphor increases with drought, but the percentage of β-pinene decreases (Kulak, 2019). Apart from these factors that affect the composition of rosemary essential oil components, soil, climate, altitude and season are also effective (Yıldırım, 2018; Yazıcı et al., 2020).

Sarmoum et al. (2019), highlighted some differences in rosemary oil chemical profile under different stress regimes. The highest essential yield of oil was obtained from rosemary plants subjected to no irrigation regime (NIR). This result confirms that water stress stimulates the production of essential oil in *Rosmarinus officinalis* plant. Owing to its high curing value and wild occurrence in diverse environments, rosemary can be considered to be a promising plant for marginal lands, new reclaimed soils, and semi-arid regions.

***Capparis* spp.**

Used as a medicinal plant and food since ancient times, among the people; It is known by different names such as kebere, thistle thistle, gevil, bubu. The genus Capparis (Capparaceae) grows in the natural flora of all tropical and subtropical continents in the world. It grows naturally in places with Mediterranean environments. In Turkey, only two species (*C. spinosa* and

C. ovata) have a natural distribution in the interior and southern regions (Yıldız et al., 2014).

It grows naturally in all kinds of unfavorable environmental conditions, even on stony, inclined, calcareous, poor nutrient soils, rocks, castle walls, city walls and concrete fractures in arid and semi-arid regions. Thanks to its chemical composition, the caper plant can withstand all kinds of unfavorable environmental conditions. Due to these features, it is at the forefront of alternative plants recommended in erosion prevention studies in Turkey. It is grown in many countries due to both providing a source of income and preventing erosion in the reclamation of areas that are not suitable for agriculture and are deserted due to erosion.

It is stated that the above-ground part of the caper (especially the strength of its leaves) shows great wind resistance and can be evaluated in areas where there is wind erosion. The caper plant, which can grow in arid and arid areas, can also be used in erosion control in sloping areas since it is perennial and its roots go very deep up to about 40 meters.

Capparis has been used for cooking and medicinal purpose, and its flower buds are traded in the international market and also its consummation. In this case, its flower buds are particularly popular in international markets because of their use as a condiment or ornament, their consumption could increase significantly, and they could also be the subject of other interesting uses from view, especially in the cosmetics sector. In addition, the caper could easily be developed in the context of agriculture. Thus, quality production offers the caper a great added value, which allows it a large diffusion in the international market (Errachidi et.al., 2019).

***Calendula officinalis* L.**

Calendula officinalis is also called as aynısefa, tıbbi nergis, portakal nergisi, ölü çiçeği, öküzgözü, çingene zamanı. in Turkey, *C. officinalis,* also known as calendula, is an annual herbaceous species of 30-70 cm tall with yellow-orange flowers from the Asteraceae family. Dried flowers have anti-inflammatory, antipyretic, anticancer and wound healing properties. *C. officinalis,* whose gene center is in the Mediterranean countries, can be easily grown in almost every region of Turkey for thousands of years.

Figure 2. *C. officinalis* grown under drought conditions in Yozgat

In the cosmetic industry, it is known that flowers are used as toothpaste, baby oil, skin care cream and shampoo due to their repairing, moisturizing, regenerating and soothing effect (Göktaş and Gıdık, 2019). The plant used in a wide variety of medicines in Europe, especially the plant used in ointments, creams and lotions, has economic importance. According to a study, it was stated that the adaptation of the *C. officinalis* plant to salty conditions was good and even the amount of essential oil increased the amount of Cadinol and Cadinene components (Khalid and Silva, 2010). According to another study, it was observed that the *C. officinalis* plant, which was subjected to different drought applications, was quite resistant when looking at stress physiology. It has been concluded that it can be grown as an alternative species in regions where arid conditions are dominant. The species, which has a high potential to be used in pharmacology, ornamental plants, food, and cosmetics industries, is in every region of the Turkey. It is predicted that it can be grown and has the potential to be produced economically (Şelem et al., 2021).

***Lavandula angustifolia* Miller.**

Lavender (Lavandula angustifolia), belonging to the family Lamiaceae, is a valuable medicinal and aromatic plant native to the Mediterranean region. It is grown mainly for its essential oil, which is of great interest economic value in the fragrance, flavour, pharmaceutic, perfume and cosmetic industries (Kumlay et al., 2022). Due to its high economic and ornamental potential, the species is now cultivated across the globe (Stanev et al. 2016). Furthermore, being widely distributed in the Mediterranean region, it is likely that lavender might be exposed to intensive water deficiency and heat stress in summer. *Lavandula angustifolia* drought tolerant plant species can be preferred for xeriscaping generally on the southern facades of structural elements (Gitmiş, 2021).

3. CONCLUSIONS

As result of climate changes around the world, it has caused the depletion of water resources, especially due to decreasing precipitation in agricultural areas. Accordingly, the economic yield of essential oil-containing medicinal and aromatic plants depends on four basic factors. These are an accumulation of dry material, the ratio of economically valuable tissues, essential oil amount, and relative content of valuable compounds. Although extensive studies have already revealed that drought stress can cause an economically detrimental loss in biomass yield and production of special secondary metabolites, some conflicting points of view are concerned with ascending trends of some bio-active products under abiotic stresses. Monitoring physiological responses and productivity of stress-tolerant subspecies will generate a broad scope for the development of the plant's cultivation, conservation, and prospective breeding plans. It is of great importance to take measures and develop alternative methods that encourage plant growth in terms of preventing the damages in crop production caused by drought. Therefore, it is important to determine the morphological, ecological, physical and biochemical changes that occur in plants against drought stress. Because it is important in terms of cultural conditions to determine the changes caused by plant growth promoting practices to increase stress resistance.

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CHAPTER 9

THE IMPACT OF GLOBAL CLIMATE CHANGE ON AGRICULTURE AND FOOD SYSTEMS

Assist. Prof. | Stanko STANKOV [1]
Assist. Prof. | Hafize FİDAN [2*]

[1] University of Food Technologies, Faculty of Economics, Department of Tourism and Culinary Management, Plovdiv, Bulgaria, docstankov@gmail.com. Orcid ID: 0000-0003-2332-1782
[2*] University of Food Technologies, Faculty of Economics, Department of Tourism and Culinary Management, Plovdiv, Bulgaria, hfidan@abv.bg Orcid ID: 0000-0002-3373-5949

1. THE IMPACT OF CLIMATE CHANGE ON FOOD SYSTEMS, DIET QUALITY, AND NUTRITION

The food environment is a set of food systems composed of the availability of raw materials and their technological, financial, and marketing characteristics, expressed in accessibility to the relevant consumers. All these conditions to which a food system responds are in continuous contact with environmental conditions, including climatic changes. The change in climatic conditions creates direct and indirect prerequisites for changes in ecosystems, and biodiversity, including humans. They all favor the unsustainable use of resources, ecosystem erosion, rapid rates of urbanization, and demographic, social, and economic conditions of the environment (FAO, 2017; FAO, 2021). Food systems go through different stages of development (Figure 1).

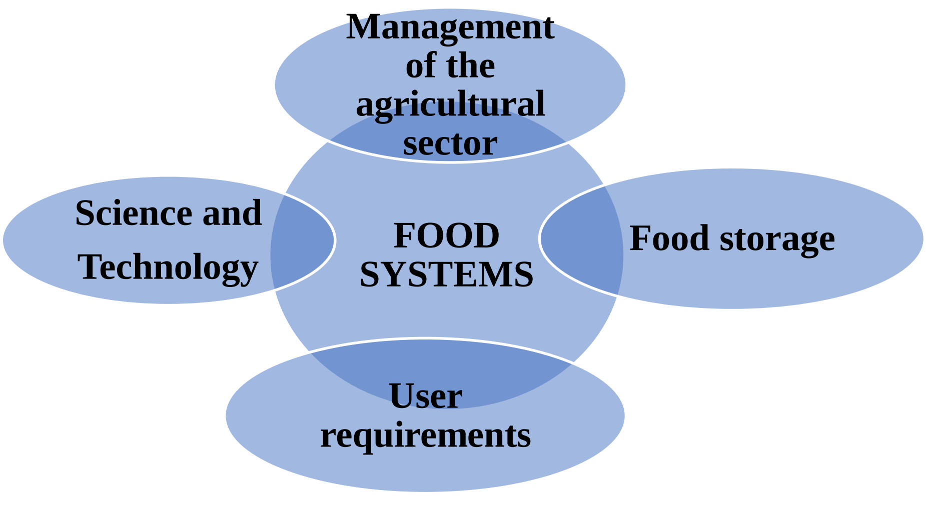

Figure 1. Evolutionary model of food systems

The movement of the participating elements of the food systems in the conditions of a changing global situation and, above all, in the course of climate change follows its multifaceted manifestation.

The creation of mechanisms for the management of chains for the extraction of raw food materials is related to their processing, storage, transportation, technological models of production, the satisfaction of consumer expectations, and others, which are changing significantly. The global increase in demand for certain foodstuffs, including meat, vegetables, fruits, and others, creates a prerequisite for introducing new methods for their cultivation, cultivation, processing, and advertising. All these processes are in changing environments and dynamic demand (Vermeulen et al., 2020).

The demand for certain food products is different in different parts of the world. Social factors mainly influence it, but on the other hand, some policies related to stimulating the cultivation or processing of raw food materials also have an influence. The financial support of specific sectors in the agri-food chain leads to more favorable conditions for the development of the industry, especially in areas with proven traditions in agriculture and animal husbandry. The redirection in producing some plant and animal species in certain parts of the world would be disastrous without established practices in this production.

The increasing demand for meat and dairy products globally is expected to grow by around 65-70% by 2050 (Herforth et al., 2019), which raises the question of increasing yields in the context of increasing urbanization and decreasing share of producers. Increased demand and the reciprocal increase in productivity in the agro-food chain create additional conditions for increasing greenhouse gas levels and changing climate conditions.

Trends in the growing demand for food in the world market will continue to grow. They were feeding a population of nearly 9 billion people in 2050 would require an increase in the need for cereals by about 1 billion tons and meat by an average of about 200 million tons. All these increased levels of major food groups in the coming years will require countries to implement sustainable food systems to produce enough food in response to growing populations (Weindl et al., 2020). The production conditions and the processing of raw materials must be in balance with the negative impact of the agro-food chain on the planet's climate.

Sustainable approaches to agri-food chain management in the context of climate change as a systemic process have a wide range of manifestations. Individual systems are associated with recovering or adapting to current environmental conditions. They can manifest themselves in three main directions: distribution of positive and negative impacts on individuals, nations, and even generations; procedural, which outlines the responsibilities and obligations of the parties involved; and responsible, whose function is to create cultural commitment of communities to the implementation of sustainable practices (FAO, 2014).

Climate climate change significantly alters systemic management approaches, creating dependencies between different spheres of influence. Climate impacts on ecosystems clearly outline the increased intensity of adverse weather conditions, including extreme heat on land and oceans, increased risks of fire occurrence, and others (FAO, 2017). In some parts of the world, these changes are having a detrimental effect on ecosystems, and hence on food security.

Climate-related changes in seasonal environmental conditions, precipitation, terrestrial, oceanic, coastal, and freshwater ecosystems, urban and rural areas, infrastructure, energy, industry, and others determine transformations of food systems (Masson-Delmotte et al., 2021).

In climate change conditions and accompanying food production, an assessment of the agro-food chain is also carried out (Shukla et al., 2019). Many countries around the world are preparing detailed analyzes of changes in climate conditions and their impact on the yield of staple crops used in the nutrition of local people (FAO, 2014).

Identifying regions related to the cultivation of local food raw materials is increasingly associated with analyzing the conditions for their cultivation (Crumpler et al., 2021). Periods of prolonged drought in the active growing season lead to lower yields of certain plant species (FAO, 2017). This, in turn, affects animal husbandry (FAO, 2021), creating conditions for increased prices of forage crops and the need for year-round application of animal nutrition. The impossibility of implementing pasture animal husbandry, including in some semi-mountainous regions, leads to a short period of plant abundance. Changes in phytoreception and the application of mixed nutrition determine the different characteristics of products obtained from individual animal species – meat, milk, and others (Masson-Delmotte et al., 2021), and at the same time, change their financial stability. As a result of these processes, there is also a decrease in purchasing power in some social groups, resulting in food insecurity or malnutrition (FAO, 2017).

1.1. Agroecological and climatic factors in soil fertility

Using about 40% of the planet's surface for arable land and providing food resources leads to intense soil erosion. Although slow, climate change is associated with changes in soil characteristics worldwide. Water scarcity and droughts affect billions of people worldwide. Lowering moisture levels in soil conditions has been reported as a significant problem (Gelybó et al., 2022). This is primarily related to changes in rainfall periods and temperature amplitudes after rainfall. Prolonged drought and lowering of soil moisture create the need to build irrigation systems (Moriasi et al., 2015). As a result of various state and institutional policies, the construction of such systems is vastly complicated. This can mainly be due to demographic, political, economic, and other conditions (Horel et al., 2022). In case of uneven provision of water for plant species, relatively lower yields of some raw materials used for human food or fodder are also reported. At the same time, a decrease in their nutritional and biological value has been reported (He et al., 2018) due to the stress periods that occurred in the active phase of development. When prolonged drying of the soil layer is created, large areas are identified, the moisture of which remains low for a long time, which is a prerequisite for desertification (Wang et al., 2021). As a result of the increased temperature, rapid and prolonged rates of dehydration of the soil layers are reported. This is a prerequisite for endangering the livelihood of farmers in many parts of the world.

The occurring degradation processes in the landscape are difficult to study due to the complex phenomena. Depletion of soil resources as a result of climatic and anthropogenic processes leads to long-term desertification and population migration (Gelybó et al., 2022). Each of the landscape forms reacts differently to changes in the environment. Thus different degrees of intensity of their manifestation can be assessed (He et al., 2018).

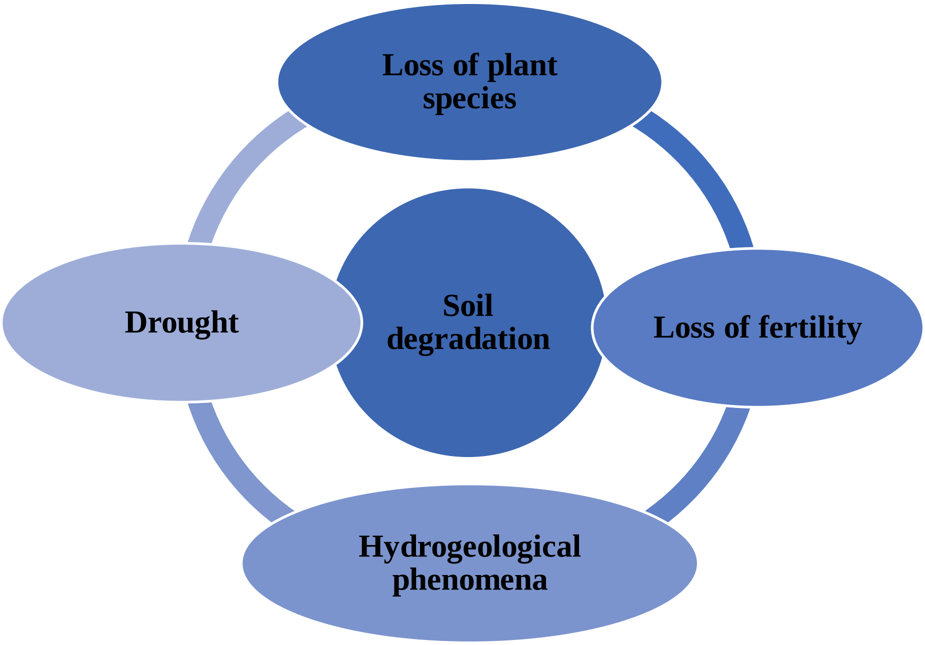

Figure 2. An example model for the occurrence of soil degradation (erosion)

In other interactions between individual factors of the environment, soil changes are considered - erosion, lowering of soil moisture, soil salinization, deforestation, change in species diversity of plant communities, and others (Horel et al., 2022).

Changes in the global or regional nature of precipitation due to climate change are significant factors in the occurrence of desertification and changes in the agro-food chain. According to some researchers (Gelybó et al., 2022; Wang et al., 2021; He et al., 2018), desertification processes will cover up to 50% of the earth's surface by the end of the 21st century, and this, in turn, will change the distribution of cultivated areas and their food capacity.

1.2. Hydroclimatic conditions of the environment

Hydroclimatic changes are complex multifactorial processes related to glaciers, snow cover, sea and ocean levels, vegetation, and water conditions. The increased frequency of extreme climatic conditions leads to more frequent phenomena such as hail, torrential rains, storms, tropical cyclones, prolonged periods of drought, and atypical heat for certain parts of the world. It could result from increased energy and a warmer atmosphere (Lal, 2020). Global warming conditions create conditions for complex development in plant species, making them susceptible to various pests (Xiao et al., 2020). It largely determines changes in species diversity.

The concentration of precipitation in specific periods of the year and the lowering of their average precipitation levels lead to unfavorable environmental conditions in the local ecosystem (Tapia-Silva et al., 2011). Short periods of heavy rainfall lead to high levels of soil moisture and, negative consequences for plant species (Ankenbauer and Loheidei, 2017). With an uneven water cycle, plant species find it difficult to grow and reduce yields compared to previous periods (Xiao et al., 2020; Blanco-Canqui et al., 2017).

Shortening the duration and thickness of the snow cover is a prerequisite for early flowering in spring, respectively, a more extended vegetation period for the individual species and needs for its cultivation (Blanco-Canqui et al., 2017). The reduction of the snow cover, on the other hand, is a prerequisite for increasing the water deficit during the summer months, and this is a condition for limiting the possibility of applying irrigation techniques in agriculture.

The impossibility of water provision and provision of optimal water resources in the agricultural sector leads to a decrease in yields for various plant species, which in turn changes some agricultural and food traditions in the regions (Tapia-Silva et al., 2011).

1.3. Demographic Aspects of Food Chain Change

In climate change, it is necessary to include anthropogenic factors. The use of land and its resources, as well as their conversion into food and other human goods, contribute to approximately 23% of emissions directly related to global warming (Vale et al., 2021). The loss of fertile lands due to various demographic and global processes leads to different desertifying territories converted into commercial and residential areas (Zhao et al., 2022). At the same time, in the course of the demographic processes of the new age, depopulation processes are also reported, further decreasing the production of local foods of national and global importance. The change in the forms of employment and the reluctance to motivate the production and processing agro-sector further changes the conditions of the agri-food chain.

The agriculture sector is among the main priorities related to changes in the environment. Agriculture accounts for about 40% of land cultivation, and food production generates an average of about 20-22% of global greenhouse gas emissions and uses up to 70-75% of the planet's freshwater resources (FAO, 2010). Demographic, economic, and social consumption patterns, including technological advances and global food trade, affect the length of the food supply chain and hence its sustainability.

Promoting certain forms of nutrition with a marketing emphasis aimed at further vegetarianism changes eating habits and creates conditions for the displacement of the food chain. Many people applying a vegetarian eating model are guided precisely by the idea of the environment and its smaller carbon footprint. Opinions about healthy eating, the link between vegetarianism and longevity, and the claims about the choice of food as a factor in determining the population's social status remain controversial. All these aspects give rise to the need to conduct additional research and evaluation to shed a more profound light on the problem of food systems.

1.4. Models for sustainability of the agro-food chain in the conditions of climate change

Implementing specific measures is recommended in the climatic imbalance and change in environmental conditions related to the cultivation of strategically important raw materials for the food industry. They are mainly aimed at creating genetic and selected species with pronounced resistance to the climatic conditions of the environment (Usman et al., 2022b). Reducing specific yields of plant or animal products creates conditions for violating food security. This further necessitates genetic interventions in plant and animal species, with characteristics determining particular quantitative and qualitative indicators. This number applies methods to increase the yields according to the growing conditions. At the same time, some higher levels of the product's nutritional value are considered (Sovacool et al., 2021).

With the advent of higher internet awareness of consumers, the application of awareness models is recommended, which would give more detailed information about the conditions of cultivation, and the influence of the used technology for production and processing on the levels of released emissions.

In the conditions of climatic changes and increased levels of CO2 in the atmosphere, lower levels of macro- and micronutrients, including proteins, iron, zinc, copper, manganese and others in the composition of cereals, nuts and potatoes, have been reported. This, in turn, would have a negative effect on the nutritional and biological value of foods. The projected increase in CO2 levels in the coming years would lead to a decrease in protein levels by an average of about 12-13%, iron by about 13-14% in the period up to 2050 (Beach et al., 2019).

Improvement in crop yields and lowering carbon emissions can be realized with precision automation in agriculture and the food industry (Smit et al., 2000). This will significantly reduce production costs and losses along the chain (Usman et al., 2022b). Automation of the future in the food industry and agri-sector is imperative, as it will primarily preserve the levels of food products imported to the population's nutrition (Thornton and Lipper, 2014). This automation, in addition to the extraction of raw materials and food, will improve the management of processes and increase the implementation of monitoring for environmental impact assessment (Usman and Balsalobre-Lorente, 2022). The measures could be crucial for objectively evaluating healthy food and the short path of its movement "from table to table".

Forms of alternative dietary sources of protein and other macro- and micronutrients fall into plant foods, edible insects, marine and river algae, cell- and culture-based microalgae, and some animal products (meat, milk, eggs) obtained in laboratory conditions. These foods are at the center of alternative sources, primarily proven for their nutritional composition and relatively low carbon footprint levels. Still, at the same time, there remains a need for their implementation in broader food systems. Some cultural and ethical norms in nutrition are why alternative sources of nutrients with a low carbon footprint are not used for food. However, efforts are being made to include them in model food systems and, through various methods, to isolate them as part of the daily human diet (Thavamani et al., 2020).

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CHAPTER 10

THE INTERACTIONS BETWEEN FOOD PRODUCTION AND CLIMATE CHANGE

Assist. Prof. | Hafize Fidan[1*]

Assist. Prof. | Stanko Stankov[2]

[1*] University of Food Technologies, Faculty of Economics, Department of Tourism and Culinary Management, Plovdiv, Bulgaria, hfidan@abv.bg, Orcid ID: 0000-0002-3373-5949

[2] University of Food Technologies, Faculty of Economics, Department of Tourism and Culinary Management, Plovdiv, Bulgaria, docstankov@gmail.com. Orcid ID: 0000-0003-2332-1782

1. BIODIVERSITY UNDER THE CONDITIONS OF CLIMATE CHANGE

The impact of climate change affects biodiversity and manifests itself in plant and animal communities. General climatic conditions affect ecosystems in numerous ways, mainly shifting their quantitative characteristics and habitat ranges. Most often, this is found in some marine, freshwater, and terrestrial species. In some regions of Europe, the decline in animal and plant species populations is associated with a change in feeding habits traditionally associated with certain species (FAO, 2019).

Cereal yields, necessary for global food security, are the subject of numerous analyzes and assessments. Changes in abiotic factors of the environment, such as the amount of precipitation, solar radiation, and temperature, affect the development of cereals and other plant species relevant to food security (Wheeler and Von Braun, 2013; Singh et al., 2022). High-temperature inversions negatively affect wheat and rice yields (Qasim et al., 2020; Turner et al., 2020), creating a prerequisite for the search for alternative approaches to dealing with the problem.

The sustainability of biological species necessary for the population's nutrition is strongly influenced by their ability to tolerate changes in the conditions of their natural habitat, including climate inversions. In addition, the biological interactions between species create additional requirements for their survival and use in the agro-food chain.

In recent decades, in various parts of the world, there has been a strong interest on the part of producers with a focus on monoculture agriculture (FAO, 2019). The concentration of production around cereals and some horticultural crops with high-yield characteristics leads to the loss of local varieties and species. Globally, about 6,000 species are cultivated plants, of which about ten comprise approximately 70% of the share of crop production (Akinola et al., 2020).

Climate changes lead to long-term changes in the composition of some local representatives of the microflora (Turner et al., 2018), determining the typical quality characteristics of foods and hence their use in human nutrition. Their loss due to natural and anthropogenic factors would lead to the loss of familiar food products with a geographical character.

Applying measures for plant protection and treatment of the grounds for growing plants changes their resistance to some unwanted microorganisms (Smith, and Myers, 2018) and creates conditions for their adaptability. High temperatures during the growing season make conditions for rapid dehydration and the appearance of disease-causing microorganisms causing diseases on a large scale. As a result, low yields are reported, and at the same time, a large part of the products on the market have high levels of some agrochemicals and pesticides used in their cultivation (Sunderland, 2011). For these reasons, food control in the agri-food chain must be adequate and minimize the possibility of such products reaching the table.

A decline in the proportion of plant and animal species used for human food can result from biodiversity losses. It can be interpreted differently, both from non-use and unsustainable use.

The creation of integrated approaches in the protection of biodiversity in the course of its use, particularly in the composition of food systems, should be part of a critical development strategy. Applying traditional and locally adapted cultivation and processing techniques must be the basis of good production practices. It is imperative to create technological models for the widespread use of food resources with a rich nutritional composition, which until now have not been part of the traditional dietary intake of the local community (Bélanger and Pilling, 2019).

2. THE INTERACTIONS BETWEEN FOOD PRODUCTION AND CLIMATE CHANGE

Feeding the people of the planet in the coming decades will be one of the main focuses of management. Climate change creates direct and indirect conditions for a change in human eating habits (Robinson & Pozzi, 2011). Global climate conditions hinder the cultivation or lead to lower yields of certain crops, resulting in a food crisis (Popkin et al., 2020). On the other hand, a shortage of specific food resources can be a prerequisite for a negative effect of food intake (Parfitt et al., 2010; Myers et al., 2017, Tumwesigye, 2019). Improper and unbalanced nutrition in climatic, financial, and demographic conditions can be assessed as threatening the lives of vulnerable population groups (FAO, 2020). The combination of unhealthy nutrition caused primarily by a changing product or market environment creates higher mortality and morbidity among people. A key place in the processes of transformation in the food chain and human nutrition depends on implementing sustainable productivity models in the agricultural sector. A necessary condition for creating a sustainable management model in food systems is their sensitivity to nutrition from production to final consumption.

Many people try to balance their nutritional intake through foods of local origin, which, due to climate change, are less and less available in stores (Meyer, 2020). Certain groups of people's cultural eating habits are threatened due to dynamically changing conditions for growing raw materials (O'Hearn et al., 2019). The search for both traditional and, at the same time, such raw materials with pronounced resistance to climate change is the subject of many discussions and studies (FAO, 2020).

Dealing with foods' quantitative and qualitative composition largely depends on their production potential. This is achieved by applying the genetic transformations that accompany the entire research process, creation, and application of good practices in sustainable agriculture (Taub, 2010). Applying traditional methods of growing plant species used for human consumption according to known conventional methods is increasingly tricky (Springmann et al., 2016). The use of non-traditional approaches and solutions in the agro-food chain creates increasing conditions for lower bioavailability and nutrients (O'Hearn et al., 2019), albeit with higher yields.

Climate change is increasingly associated with applying non-conventional tillage methods and treating it with chemicals during the growing season to ensure good yields (Myers et al., 2017). These growing conditions form some characteristics of the products of plant origin, which do not follow the taste norms of the past. To some extent, this can be a prerequisite for refusing to use already established traditional raw materials and replacing them with others that are imported (Meyer, 2020). The reasons for the negative effects of climate change on agricultural production could be prolonged droughts, extreme and heavy rains and floods, increased yields, use of chemical pesticides in pest control, destruction of livestock, spread of agricultural pests and diseases (FAO, 2019) (Figure 1).

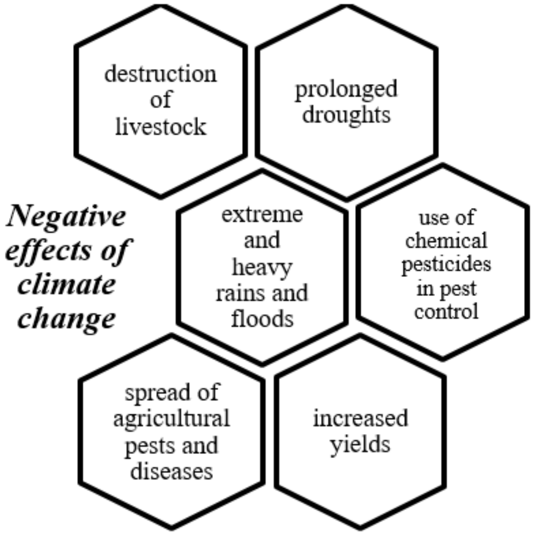

Figure 1. Negative effect of climate change on the agricultural production

Part of the measures to deal with food and reduce the harmful impact of the agro-food chain on the climate can be related to the reduction of waste in food processing, the sparing use of freshwater resources, and, last but not least, the transition to healthy, ecologically sound diets (Bommarco et al., 2018).

Food production from agriculture is highly dependent on various factors including temperature and rainfall, and therefore is vulnerable to climate change. Climate change affects food production in complex ways. Direct impacts include changes in agroecological conditions; indirect effects include changes in economic growth and distribution of incomes, which in turn affect the demand for agricultural produce.

Climate change is changing the forms of agricultural production. Climate change is reducing the productivity of farm products and putting stress on the amount of the world's food supply. The Food and Agriculture Organization of the United Nations (FAO) stated that 790 million people living in developing countries did not have enough food. The Food and Agriculture Organization of the United Nations (FAO) report on food security identified countries and groups at risk and indicated that more than half of the population living in Central, Southern, and Eastern African countries is inadequately and malnourished (FAO, 2019). Climate change may affect the food security in four ways (food delivery, food accessibility, effective use of food and stabilization of food systems) (Figure2). While these effects may occur in the short term due to extreme weather events, in the long-term changes in temperature and precipitation patterns put food security at risk (FAO, 2019). For example, Ali et al. (2017) examined the effects of climate change (e.g., maximum temperature, minimum temperature, rainfall, relative humidity, and the sunshine) on the major crops of Pakistan (e.g., wheat, rice, maize, and sugarcane). The results of the study revealed that maximum temperature adversely affected wheat production, while the effect of minimum temperature is positive and significant for all crops. Rainfall effect towards the yield of a selected crop is negative, except for wheat. To cope with and mitigate the adverse effects of climate change, there is a need for the development of heat- and drought-resistant high-yielding varieties to ensure food security in the country. In other study, Wang et al. (2022a) determined the climate trends and staple food yields over the past 30 years. They revealed that the upward trend in wind speed and potato yield throughout Kazakhstan was apparent. Furthermore, barley and wheat yields had increased in the southeast. On the other hand, for wheat, frostbite should be prevented after the warmer winters in the high-latitude areas. Except for July–August in the low-latitude areas, irrigation water should be provided in the other growth periods and regions. On the other hand, according to Shayanmehr et al. (2020), the effects of future climatic change on potato yield and its variability would vary among the different agro-economic zones, and major potato producing zones would experience a decrease in mean potato yield in the presence of climate change.

Food security and climate change are multidimensional issues, so knowledge about the variables is very important (Allipour Birgani et al., 2022). Wang et al. (2022b) reported that climate change, especially extreme temperatures, has a significant negative impact on food security and food production. They also suggest the presence of geographical variations in the contribution of agricultural insurance to ensuring food security, with greater coverage in major food producing regions. In their study, Affoh et al. (2022) investigated the relationship between climate variables such as rainfall amount, temperature, and carbon dioxide (CO_2) emission and the triple dimension of food security (availability, accessibility, and utilization) in a panel of 25 sub-Saharan African countries from 1985 to 2018. Their results revealed that rainfall and CO_2 emission had a significantly positive effect on food availability, accessibility, and utilization in the long run. In contrast, according to the researchers, the temperature was harmful to food availability and accessibility and had no impact on food utilization (Owino et al. 2022).

Natural factors and human activity are among the reasons for the decrease in the volume of agricultural production. In addition, the use of arable land, drought, barren soils, extreme droughts, cold weather, landslides, and extreme rainfall are the main reasons for the decline in global yields of food commodities. In addition, it is believed that as temperatures rise, the areas where some agricultural products are grown are expected to expand northward and into higher elevations (Filho et al., 2022). Countries located in northern latitudes may be able to engage in agricultural activities over larger areas due to global warming. However, even if climatic conditions improve with the effect of air warming in these countries, some doubts are expressed as to whether soil conditions will be suitable for intensive agriculture. It is believed that global warming may reduce soil and seed quality and allow agricultural pests to multiply, leading to reduced agricultural production (Wheeler et al., 2013).

Figure 2. Climate change effect on food security

On the other hand, the favorable climatic conditions and the increasing agricultural production in the northern countries with the weather's warming will adversely affect the countries' economies. However, it should be noticed that rising temperatures may disrupt local agricultural production. Production of some food products is predicted to be adversely affected by rising temperatures, and in a situation where the temperature increase is 1 °C, their production is expected to decrease (Mekonnen et al., 2021). For example, Malhi et al. (2021) reported that the average global temperature is rising continuously and is projected to increase by 2 °C by 2100, which would cause significant economic losses to agricultural crops globally. CO_2 concentration is also growing at an alarming rate, leading to higher plant growth and productivity due to increased photosynthesis. However, increased temperature offsets this effect, leading to increased crop respiration and evapotranspiration, higher pest attack, change in weed flora, and reduced crop duration. Climate change also affects the microbial population and their enzymatic activity in the soil.

Climate changes undoubtedly leads to several negative aspects of food production. For this reason, agricultural systems must transform to reduce risks to global food security and socio-economic vulnerability. Climate change creates more uncertainty and risk for farmers. To address food security at all stages of the climate change spectrum, transformative approaches that are integrated as a result of evidence should be outlined. In addition, coordinated action is needed, from research to policy, investment, private, public, and civil society sectors, from the global to the local level. With exemplary practices, policies, and investments, the agricultural sector contributes to food security in the long term while helping to quickly eliminate food insecurity and reduce poverty (Garbero et al., 2021).

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CHAPTER 11

INTERACTION BETWEEN CLIMATE CHANGE AND LIVESTOCK PRODUCTION

Prof. Dr. | Duygu BAKİ ACAR[1*]
Res. Assist | Ece TUNÇ[2]

[1*]Afyon Kocatepe University, Faculty of Veterinary Medicine, Department of Obstetrics and Gynecology, Afyonkarahisar, Turkey, dbakiacar@aku.edu.tr ORCID: 0000-0002-6884-2621
[2]Afyon Kocatepe University, Faculty of Veterinary Medicine, Department of Obstetrics and Gynecology, Afyonkarahisar, Turkey, etunc@aku.edu.tr ORCID: 0000-0001-6913-4961

INTRODUCTION

Climate change is a global crisis affecting humans, animals, fisheries, aquaculture, forestry, and crop and farm animal production in the last four decades (FAO, 2017; IPCC, 2021). Global warming is increasing at an alarming rate and changing the atmosphere, land, ice, and ocean regions. Earth's surface temperature increased by 1.1℃ (2°F) from 2011 to 2020, and continuing warming. It is expected that the rise of the mean ambient temperature will be by 2℃ by the year 2050; 0.3-4.8℃ by the year 2100 (Figure 1). Rainfall intensity and patterns have changed since the 1950s, glaciers are rapidly melting and thawing (defrosting), the ocean is warming, and the sea level has risen by about 20 centimeters since 1900. The water of the ocean is more acidic because of carbon dioxide absorption (IPCC, 2021).

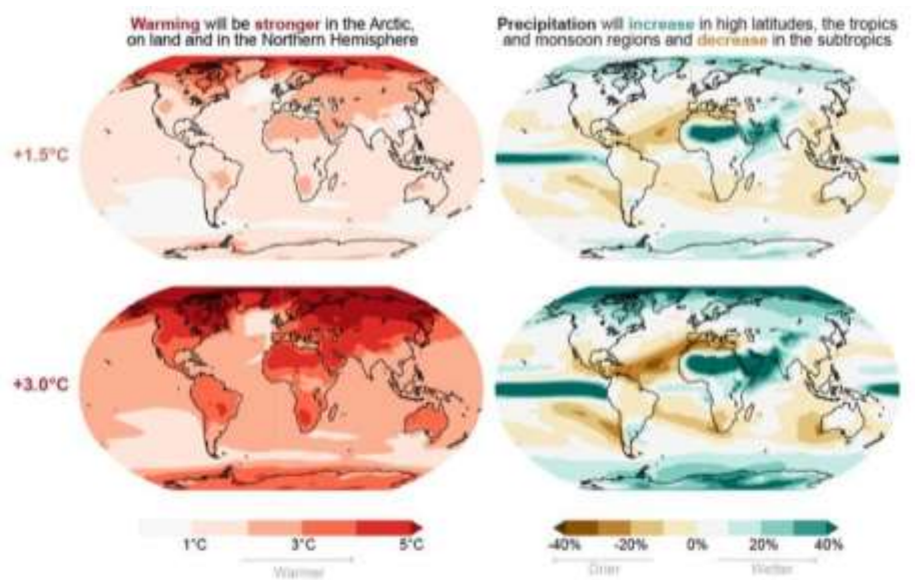

Figure 1. Climate change and regional patterns (IPCC, 2021)

The climatic changes and global warming are mostly caused by greenhouse gas (GHG) emissions. Carbone dioxide (CO_2), methane (CH4), and nitrous oxide (N_2O) are the main GHGs, and human activities, burning coal, oil and gas, deforestation, livestock production, and fertilizers are immediate causes of these emissions (European Commission, 2022). The livestock sector contributes 14.5% of the total GHG emissions on the Earth. Ruminants are directly producing GHG by enteric fermentation and other physiological activities. However, the livestock industry is a dispensable sector due to the global animal-sourced food production necessity, and all the agricultural systems and livestock production expose the deleterious effect of global warming (Figure 2). The predicted human population will be 9.6 billion by 2050, and concerning this population increase, the agricultural product requirement is expected to increase by 70% in the same period (Rojas-Downing et al., 2017). Therefore, new strategies need to develop for livestock production with decreased GHG production and preventive heat stress measures.

1. THE IMPACT OF CLIMATE CHANGE AND GLOBAL WARMING ON LIVESTOCK

Animals need a thermal comfort zone to live and produce under optimal conditions. Comfort zones vary among animal species and breeds. Minimum use of thermoregulatory systems in the body achieves homeothermy, and environmental factors directly affect this comfort zone. Heat stress harms homeothermy by increasing core body temperature and triggering the physiological reactions to dissipate heat from the body. This negative thermal environment impairs animal welfare, health, growth, reproduction, and productive capacity (quality and quantity of milk, meat, fiber, and egg) (Nardone et al., 2010; Scholtz et al., 2013). Air temperature, humidity, precipitation, solar radiation, and wind speed affect the heat stress severity. Dry-bulb temperature is generally the primary biological environment measurement chosen. Moreover, high humidity and solar radiation worsen the negative effect of increased temperature. Humidity decreases the animal's skin and respiratory evaporation capacity. Solar radiation alters the metabolic heat process and blocks the maintenance of body temperature. Wind speed and draft, in combination with precipitation, raise the effect of cold on animals (da Silva, 2006). However, the studies revealed that air temperature and relative humidity are the most available data for detecting heat stress. Different researchers presented the Temperature-Humidity-Index (THI) definition since the 1970s. National Mastitis Council (1971) calculated THI in a combination of air temperature (°C) and relative humidity (in %), Buffington et al. (1981) described Back Globe Humidity Index (BGHI), Gaughan et al. (2009)

described Heat Load Index (HLI), and Van Laer et al. (2015) presented Comprehensive Climate Index. THI and BGHI calculations are more useful for indoor conditions. Still, HLI and CCI calculate heat stress in addition to the ambient wind speed and solar radiation for pasture conditions.

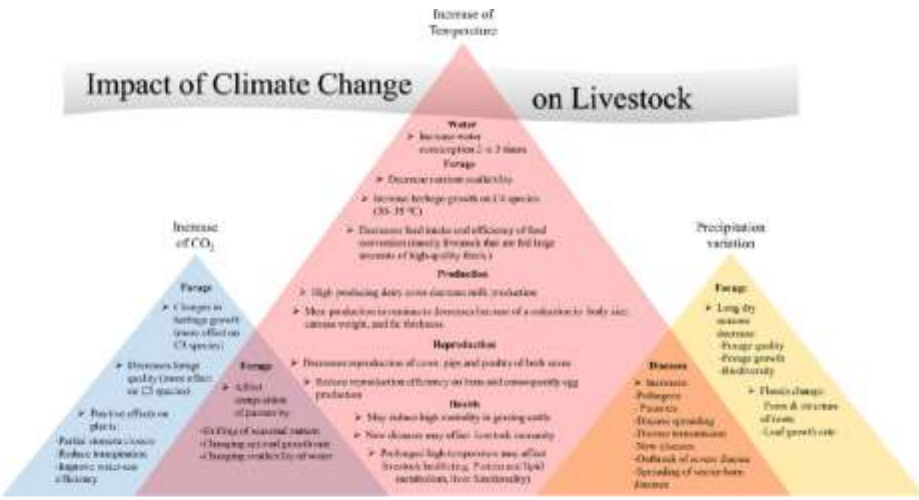

Figure 2. The effect of global climate change on livestock (Rojas-Downing et al., 2017)

Different farm-based (pasture, indoor, or mix livestock systems), regional (tropical, subtropical, temperate, boreal, or arctic), and individual (breed, milk yield, pregnancy, parity, and health status) factors alter the thermoneutral zone and THI response of animals. For optimal conditions, temperatures between 5-25℃ considered minimal heat stress for livestock (Figure 3). Under THI: 68 level ensures comfort zone for animals. Most of the research revealed mild heat stress signs in cattle THI between 72 and 74; THI: 74-78 causes severe heat stress signs and decreased production performance, and ≥ 78 causes hyperthermy and very severe heat stress signs, even death (Habeeb at al., 2018; Sammad et al., 2020; Dimov et al., 2020).

THI calculation formula according to Mader and Davis, 2006:

$$THI = (0.8 \times T) + [(RH/100) \times (T - 14.4)] + 46.4$$

T: dry bulb temperature (ºC); RH: relative humidity (%).

	Relative Humidity %																				
Deg C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
23.8														72	72	73	73	74	74	75	75
26.7							72	72	73	73	74	74	75	76	76	77	78	78	79	79	80
29.0			72	72	73	74	75	75	76	77	78	78	79	76	76	77	78	78	79	79	80
32.0	72	73	74	75	76	77	78	79	79	80	81	82	83	80	81	81	82	83	84	84	85
35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	84	85	86	86	87	88	89	90
37.8	77	78	79	89	82	83	84	85	86	87	88	90	91	88	89	90	91	92	93	94	95
40.5	79	80	82	83	84	86	87	88	89	91	92	93	95	92	93	94	95	97	98	99	
43.3	81	83	84	86	87	89	90	91	93	94	95	96	98	98	97						
46.0	84	85	87	88	90	91	93	95	96	97											
48.9	86	88	89	91	93	94	96	98													

Figure 3. Temperature-Humidity-Index chart (Dimov et al., 2020)

1.1. Acclimation

Animals under environmental stress factors develop physiological, behavioral, metabolic, and endocrinological adaptations, named as acclimation, to survive in these adverse circumstances (Bernabucci et al., 2010). Under mild heat stress conditions, animals develop adaptive changes such as feeding alterations, increased respiration rate, heart rate, vasodilatation, sweat rate, and water intake. While heat stress is getting severe, physiological and behavioral signs become more apparent; nervous, biochemical, cellular, and metabolic changes occur. Respiration rates increase to maintain homeothermy, feed intake decrease to reduce metabolic heat production and stabilize body temperature, and water intake increase. The exposure time, intensity, and heat load duration directly affect the acclimation capacity (Gauly and Ammer, 2020).

1.2. Health Status Under Heat Stress

Heat stress induces temperature-related illness, morbidity, and death directly or indirectly by variating microbial populations, vector-borne diseases, feed and water shortages, food-borne diseases, and host resistance to infectious diseases. Individual heat stress responses can be influenced by species, breed, pregnancy, production performance, parity, lactation stage, body condition, hair length, and color (Nardone et al., 2010; Henry et al., 2018).

Increased respiratory rate is the first answer to heat stress in animals. Blood CO2 level decreases due to hyperventilation, and HCO3 secretion by kidneys increases to buffer rumen pH. Panting reduces the saliva quality, and a reduced forage/concentrate feed ratio leads to a decrease in rumination and less saliva production. These changes result in susceptibility to subclinical or acute rumen acidosis and lameness. Animals lower feed intake under prolonged heat stress conditions, and the risk of subclinical or clinical ketosis increases. With decreased feed intake, energy intake decreases, and calorigenic hormones such as catecholamines, glucocorticoids, and growth hormone secretion decline. Following this period, digestion, energy metabolism, lipid, protein, mineral metabolism, and metabolic rate decrease, and metabolic heat production reduces. As a result of hot conditions, blood glucose and non-esterified fatty acids (NEFA) levels decrease despite a negative energy balance. The hepatic glucose synthesis and insulin response interrupt glucose turnover, and the cellular glucose entry process reduces. Heat stress affects not only glucose metabolism but also cholesterol and albumin secretion and enzymatic activities of the liver (Nardone et al., 2010; Gauly and Ammer, 2020; Borshch et al., 2021).

Heat stress negatively influences rumen motility, passage rates, and short-chain fatty acids (SCFA) production with dry matter intake. Forage consumption reduction is more than dry matter intake of concentrate. Because of this situation, the ruminal bacterial quantity of specific groups differs. Fibrolytic bacteria amount decreases, and saccharolytic bacteria quantity increases due to higher concentrations of hay ratios. The change in the rumen microbiota alters ruminal fermentation patterns. High environmental temperature effects on rumen motility, passage rate, gut fill, and digestibility are reproducible (Gauly et al., 2012).

Decreased feed intake due to hot conditions adversely affects mineral intake. Increased sweating to compensate for heat stress increase potassium (K) demands, which is the primary cation in sweat. During the acclimation process, macro minerals, including calcium (Ca) and phosphate (P) absorption declines, and dietary electrolyte balance alters. Dietary K and sodium bicarbonate additions to animals may help to achieve heat stress (Scholtz et al., 2013). Extreme weather conditions also affect calf health. Heat stress and summer months increase calf mortality. The cows produce colostrum, including fewer immunoglobulins, which causes inadequate passive transfer of immunoglobulins to calves (Bernabucci et al., 2006; Nardone et al., 2010).

Climate change indirectly affects global microbial communities and vector-borne diseases. Global warming and changes in rainfall patterns alter the growth and spread of pathogens, parasites, and pests. New diseases, outbreak, and disease spreading observed in the United Kingdom, Europe, Africa, topical, and subtropical regions of the world in the last few decades (Herrero et al., 2008; van Dijk et al., 2008; Thornton et al., 2009). Helminth infections caused severe health and economic risks in the livestock sector. Larval development of gastrointestinal nematodes and trematodes (especially for a liver fluke, *Fasciola hepatica*) needs suitable temperature and humidity. Rising precipitation and humidity with increased temperature due to global warming shifted this development and spread. Climate change also modified the habitat suitability of vector-borne pests such as flies, ticks, and mosquitos. Elevated rainfall creates a proper condition for breeding mosquitoes. One of the vector-borne disease Rift Valley fever transmits by infected *Aedes* and *Culex* mosquitos, especially in Africa. This disease affects cattle, sheep and goats, and human health. The change in rainfall patterns and extreme weather conditions (El Nino/El Nino Southern Oscillation-ENSO) is linked with outbreaks of Rift Valley fever in different countries such as Egypt, Mauritania, Madagascar, Kenya, and Somalia. The rise of the equatorial Pacific and Indian Ocean temperatures accelerated the intensity and duration of Rift Valley fever activity (OIE 2009; Scholtz et al., 2013). Another vector-borne disease, Bluetongue virus infection, transmits by *Culicoides imicola* mosquitos and has a global distribution following increased humidity and precipitation. The reports revealed climate change directly affected the spread of Bluetongue disease which affects mainly sheep and also cattle, goats, and deer (Wittmann et al., 2001; Nardone et l., 2010). Ticks are another vector-borne disease blamed on animals. *Theileriosis* (East Coast fever), *Babesiosis* ((Red water), *Anaplasmosis* (Gallsickness), and *Cowdria ruminatum* (Heartwater) are tick-related diseases. The research showed that a temperature above 26.8°C and humidity between 39% and 65% open the way for tick activity; however, higher altitudes and lower temperatures delay this activity (Sajid et al., 2009). All these vector-borne diseases stated above negatively affect livestock health and productivity, causing systemic diseases, abortion in pregnant animals, reduced growth rate, milk yield decrease, etc. In addition, mycotoxin-producing fungi growth increases with climate change with higher temperatures and moisture. Mycotoxin causes acute or chronic pathologies in the liver, kidney, oral and gastric mucosa, brain, and reproductive organs. The amount of mycotoxin exposure changes the severity of clinical signs, and the origin of the toxins is mainly foodborne in humans and animals (Nardone et al., 2010).

1.3. Reproductive Functions Under Heat Stress

Reproductive efficiency is the main driver for the sustainability and survival of species. Optimal conception rates and healthy offspring targets ensure economic livestock production and human requirements. Different factors affect reproductive performance, and heat stress is one of the current topics in the worldwide livestock industry (Figure 4). Especially, in dairy cows with high milk yield have low reproductive performance, and heat stress severely deteriorates this negativity (Boni, 2019; Sammad et al., 2020).

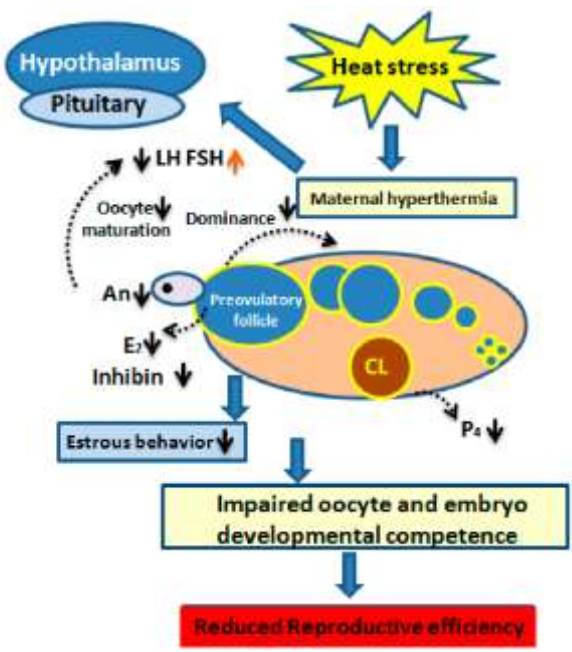

Figure 4. Impact of heat stress on dairy cow fertility. LH: Luteinizing hormone, E2: Estradiol, An: Androstenedione, FSH: Follicle-stimulating hormone (Khan et al., 2020).

1.3.1. Effect of Heat Stress on Ovarian Functions

Ovaries of mammals have two functions: *i)* exocrine function with oocyte development, *ii)* endocrine function with ovarian hormone synthesis and secretion such as estrogen and progesterone. If any stage of this function is interrupted, the reproduction may fail. Ovarian folliculogenesis is a period of both exocrine and endocrine functions. Follicles begin this period as primordial follicles in the growing follicle pool and develop to the pre-ovulatory stage at the end of the process. This period controls by gonadotropic and ovarian hormones and proteins. In the summer season, inhibin concentrations are lower in heat stress conditions. High temperatures may cause reduced follicular dynamics, irregular oestrus cycles, and prolonged anoestrous (Figure 5). Preantral follicles are resistant to heat stress, but at the beginning of the early antral transition stage, susceptibility to increased temperature occurs. In this transition stage, Follicle stimulating hormone (FSH) and Luteinizing hormone (LH) become a part of this activity, granulosa cells develop these hormone receptors, and the preovulatory follicle develops under FSH and LH effect. It was reported that preovulatory follicles have 0.74°C and 1.54°C cooler mean temperatures than the uterine surface and rectal temperature, respectively, in cows. Any difference in mean temperatures was not detected in non-ovulatory follicles. The lower temperature of preovulatory follicles originates from heat consuming process with intraovarian blood vessels. This protective process remains incapable under heat stress conditions. The negative effects of heat stress can be restored in months due to the time-consuming folliculogenesis period (Hyttel et al., 2001; Lopez-Gaitus and Hunter, 2017; Boni, 2019; Sammad et al., 2020).

Buffaloes are also affected by heat stress. In the warm season, reproductive performance diminishes due to hyperprolactinemia, lower blood progesterone levels, acyclicity, and infertility. The summer season is called the low reproductive season in buffaloes. Pigs are susceptible to warm temperatures due to their low sweating capacity. Especially in periparturient periods, higher death rates occur in pigs. Heat stress alters estrous cycles, oocyte quality and maturation success, embryonic development, and pregnancy rates in sows and gilts (Nardone et al., 2010).

The postpartum period is a stressful term in animals, especially in high-producing dairy cows. Heat stress has additive adverse effects on the postpartum period with decreased feed intake, intensified negative energy balance, and hyperthermia. Negative energy balance alters the glucose, insulin growth factor-1 (IGF-1), leptin, NEFA, and β-hydroxybutyric acid (BHBA) profiles. Following the alteration of those profiles, follicular dynamics and growth affect adversely, preovulatory follicle size reduces, granulosa cell development disrupts, and serum estradiol concentration lowers (Mamm, 2011). Granulosa cells are the most important cell types in the follicles surrounding, supporting, and nurturing the oocyte. FSH stimulates granulosa cells to proliferate and convert androgens to estradiol. After ovulation, granulosa cells transform into luteinized cells and produce progesterone. Under heat stress conditions, intracellular reactive oxygen species (ROS) accumulation increases, apoptosis induces, and steroid synthesis reduces in granulosa cells. As a result of this, silent estrous, altered sexual cycles, and lowered LH response occur due to inadequate estradiol synthesis or insufficient progesterone synthesis happens due to a lack of luteal cell function (Khan et al., 2020). In addition to granulosa cell alterations, hyperthermia hinders follicular development, dominant follicle size, and ovulation in other ways. Luteolytic mechanism hitch and delayed luteolysis occur, and in some cases, the follicular wave process alters, and ovulatory deficiency happens. Double ovulations are seen due to heat stress. Progesterone synthesis of luteal cell decrease in warm temperatures owing to insufficient luteal cell function and hepatic metabolism in conjunction with dry matter intake. Low serum progesterone levels following artificial insemination or breeding lead to embryonic deaths and infertility (Boni, 2019; Sammad et al., 2020).

Irregular estrous cycles are seen in livestock due to heat stress. Stress hormones such as cortisol secretion increase at warm temperatures. Cortisol inhibits Gonadotropin Releasing Hormone (GnRH) and LH secretion, preovulatory LH surge, and ovulation delays or ceases. Increased glucocorticoid secretion on account of heat stress blocks estradiol-induced estrus behaviors and reduces fertility. All these effects increase in the number of days open, the anestrus period, and reduce conception rates (Sammad et al., 2020; Gauly and Ammer, 2020).

Silent estrus is a common problem in cows under heat stress. Hormonal treatments and timed artificial insemination (AI) solve this problem, and conception rates can increase. GnRH injection in the early stage of oestrus improves pregnancy rates. In chronic heat stress issues, administration of GnRH or Human chorionic gonadotropin (hCG) on day 5 of oestrus results in ovulation in the first follicular wave, and progesterone levels maintain adequately. In high-producing dairy cows, GnRH treatment at the time of AI or six- and twelve-days post-AI increases conception rates in the summer season (Sammad et al., 2020).

1.3.2. Effect of Heat Stress on Oocyte Quality and Embryo Development

Oocyte quality and maturation competence directly affect reproductive efficiency. Oocytes are highly sensitive to high temperatures concerning folliculogenesis and follicular microenvironment. Heat stress damages oocytes associated with their growth stage and maturation. Resumption of meiosis, metaphase II formation, cytoskeletal rearrangement, and cortical granule translocation are failed in the oocyte maturation period in heat stress conditions. The deleterious effect of high temperature occurs both in the endocrine way, such as suppressed LH pulse amplitude/frequency and inhibited oocyte maturation process, and in oxidative stress way with an alteration of granulosa cells and developmental competence of oocyte (Khan et al., 2020). In vivo and in vitro studies reported that high temperatures disrupt the cytoskeletal structure of oocytes, induce apoptotic genes (Caspase 3, B-cell lymphoma 2, and Bcl-2 Associated X-protein) and heat shock proteins (HSP70), and antioxidant genes (superoxide dismutase1, catalase, and CPX4) in cumulus oocyte complexes (COCs) (Payton et al., 2004; Boni, 2019; Stamperna et al., 2021).

Heat stress increases polyspermy by disrupting the anti-polyspermy process during in vitro fertilization. Fertilization rates also decrease due to morphological changes, oxidative stress, nuclear fragmentation, and mitochondrial impairment in oocytes exposed to heat stress. The apoptosis was seen in the inner cell mass cells of the blastocysts. The development competence of embryos affects especially early-stage embryos. However, advanced-stage embryos are more thermotolerant to high temperatures than early-stage embryos (Sammad et al., 2020; Gauly and Ammar, 2020). In dairy cows, exposure to heat stress one day after insemination significantly decreases embryo viability and development. The 3-day-old embryos become more resistant to maternal heat stress. Similarly, in-vitro cultured Day 3 embryos lose blastocyst development efficiency following two days of heat shock exposures. Morula and blastocyst stage embryos have an antioxidant capacity against heat stress-induced ROS production, and the ability to synthesize HSP70. Also, these embryos can repair heat-induced unfolded proteins and prevent DNA damage and apoptosis. Because of the resistance of advanced-stage embryos (morula and blastocyst), embryo transfer may be an alternative strategy to bypass heat stress problems. Pregnancy rates may increase in the summer months with embryo transfer. However, it must be kept in mind that frozen-thawed embryos are more sensitive than fresh embryos, and in vivo collected embryos are more resistant than in vitro-produced embryos (Boni, 2019).

1.3.3. Effect of Heat Stress on Pregnancy

The embryo and fetus do not have a self-thermoregulation system, and maternal thermoregulatory capacity designates the embryo/fetus's body temperature. Thus, heat stress severity and exposure time directly affect the mother’s body temperature and, indirectly fetus’s body temperature. Warm temperatures alter the prostaglandin E2 (PGE2) and prostaglandin F2 alpha (PGF2α) secretion from maternal uterine endometrial epithelial and stromal cells. Increased PGF2α secretion cause corpus luteum lysis, embryonal resorption, and abortion by the term of pregnancy. Placental vascular deficiencies and endocrine abnormalities may occur in heat stress conditions, and this situation eventuates in reduced angiogenesis and lower placental perfusion, placental weight decrease, placental hormone insufficiency, fetal hypoxia, malnutrition, fetal growth retardation, and fetal death (Wiltbank et al., 2016; Sakai et al., 2018). Maternal hyperthermia may cause fetal teratogenesis, especially with long-term hyperthermia. In late-term pregnancies, altered prolactin signaling affects immune function. Moreover, decreased fetal growth may fail the fetus’s immune status and survival rate after birth (Boni, 2019).

1.3.4. Effect of Heat Stress on Male Reproduction

The male reproductive system protects by scrotum in most mammalian species from heat and maintains the testicular temperature below body temperature. The spermatogenesis process is heat sensitive, and environmental or body temperature increase negatively affects spermatozoa. Heat stress directly affects spermatogenesis, reduces sperm quality, and induces oxidative stress and apoptosis. Sperm motility, membrane integrity, and DNA integrity decrease, and morphologically abnormal sperm rate increases. In vitro fertilization rates are low in heat exposure sperms. Mostly, the effect of high temperatures is reversible, and in a few months, the sperm parameters recover (Boni, 2019; Gauly and Ammer, 2020).

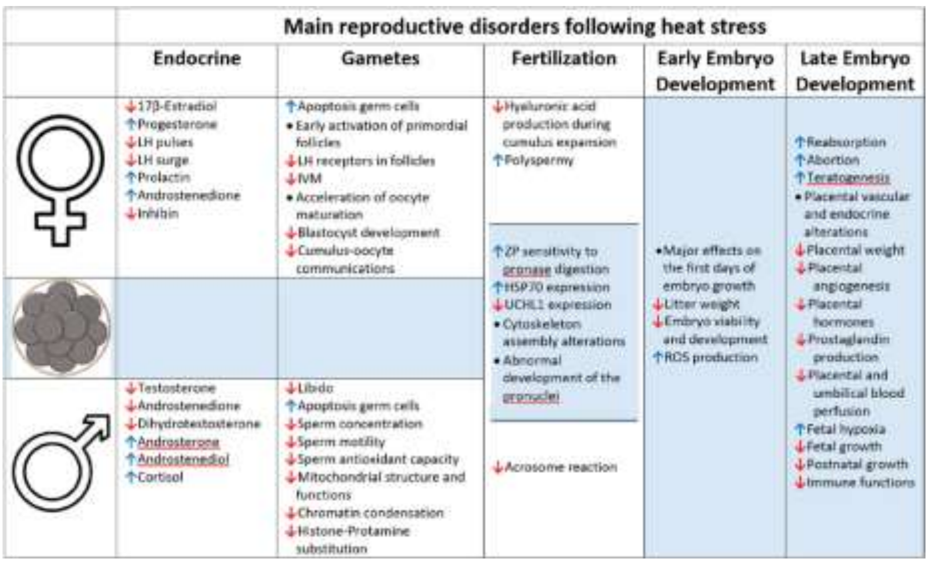

Figure 5. Summary of heat stress effect on reproduction in mammals (Boni, 2019).

1.4. Livestock Production Under Heat Stress

The climate change issue has been argued since the 1990s. The global temperature rises by 2.0 ℃ foreseen to be a critical point for the earth by 2100. The reports show that the expected global warming is more rapid than projected (United Nations Framework Convention on Climate Change, 2022). The tropical, subtropical, and Mediterranean regions are at risk earlier than the rest of the world. In addition, the effects of climatic change are already being observed different areas such as Australia and South east Asia (Henry et al., 2018; Summer et al., 2019). The tropical and subtropical regions have mostly poor people than other sides of the world. The grasslands and grazing lands are sufficient in these regions, so ruminant livestock meets their nutritional needs for socio-economic factors and local food production. Unfortunately, global warming affects these regions more harmful than Europe or other developed countries, and livestock production decrease impairs all poor populations (King et al., 2017; Thirumalai et al., 2017; Henry et al., 2018). After all, developed countries face economic losses due to heat stress in livestock production. In the United States, dairy industries lose $897 million, and beef industries lose $ 369 million per year from global warming (St. Pierre et al., 2003). Heat stress causes a decrease in the quality and quantity of milk, meat, and egg in livestock animals, including dairy and beef cows, sheep, goats, buffalo, pigs, broilers, and hens.

1.4.1. Milk Production

Dairy cows directly affect environmental temperature because of decreased dry matter intake. There is a negative correlation between THI and milk yield. Berry et al. (1964) calculated milk yield decrease in relation with THI. With this formula, milk yield loss can be detectable, and the difference between THI 72 to 80 can be comparable.

$$\text{The decline in milk production (kg /d)} = -1.075 - 1.736 \times NL + 0.022474 \times NL \times THI$$

NL: Normal level of milk yield (kg/day) (Berry et al., 1964).

High-yielding dairy cows have a greater metabolic energy production, which reduces cows' threshold temperature to the thermoneutral zone. The mammary gland health may be affected by this negative situation. The somatic cells are a safe detection method if there is an inflammation or infection in the mammary gland. Although there is no difference between THI <75 or THI >75 in somatic cell count, the analyses reveal an increase in the summer season in cows (Nardone et al., 2010; Cheng et al., 2022).

Sheep, goats, and buffalo are supposed to have higher adaptive capacity than cows in hot weather. However, these animals have different thermoneutral zone levels concerning breeds. Sheep are more sensitive to THI than relative temperature, but it varies by breed. High temperatures affect goats' milk yield, which cannot reach enough water (Finocchiaro et al., 2005). Buffaloes are also resilient to heat stress; milk yield decreases due to physiological changes under heat stress. However, buffaloes are rated below due to their adaptability to environmental factors and lower milk yield capacity than cows (Rojas-Downing et al., 2017).

Warm temperatures affect milk content and quality as well. Milk protein and casein levels decrease above 72 THI, and it was revealed the decrease is directly related to heat stress, not to dry matter intake. The mineral content of milk also alters due to hot temperatures, including phosphorus and ash. Milk pH level decreases too. The changes in milk content negatively affect cheese production and yield. The fat level decrease under warm conditions is controversial. Some studies reported a reduction in THI > 75, or the summer season. Solar radiation also affects the milk content in ewes (Abeni et al., 1993; Bernabucci et al., 2015; Summer et al., 2019). On the contrary, Cowley et al. (2015) did not detect any alteration in milk fat content due to heat stress. The stage of lactation affects the susceptibility to heat stress. Peak milk yield obtains in the mid-lactation term in cows. Therefore, mid-lactating cows are more sensitive than early and late-lactating cows. Reports showed that almost 38% of the milk yield decline occurs in cows on mid-lactation term due to heat stress (Calamari et al., 1997).

1.4.2. Meat Production

Global warming adversely affects high milk yielding dairy cows primarily more than beef cattle. Beef cattle are less resilient because of their lower metabolic heat production, higher panting, sweating, and urination capacity, and behavioral adaptation alterations (Summer et al., 2019). However, beef cattle are usually raised in pasture-based outdoor systems. These extensive systems exposed them to environmental factors such as relative temperature, humidity, solar radiation, and wind. The cattle have thicker fat under the skin, and heavier and darker hair coats are affected harder under hot environmental conditions. The dry matter intake, carcass weight, fat thickness, meat quality, and daily weight gain decrease, and disease incidence increases under heat stress. Similarly, pork quality affects negatively; the growth rate decreases, carcasses are leaner, pH increases, moisture loss lower, and lipid content of leaf fat decreases. Sheep and goats show a remarkable decline in growth rate, wither height, oblique trunk length, hip width, and body condition following heat exposure (da Silva, 2006; Nardone et al., 2010).

1.4.3. Egg Production

Global warming reduces poultry production both in broilers and laying hens. High mortality, reduction in feed intake, body weight, carcass weight, and carcass calorie content occur above 30 °C temperatures. Heat stress alters egg production, hormone secretion and ovulation, egg weight, shell weight, shell thickness, and ash content. The eggs break easily due to reduced free ionized calcium in the blood. (Smith et al., 1993; Mashaly et al., 2004)

1.5. The Adaptation Strategies Against Heat Stress

The adaptation and support of animal welfare strategies are needed to plan on-farm and regional decisions. On-farm decisions include the selection, design, and management of production facilities. In addition to these measures, working in cooperation with regional and national policy may help to share information and improvements (da Silva, 2006). Veterinarians, agronomists, physicists, meteorologists, engineers, and economists should work together to mitigate global warming and climate change (Nardone et al., 2010).

The mitigation strategies are divided into two main topics i) genotypic, and *ii) phenotypic*. *Genotypic* adaptation means the selection of heat-resistant individuals. Different genes associated with the thermoregulatory system can be mapped and selected between breeds and individuals. Different studies were performed to modify the thermoregulatory system such as smooth hair genes, lighter hair, and shorter hair to tolerate the higher temperatures (Dikmen et al., 2008; Bernabucci et al., 2010). Heat stress genes (heat shock proteins-Hsp) play an important role in the recovery of cells from the harmful effects of hot and cold temperatures. Those gene expressions (Hsp40, Hsp60, Hsp70, Hsp90, and Hsp100) are controlled by the endocrine system and induce acclimatization. Some local breeds have those genes with heat resistance so that they may be used as markers of the selection of heat-resistant animals at an early age (Borshch et al., 2021).

Different selection studies revealed the selection of high-performance animals led to increased productivity in livestock. However, these animals breed in industrial and more controlled systems in temperate climates. High yielding animals have higher metabolic energy production and lower resistance to environmental factors. These animals are more vulnerable to climate change than many local breeds. Therefore, different selection research is needed to improve livestock production and animal resistance. Natural selection aims to select tropically adapted breeds with high growth and reproductive capacity under unfavorable conditions and replace them with temperate climates. The *genomic selection* gives information from DNA analysis. It ensures genetic gains such as milk production, meat quality, and growth rate using genome-wide single nucleotide polymorphism markers. Genomic selection needs more technological and costly equipment, but it provides faster results to develop more adaptive breeds to warm conditions. *Epigenetic* means all variances in DNA function without variances in DNA sequences. Environmental, disease, nutrition, temperature, etc. factors can modify the phenotypic expression of the genome through epigenetic mechanisms. Epigenetic ensures collective heritable changes in phenotype which emerge independent of genotype. If the parents coped with challenging environmental situations, the offspring are pre-programmed to this information to survive. However, if the offspring is born to a mismatched environmental condition, the offspring face maladaptation. This situation is called *nutrigenomics* (Tollefsbol, 2011; Neibergs and Johnson, 2012; Henry et al., 2018).

Phenotypic adaptation strategies are environmental and feeding precautions to decrease the harmful effects of heat stress. The most crucial step is providing adequate access to water, especially in pasture systems. Cooling the water by 10 °C in the warm season supports thermoregulation. Livestock exposed to warm conditions and solar radiation need to drink more water for thermoregulation. The cooling techniques including shade, evaporation, ventilation and a combination of them are effective management practices. Using shades reduces heat stress signs such as respiration rate and vaginal and body temperature, increasing milk yield. Shades also help to decrease solar radiation effect on farm animals. Sprinklers can be used alone or with shade in pasture and indoor free stall systems during summer. It was observed that shade reduced respiration rate by 30%, sprinklers by 60%, and a combination of shades and sprinklers reduced 67% with the most effective result. In dry climates, evaporative cooling reduces air temperature while increasing humidity. Evaporative tunnel ventilation increased feed intake and decreased milk somatic cell count under heat stress cows. Fans are another cooling choice to lower respiration rates and increase animal welfare due to hot weather. All the cooling systems positively affect reproduction, milk production, meat quality, and diseases in hot temperatures in extensive, semi-extensive, and industrial systems (Nardone et al., 2010; Gauly et al., 2013; Henry et al., 2018).

Feeding strategies are as crucial as genotypic and phenotypic implementations. Preventive use of dietary fats, trace elements, minerals, microbial ingredients, vitamins, fiber, plant extracts, and other additives supports the acclimation of livestock under heat stress. Adding and balancing those nutrients improve the immune system and antioxidative functions. Hot temperatures alter feed intake, and some vitamin and mineral levels decrease in the body due to physiological changes. As stated above, blood potassium, bicarbonate, calcium, and phosphate need increases. Thus, trace elements and minerals such as bicarbonate, P, K, Ca, zinc, and vitamin C, E, and B3 supplements are needed to add to the feed rations (Borshch et al., 2021). Nicotinic acid (niacin) addition induces cutaneous vasodilation. In dairy cattle, rectal and vaginal temperatures decrease during mild heat stress, with THI >72. The supplementation of conjugated linoleic acid (CLA) in feed use helps to reduce mean rectal temperature and respiratory rate (Liu et al., 2008; Zimbelman et al., 2010). Fats or fatty acid addition to the diets of livestock positively affect enteric CH4 production. The rumen microbial population changes by fat addition, and the energy rate from fermentable carbohydrates decreases. Byproducts such as cottonseed, brewer’s grains, and cold-pressed canola meal help to reduce enteric fermentation. Another mitigation strategy is the addition of lipid diet supplementation (between 5% and 8% of dry matter intake) to reduce enteric CH4 reduction (Grossi et al., 2019).

Climate change affects not only livestock health, reproduction, and productivity directly but also the quality of pasture and forages, so it indirectly affects livestock by the nutritional value of grasslands. However, the impacts are regionally specific. In tropical and subtropical regions, precipitation variation harms the form and structure of roots and leaf growth rate in forages. During long dry seasons, water scarcity decreases forage quality, growth, and biodiversity. In temperate regions, climate change is not as harmful as tropical and subtropical regions. A slight increase in the ambient air temperature leads to prolonged growth in grassland production. Elevated CO_2, enough water, and nutrient supply support crop production in temperate regions (Henry et al., 2018).

Grasses and legumes are both crucial in animal feeding. Legumes are divided into two groups based on leaf anatomy under the cool season (C3) and warm season (C4). While increased CO2 concentration contributes to C3 crops (soybean, wheat, and cotton), temperature rising positively affects C4 crop yield. Climatic factors such as precipitation, temperature, and drought affect crop growth and livestock feed supply. Corn, sorghum, rice, and soybean need the precipitation. Although, C4 species need high temperatures, not rainfall. In continental climate regions, increased temperature and decreased precipitation reduce forage crude protein (CP) content and raise the digestible organic matter. As a result of global warming, the forage quality and rangeland composition will affect different periods and severity in all regions in time. The range of C3 crop species shift to C4 crops, which are more resistant to heat stress but less valuable and digestible. The biodiversity of forage and feed crops will decrease day by day (Rojas-Downing et al., 2017; Henry et al., 2018; Chen et al., 2020).

1.6. The Importance of Water Under Heat Stress

Access to water becomes crucial under heat stress conditions in livestock, especially in extensive and pasture-based systems. The animals with difficulty accessing water have severe physiological signs in hot temperatures. The water requirement of beef cattle for drinking, feeding, and cleaning is 3.7 tons to produce 30 g of protein. The problem of water in livestock production is not only availability. The quality and hygiene of water is also an issue. Because water is getting salinated in many areas of the world. Chemical contamination, organic and inorganic contaminants, heavy metals, and biological contaminations of the water are alarming. Water pH is also altering, and this alteration negatively affects fertility, metabolism, and digestion (Nardone et al., 2010).

2. THE IMPACT OF LIVESTOCK ON CLIMATE CHANGE AND GLOBAL WARMING

Some greenhouse gasses such as CO_2, CH_4, and N_2O cover the Earth like a blanket and prevent heat release into outer space. Thus, Earth gets warmer by this gas blanket, and global warming intensifies (IPCC, 2021). Livestock production has a significant role in climate change by releasing GHGs. Thus, livestock industries are responsible for reducing the carbon footprint and water footprint. The first thing coming to mind is decreasing livestock numbers and increasing the livestock yield *per* animal. Increased production leads to less GHG release. However, this offer is a vicious circle that increasing milk yield causes suppressing the reproduction and sustainability of livestock production, and increasing the vulnerability of animals to diseases (Scholtz et al., 2013). Livestock-sourced GHGs release in different ways *i)* directly, such as enteric fermentation, respiration, and excretion; *ii)* indirectly, such as feed crops, manure applications, farm operations, livestock product processing, transportation, and land use allocation (Figure 6). Indirect GHG emissions play a prominent role in increasing carbon in the atmosphere (Rojas-Downing et al., 2017).

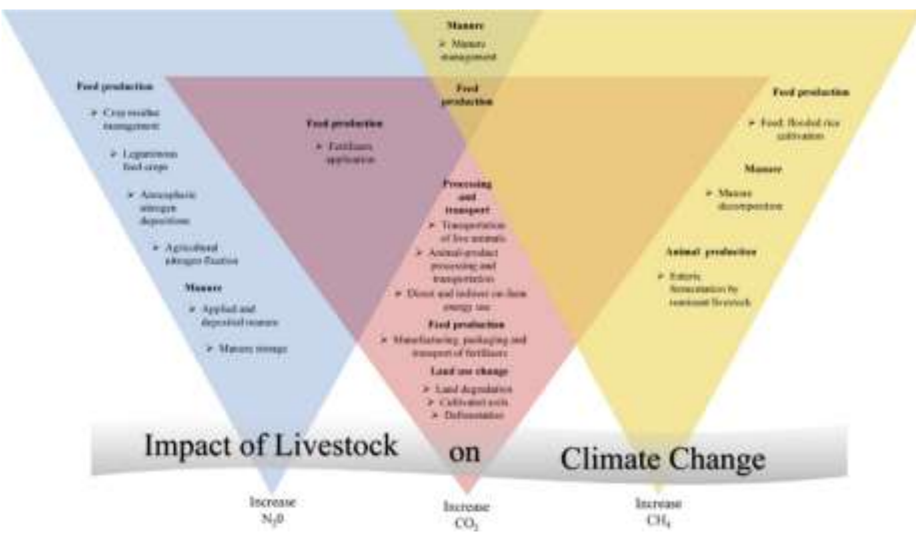

Figure 6. The effect of livestock on global climate change (Rojas-Downing et al., 2017)

In the livestock industry, enteric fermentation is the largest resource (39.1%) of GHG, and manure management is the second contributor. Methane production occurs by enteric fermentation in the digestive system. Rumen and enteric bacteria break down rough plant feed, and methane is emitted by exhaling, belching, and other ways. Higher digestible feed leads to lower enteric methane production. During manure storage, processing, and handling, CH_4 and N_2O release from the anaerobic decomposition of organic material. Farming system type and the region directly affect GHG emissions. Industrialized systems with intensification increase CO_2 release by using more significant fossil fuels. In regional comparison, Asia is the greatest GHG emission producer, and Latin America, the Caribbean, Europe, North America, Africa, and Oceania follow, respectively (Steinfeld et al., 2006; Gerber et al., 2013; Cheng et al., 2022). The European Environment Agency (EEA) reported that almost 50% of all CH_4 is released by the European agriculture system, mainly ruminant animals. GHG emissions according to animal species show that cattle are the primary producers (62.2% of total livestock GHG emissions), followed by pigs (10.1%), chickens (9.8%), buffalo (9.5%), small ruminants (7.4%), and other poultry (1%). Dairy and beef cattle contribute similar emissions (Cheng et al., 2022).

Another livestock originated GHG producer factor is land usage. Since the 1850s, the forests and natural habitats have been converted to cropland and forage for livestock feed. Latin America converted most of the rainforest to pastures and croplands in the past 40 years. Deforestation for livestock production is the main factor of the CO_2 output, with almost 28 million tons of CO_2 released yearly. Pasturelands produce more carbon than croplands. Soils store 1.100 to 1.600 billion tons of carbon; carbon can be lost by burning, land use change, agricultural practice management, volatilization, and erosion. Logging or burning forests to convert to cropland and forage releases high amounts of carbon into the atmosphere (Rojas-Downing et al., 2017). Feed production, processing, and transport cause severe emissions. Fertilization for feeding crops releases major N_2O, and cultivation of leguminous feed crops produces a small amount of N_2O. Fertilizer usage is important for crop production, but the timing, and quantity of fertilizer directly affect soil N_2O emission. Fertilizer management gained more importance following global warming. Manure application for pasture generating releases CH_4, but this amount is less than feed-related CO_2 and N_2O. Manure storage causes CH_4 release owing to increase temperature in stored manure. Storage temperature management, and decreasing temperature drop the gas emission by 30-50%. The origin of CO_2 in feeding production is the production of fertilizers and pesticides, feed transportation and processing, and fuel use (Grossi et al., 2019; Cheng et al., 2022).

3. CONCLUSION

Human- and livestock-caused climate change and global warming are getting more severe than estimated in a few decades. Global warming hazards food security, availability, accessibility, utilization, system stability, and water security. Livestock welfare, health, reproduction, milk and meat yield and quality, and sustainability are also at risk due to climate change. The livestock industry and climate change are directly relative, and the increase of each one negatively affects the other. Therefore, effective strategies should plan and action to reduce both global warming and heat stress's effect on livestock production.

Regional and local animal breeding strategies may improve local impacts of heat stress. Crossbreeding more heat-tolerated indigenous breeds with vulnerable and high-yielding exotic breeds may help to increase productivity. Genomic and epigenetic selections, gene banks, and embryo transfer technologies provide to select and sustain high-performance and heat-resistant animals. Adaptive cooling systems such as shades, sprinkles, evaporative ventilators, fans, and windbreaks support to decrease heat stress effects and increase reproductive performance and milk yield/quality. Feeding strategies and feed additives may help increase heat tolerance and reduce GHG emissions. Feeding at cooler times of day and cooled water access positively affect physiological signs of heat stress. Housing types, nutrition regimens, and reproductive control programs may plan as tailor-make regional conditions to improve livestock production and decrease GHG emissions.

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CHAPTER 12

THE EFFECT OF GLOBAL WARMING ON PRODUCTION AND PRODUCTS OBTAINED FROM SHEEP AND GOATS

Assist. Prof. | Hacer TÜFEKCİ[1*]
Assist. Prof. | Hilal TOZLU ÇELİK[2]

[1*] Department of Animal Science, Agricultural Faculty, Yozgat Bozok University, Yozgat, Turkey. hacer.tufekci@bozok.edu.tr, Orcid ID: 0000-0003-2272-4088

[2] Department of Food Processing, Ulubey Vocational School, Ordu University, Ordu, Turkey. hilalcelik@odu.edu.tr, Orcid ID: 0000-0002-9744-7719

1. INTRODUCTION

Sheep and goat breeding is an important area in the livestock sector with the production of meat, milk and wool and hair for other needs, which have an important place in human nutrition worldwide. In addition to meeting the need for animal protein in global food security and healthy nutrition, sheep and goat breeding has an important place for the utilization of areas that are not suitable for agricultural production and for the livelihood of low-income families, especially in rural areas. According to studies, global demand for food products is estimated to increase by 35-50% between 2012 and 2050 (FAOSTAT, 2019). Climatic variables can trigger physiological, biochemical, hematological and hormonal changes that affect the maintenance of homeotherm and affect production and productivity in sheep and goats.

2. PRODUCTION IN SHEEP AND GOATS

The quantity and quality of products obtained from sheep and goats may vary depending on genetic structure and environmental effects. Changes in environmental factors can affect the quantity and quality of products positively or negatively. As environmental factors, there are climate-related effects that cannot be controlled apart from the current applicable ones. Global warming causes the emergence of climatic effects. These climatic effects are temperature, humidity, high winds, direct and indirect solar radiation. Water resources are projected to decrease and become more variable in many regions under the impact of global warming. Animal health is expected to be negatively affected by increased temperatures and a greater number of pests and diseases. Mainly due to increases in precipitation and increased climate variability, the use of land and water resources for agricultural activities will also be used for animal production, creating competition (Harle et al., 2007). This situation is expected to affect the quantity and quality of products obtained from ovine animals. Measures should be taken to prevent the quality of sheep and goat production and products from being negatively affected by the effects of global warming. Studies should be planned by taking climatic parameters into consideration for sheep and goat breeders and the food sector that processes the products.

2.1. Milk Production and Products in Sheep and Goats

Milk from sheep and goats is important for the cheese industry. Different types of cheese, yogurt and butter are produced from the milk obtained. In recent years, organic products are more preferred. The products obtained from sheep and goats are demanded by the consumer due to the fact that sheep and goats are raised under extensive production conditions.

In sheep and goat breeding, it is becoming increasingly important to support and economize traditional breeding with production oriented towards animal welfare and product authenticity. Local products, especially those with "guaranteed and certified quality labels", may influence preferences in the near future, as competition between geographical regions is likely to be more pronounced than competition between individual farms (Napolitano et al., 2002). Worldwide average sheep milk production was 10.364.548 tons in 2018 and 10.618.551 tons in 2020 (Figure 1). According to the latest data, it can be said that production has increased slightly. However, this production is not sufficient to meet the protein requirement in human nutrition.

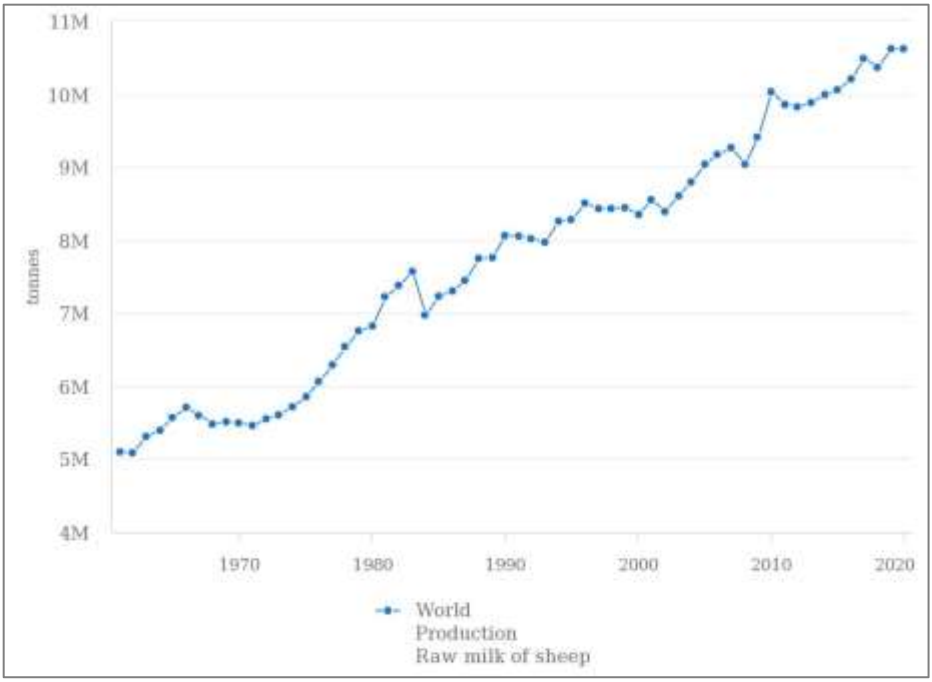

Figure 1. World sheep milk production by years (FAOSTAT, 2022a)

Figure 2 shows that cheese and butter production from goat milk has increased in recent years. Considering these data, it is seen that there has been an increase in the products obtained from goat milk in recent years. The reasons for the increase in goat milk production in the world in recent years include the increase in demand for goat milk products in many developed countries and the fact that goat milk has some advantages over other milks (Morand-Fehr et al., 2002). In addition, these products can be transformed into high value-added products in both family and professional enterprises.

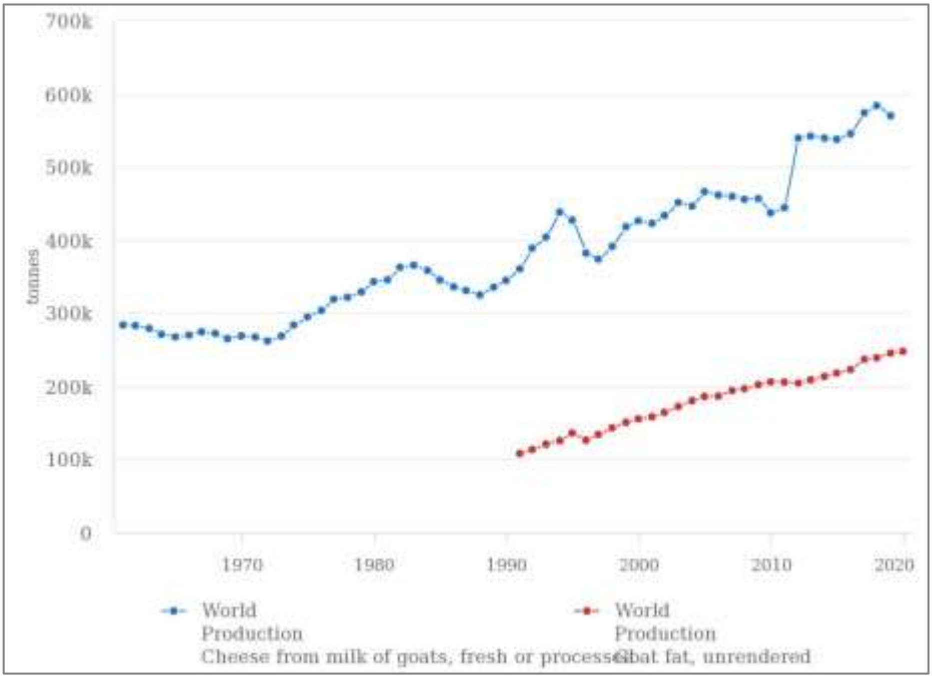

Figure 2. Cheese and butter production from goat milk by years (FAOSTAT, 2022b)

2.2. Meat Production and Products in Sheep and Goats

In addition to genetic variation among breeds worldwide, nutritional deficiencies (energy and protein intake) and early age of slaughter affect carcass productivity (Gowane et al., 2017).

Many different factors are used to define meat quality. Apart from those directly linked to the muscle (health, nutrition, sensory and technological factors), there are other components related to the image of the product, such as the welfare of the animals used for meat production. Both groups of factors can influence consumer perception and preference for meat products (Napolitano et al., 2002). Meat quality is a critical issue as it determines the acceptability and consistency of the product by consumers. Meat quality is often defined as eating quality or processing quality depending on the use (Webb et al., 2005). However, consumers' perception of meat quality is also important. Consumers generally expect meat to be nutritious, healthy, fresh, lean, tender, juicy and flavorful (Hoffman and Wiklund, 2006).

The average number of animals slaughtered for meat from sheep and goats worldwide was 1.062.522.030 heads in 2019 and 1.085.616.534 heads in 2020 (Figure 3) (FAOSTAT, 2022c).

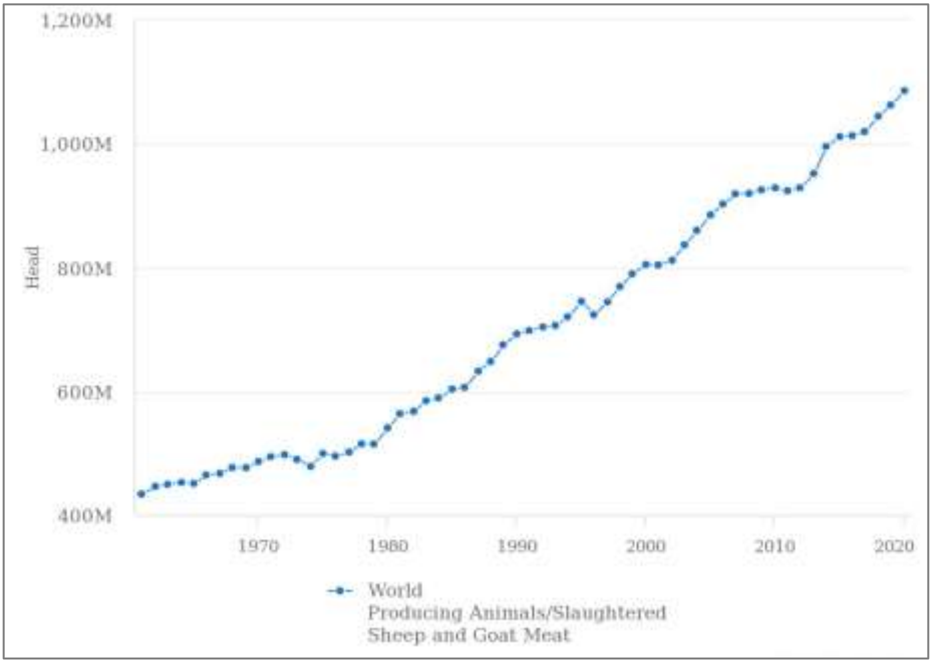

Figure 3. Number of sheep and goats slaughtered for meat production in the world by years (FAOSTAT, 2022c)

Figure 4 shows that sheep and goat meat produced in the world was 15.550.194 tons in 2019 and 16.027.615 tons in 2020. When these data are analyzed, it can be said that products obtained from ovine animals are preferred more and more every year.

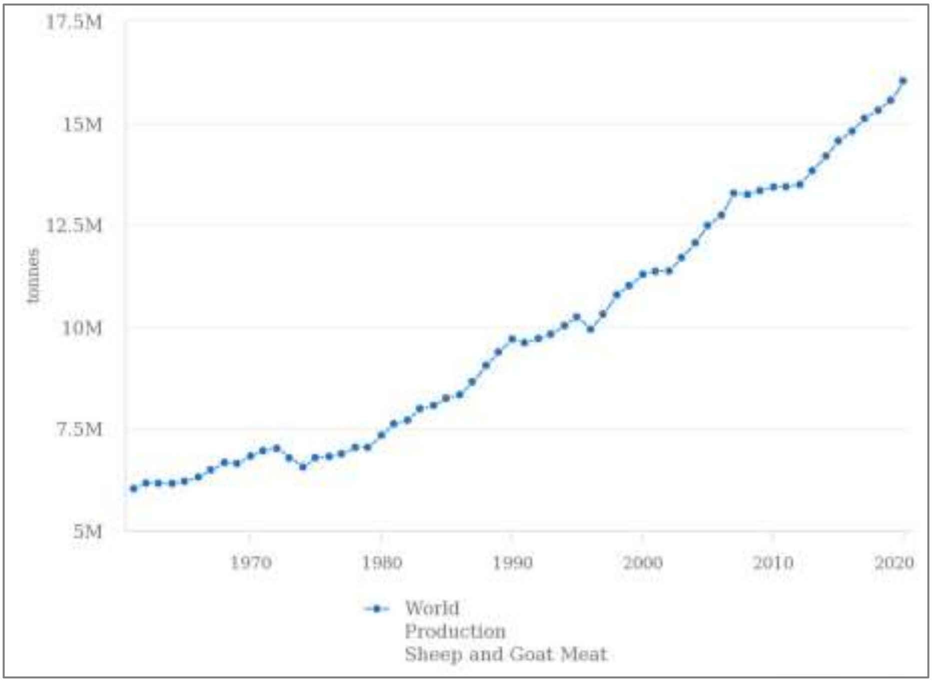

Figure 4. Amount of meat obtained from ovine animals in the world by years (FAOSTAT, 2022d)

It is stated that the meat industry needs to increase production by about 50-73% to meet the per capita demand for meat from a growing population (Bonny, 2015). Small ruminant production has an important potential to provide meat and meat products, which are essential nutrients for a balanced human diet. Sheep and goat meat is an animal protein source that has different marketing opportunities according to different geographical or cultural conditions within red meat production and consumption.

The amount of meat obtained from sheep and goats in the world by years is given in Figure 5. The amount of meat obtained from sheep in 2020 is 9.885.475 tons, while the amount of meat obtained from goat is 6.142.140 tons.

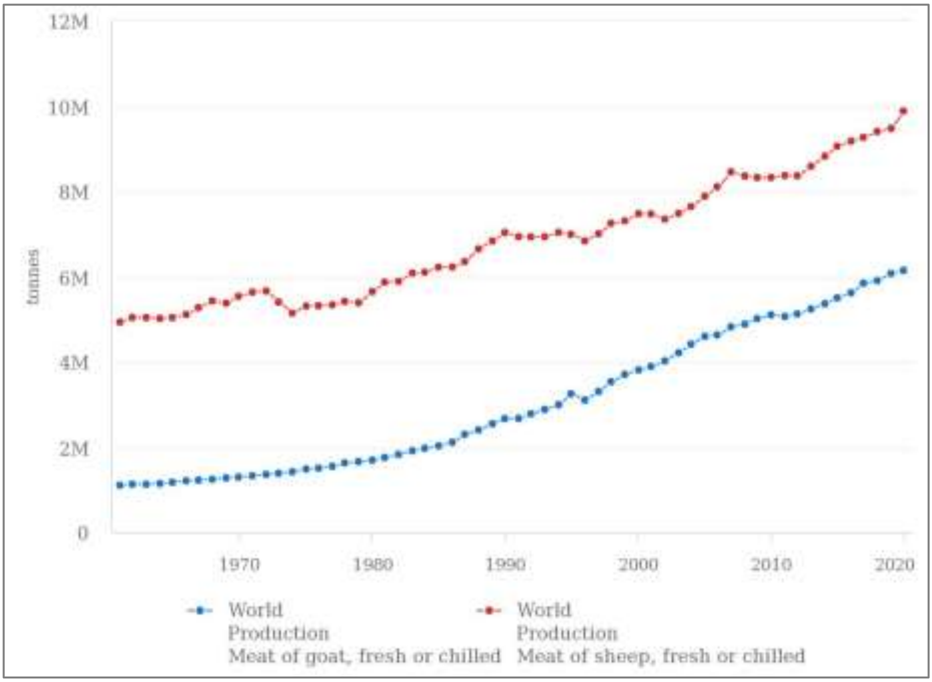

Figure 5. Amount of meat obtained from sheep and goats in the world by years (FAOSTAT, 2022e)

2.3. Wool and Hair Production and Products in Sheep and Goats

Wool is an important by-product of sheep farming, critical to the well-being of millions of people around the world. Wool has become a livelihood for farmers and a luxury fiber for people in the textile trade. The economic value of wool is primarily determined by its fiber quality. Fiber grade is a numerical representation of wool fineness based on average fiber diameter and variation. The wool produced all over the world is basically divided into three classes: fine, medium and coarse grade wool. Wool below 25 µ diameter is classified as fine wool. Fine wool has a high economic value and is suitable for clothing. Medium wool is suitable for making carpets, felts and blankets and has a fiber diameter between 25-35 µ. Coarse grade wool has a fiber diameter of more than 35 microns and has relatively less commercial value. The commercial value of wool also depends on the wool yield (weight of clean wool and oily wool). Most sheep breeds produce wool. The amount of wool obtained from sheep depends on climatic zone, breed, age, sex, diet and shearing interval. Lambs produce less, but better wool than older sheep (Atav and Buğdaycı, 2022).

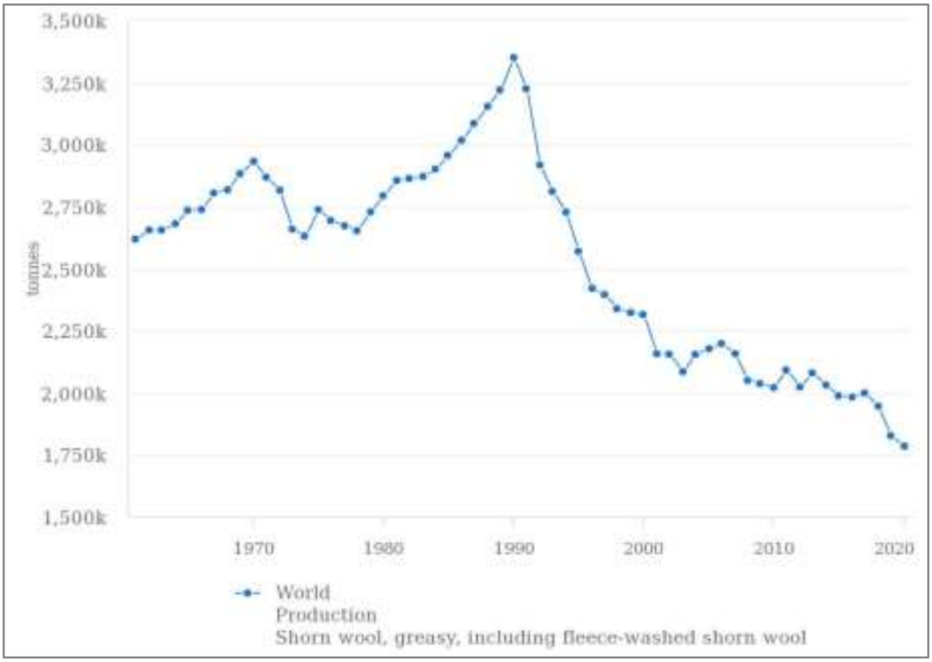

Figure 6. Total wool production in the world by years (FAOSTAT, 2022f)

Figure 6 shows that while 3.350.481 tons of wool was produced in 1990, 1.784.925 tons was produced in 2020. According to these data, wool production has decreased every year after 1990. The use of synthetic fibers in production instead of wool has reduced the production of wool. The amount of leather produced from sheep and goats for use in the leather industry is given in Figure 7. According to this data, the amount of leather obtained from sheep and goats has increased compared to previous years. In 2020, sheep leather production was 1.919.556 tons and goat leather production was 1.232.880 tons.

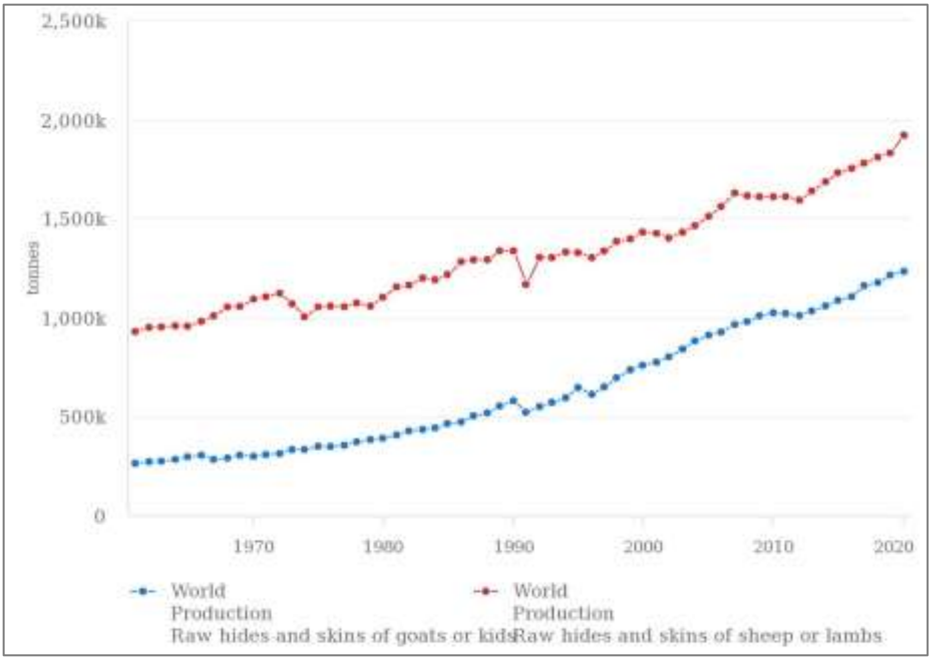

Figure 7. World sheep and goat leather production by years (FAOSTAT, 2022g)

3. STRESS FACTORS IN SHEEP AND GOATS

Stress is a factor affecting prenatal and postnatal offspring growth rate, immunity, adaptation, efficiency, behavior, and reproductive ability. Stress can negatively affect the emergence of hereditary traits (Altınçekiç and Koyuncu, 2012). Napolitano et al. (2002) reported that the stress caused by separation from the dam was more stressful than separation from the lambs in the same pen. In the same study, it was reported that plasma cortisol levels reached the highest level 10 minutes after separation ($P<0.001$) and that they produced a full adrenal response to emotional stress caused by separation from the pen, isolation, exposure to a new environment and barking (Napolitano et al., (2002). The automated collection of phenotypic measurements in livestock production is becoming increasingly important for both researchers and farmers. Real-time data collection provides the opportunity to better understand livestock behavior and physiology and improve animal management decisions. Current climate models predict that temperatures will increase worldwide, affecting both local and global agriculture. In sheep and goats, those exposed to high temperatures experience heat stress and their physiology, reproductive function and performance are compromised. Body temperature is a reliable measure of heat stress and thus a good indicator of an animal's health and welfare (Lewis Baida et al.) Different mechanisms (coat and skin color, body size, fat distribution, physiological reactions, coat type (hair/wool)) are responsible for tolerance to heat stress (Mcmanus et al., 2020).

The incidence of disease is higher in extensive breeding system and rainy season compared to other systems and seasons. Sending sheep to be grazing, especially during the rainy season, has been shown to cause more health-related problems. Higher rates of anorexia cases in extensive rearing and summer are directly related to heat stress. During heat stress, the efficiency of dry matter intake in sheep will be reduced, resulting in anorexia and anorexia (Karthik et al., 2021). Factors causing stress in sheep and goats are given in Table 1.

Table 1. Factors causing stress in sheep and goats

Stress Factor	**Source**
Hunger	Durmuş and Koluman (2020)
Thirst	Durmuş and Koluman (2020)
Bad treatment	Durmuş and Koluman (2020)
Increase or decrease of heat	Macías-Cruz et al., (2018); Kalaitsidis et al., (2021)
Noise	Durmuş and Koluman (2020)
Congestion	Durmuş and Koluman (2020)
Disease	Harle et al., (2007); Napolitano et al., (2002)
Fear	Durmuş and Koluman (2020)
Toxin intake with feed	Cao et al., (2021)
Poor shelter conditions	Durmuş and Koluman (2020)
Temperature, humidity and wind	Kalaitsidis et al., (2021)
Breeding practices	Napolitano et al., (2002)
Separation from mother	Napolitano et al., (2002)

Many physiological and biological parameters are evaluated to measure the effects of stress. These are given in Table 2.

Table 2. Parameters used to measure the effects of stress

Effect	**Source**
Respiratory rate	Fonseca et al., (2019); Maurya et al., (2019)
Pulse	Fonseca et al., (2019); Maurya et al., (2019)
Rectal temperature	Fonseca et al., (2019)
Changes in T3, T4 and Cortisol hormones	Macías-Cruz et al., (2018); Maurya et al., (2019)
Body weight loss	Durmuş and Koluman (2020)
Increase in body temperature	Fonseca et al., (2019)
Increased incidence of diseases	Karthik et al., (2021)
Decline in yield	Kalaitsidis et al., (2021)
Plasma Cortisol	Napolitano et al., (2002); Pulido-Rodríguez et al., (2021)

4. THE IMPACT OF GLOBAL WARMING ON THE PRODUCTS OBTAINED IN SHEEP AND GOAT

Changing climate conditions with global warming affect the lives of all living things. Climate change causes sudden changes in temperatures, resulting in a decrease in feed and water resources and a decrease in the species and diversity of forage plants in pastures. Sheep and goat breeding is based on grazing on pasture. Changes in feed and water resources cause stress. Stress makes it easier to catch diseases and increases the use of drugs for treatment. The use of drugs causes losses in animal production and reduces the quality of the product that can be processed (Altınçekiç and Koyuncu, 2012).

High ambient temperatures, together with relative humidity (RH), air flow and solar radiation, raise body temperature above critical levels. This causes physiological side effects in animal production (Kadim et al., 2008).

Under the influence of heat stress, animals will reduce food intake and digestive capacity and consequently nutrient absorption will be smaller. In this case, reproduction will be the first to be affected, followed by production and growth. In the later stages of heat stress, energy will only be used for vital activity (McManus et al., 2020). When sheep are exposed to high temperatures, they primarily maintain a constant metabolism and increase evaporation. It has been reported that sheep are more sensitive to cold, with heat loss affecting metabolism even at a relatively moderate air temperature of 24 °C (Fonseca et al., 2019).

Figure 8 shows that the temperature change of the world has been increasing in recent years. When evaluated by years, while the world temperature change was 0.207 in 1961, it changed to 1.713 in 2020. Considering these data, measures should be taken to ensure continuity in animal production.

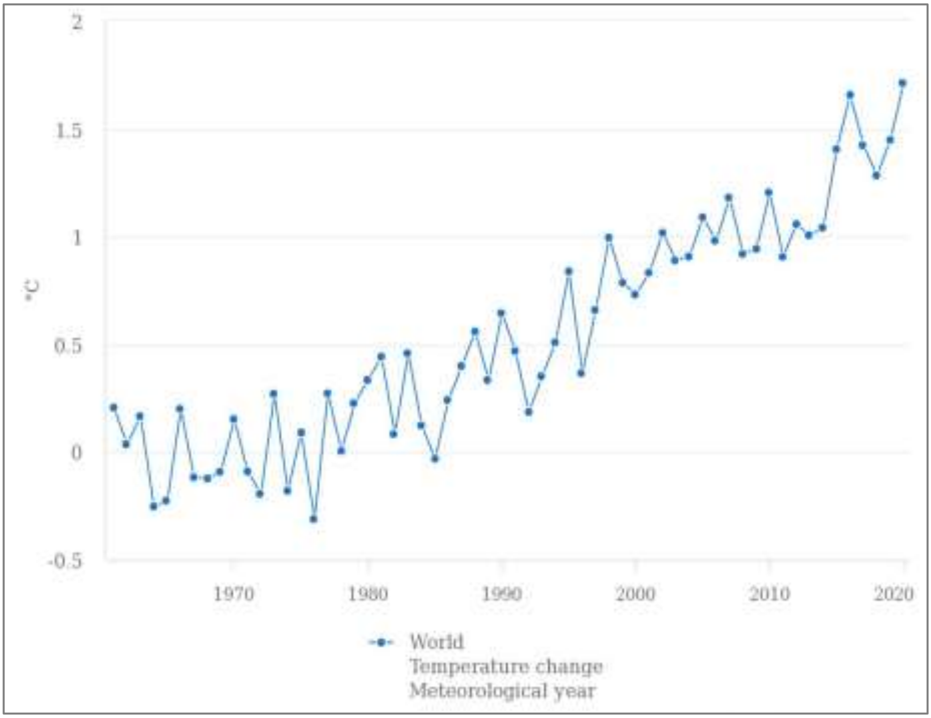

Figure 8. World temperature change by years (FAOSTAT, 2022h)

4.1. Effects of Global Warming on Milk Production and Products in Sheep and Goats

Sheep milk is of great economic importance for the cheese industry as it is a sought-after milk for cheese making.

Heat stress leads to behavioral, physiological, and biochemical changes that negatively affect the welfare and performance of sheep. Rectal temperature (RT) is considered an indicator of thermal balance and is used to assess the effects of hot conditions on sheep (Joy et al., 2022).

Lambs are less tolerant to heat stress due to immaturity of the thermoregulation center, whereas lactating ewes are less tolerant to high temperatures because they have higher metabolic rate and metabolic heat production (Macías-Cruz et al., 2018). Heat stress can affect milk yield and lipid peroxidation in dairy products in dairy ewes (Kalaitsidis et al., 2021).

Goats are considered more tolerant to heat stress compared to dairy cows due to higher sweating rate and lower body weight, surface ratio and greater heat dissipation. Dairy goats kept under heat load in the climate chamber experienced a 22-35% loss in feed intake and produced lower milk with 3-10% lower fat, protein, and lactose content. Furthermore, milk from goats under heat stress altered its coagulation properties, which could have a significant impact for the cheese industry. Blood non-esterified fatty acids and blood glucose did not change in goats under heat stress despite the reduction in feed intake. Lower insulin secretion and muscle breakdown after feed intake are possible mechanisms to maintain blood glucose levels under heat stress. In conclusion, heat stress caused significant changes in metabolic functions, gene expression, inflammatory status, and productivity of dairy goats (Salama et al., 2014).

Heat stress and mastitis are important economic problems in milk production. Changes in milk composition and mammary glands were evaluated and analyzed in dairy goats under thermal-neutral (TN; n = 4; 15 to 20°C; 40% to 45% humidity) or heat stress (n = 4; 35°C Day, 28°C night; 40% humidity) conditions. Heat stress reduced feed intake and milk yield by 28% and 21%, respectively. As a result, heat stress increased the risk of developing mastitis in the udder and decreased milk yield in dairy goats (Salama et al., 2020). It was reported that when the Temperature Humidity Index (THI) was 23, heat stress was effective in sheep and milk yield decreased, but there was no change in milk composition (Finocchiaro et al., 2005). Heat stress increased somatic cell count in milk (Peana et al., 2007a). All meteorological factors analyzed significantly affected milk yield in Sarda dairy ewes except wind speed. Milk yield was more affected by minimum air temperatures than other meteorological parameters. Increases in minimum temperatures from the optimal range of 9-12 °C to 27-30 °C resulted in an average 36% decrease in milk yield (0.35 kg/day per animal). At maximum air temperatures ranging from 24 to 30 °C and average temperatures ranging from 15 to 18 °C, gradual decreases in milk yields of up to 20% (about 0.22 kg/day per animal) were found at higher temperatures. The optimum air relative humidity for milk production is between 65% and 75% according to values reported in the literature. Rainfall negatively affected milk yields, probably because it disrupted grazing, with decreases of up to 23% (0.20 kg/day per head) under cumulative rainfall conditions of 6 mm over two days. Milk production was also affected by the Temperature Humidity Index (THI) with a decrease of 25% (0.23 kg/day per capita) as the THI increased from 60-65 to 72-75. Wind affected milk yield only when associated with other meteorological factors (Peana et al. 2007b).

Kalaitsidis et al. (2021) examined the changes in milk yield and composition of milk products in ewes exposed to heat stress. According to this study, it was reported that Cornus extracts added to the feed alone or in combination with thyme supported the composition of milk and dairy products and sheep milk production in ewes under heat stress. Feed supplementation with Cornus extracts and essential oils reduced lipid and protein oxidation in milk, yogurt and cheese samples compared to control (Kalaitsidis et al., 2021).

Dairy goats showed a 22-35% decrease in feed intake and a 3-10% decrease in milk composition (fat, protein, and lactose) and milk yield under heat stress. In addition, the coagulation rate, which is important in cheese production, decreased (Salama et al., 2014).

4.2. Effects of Global Warming on Meat Production and Products in Sheep and Goats

Factors such as high and low temperatures, standing in the sun, etc. cause stress in animals. In case of stress, pulse and respiration rate increase, body temperature, blood pH and blood pressure change. Under normal conditions, the body's protection system works, but in case of stress, this system becomes ineffective and metabolic changes occur.

Sheep and goats, which are primarily fed on pasture-based grazing, are prone to the effects of climate change. The impact of climate change is reflected in changes in the availability of feed and feed resources for sheep. Low energy and protein sources have a negative impact on slaughter weight and carcass weight. Meat yield may be due to genetic differences between breeds, but energy and protein deficiency and early slaughter age are the main factors limiting carcass yield (Gowane et al., 2017).

Meat quality was evaluated in goats slaughtered in cool season (mean temperature 21 C and 59% RH) and warm season (mean temperature 35 C and 47% RH). Higher ambient temperatures caused an increase in muscle pH. Myofibrillar fragmentation index was significantly ($P < 0.05$) higher for warm season samples (86.88%) than for cold season samples (85.59%). Meat color (L* (37.6 vs. 39.6), a* (20.0 vs. 23.3) and b* (3.6 vs. 23.3)) was significantly ($P < 0.05$) darker in goat meat slaughtered in the warm season than in the cold season. These results suggest that seasonal high temperatures (>35 C) may affect muscle glycogen levels and subsequently final pH, resulting in deterioration of meat quality characteristics (Kadim et al., 2008).

Temperature stress also had a significant ($P<0.05$) effect on the pH of meat from different groups of Black Bengal goats. Cooking loss in meat increased significantly ($P<0.01$) with increasing temperature. Cooking loss, pH and by-products were significantly affected in temperature stressed goats compared to the non-temperature stressed group. Temperature stress limited the qualitative and quantitative production characteristics of goat meat (Hashem et al., 2013).

Kadim et al. (2008) concluded that pH above 6.0 was associated with dark meat color. In addition, pH above 6 may favor bacterial spoilage in meat. Temperature stress, an important factor in climate change, can affect meat safety as well as organoleptic quality.

Feed stores should be planned according to climatic changes. The most important reason for this is that molds ingested with feed cause stress in sheep. Especially aflatoxin B1 (AFB1) is a common and highly toxic mycotoxin. Molds have a great impact on animal production and human health in the world. One study found that changes in sheep meat quality caused by AFB1 exposure were associated with oxidative stress, inflammation and intestinal microflora changes. After exposure to AFB1, body temperature increased slightly, the mental state of the sheep was suppressed, and biochemical indicators changed significantly. AFB1 is reported to cause deterioration in sheep meat quality, increased muscle drip loss and changes in the structure of muscle fibers (Cao et al., 2021). Therefore, care should be taken to ensure that the feeds to be given to sheep are kept under appropriate storage conditions.

In addition to the effect of climate change, meat obtained from lambs raised separately from their mothers showed lower saturated fatty acid content ($P<0.001$) and higher unsaturated fatty acid content ($P<0.001$) (Napolitano et al., (2002). All effects of stress affect vital activities in animals and are also seen in the products obtained from animals.

4. 3. The Effect of Global Warming on Wool and Hair Products in Sheep and Goats

In addition to sheep breeding, wool production is also affected by climate change. In developing countries and the least developed regions of the world, limited resources and deeper groundwater withdrawal make the effects of climate change more pronounced.

It is known that obtaining wool from sheep as a primary product alone cannot be profitable, so changing sheep breeding systems with renewed goals and priorities is the need of the day. Changes in rainfall can adversely affect feed quantity and quality. This can lead to malnutrition of sheep. In addition, temperature changes due to climate change may adversely affect sheep health with increased pest and disease agents. All these factors will have an impact on wool quality, wool yield and ultimately on the wool industry and its stakeholders (Gowane et al., 2017).

Wool yield will depend on climate and pasture variables for specific regions. Wool production is a function of pasture capacity and animal genetics. The ability of lambs to produce wool depends on secondary follicle formation, which depends on feed intake during the gestation period of the ewe. Low feed intake can cause follicle deterioration in lambs (Harle et al., 2007). Heat loss through the skin was reduced and respiratory rate increased when sheep were exposed to heat stress (Pulido-Rodríguez, 2021).

By 2030, climate change is expected to have impacts on the Australian wool industry, mainly through impacts on feed and water resources, land carrying capacity and sustainability, animal health and competition with other sectors, particularly crops. These impacts are driven by changes in the growth and quality of pasture and forage crops, changes in rainfall amounts and variability, as well as higher CO_2 concentrations. The impact of these climatic changes is likely to have an impact on both wool production and quality, with changes in average fiber diameter and fiber strength. Early adaptation, especially through more sustainable management of rangelands and better management of climate change impacts, can significantly reduce the negative aspects of climate change impacts (Harle et al., 2007).

Fiber diameter, nozzle length, nozzle strength and kemp hair amount are some of the important characteristics that determine the performance of the wool during the processing stages. All these important traits are likely to be affected by climate change. Increases in temperature and decreases in rainfall can lead to thicker fiber diameter and lower quality. With climatic variability, it is difficult to produce and maintain good quality wool for clothing, while coarse quality wool is more resilient to climate change. Soft wool is obtained from wool with a fine fiber diameter that can provide a good income. Adequate capacity of pastures, one of the food sources of sheep, will affect wool yield and quality. Vegetable matter, dirt and dust in raw wool is another feature that will be affected by climate change. In regions with high rainfall, there will probably be a high content of vegetable matter in the wool. In areas with low rainfall, there may be a high accumulation of dirt and dust in the wool. In both cases, the energy cost for cleaning the wool will increase (Harle et al., 2007).

Wool is a healthy clothing raw material for humans. In recent years, increasing synthetic fabrics affect the preferability of wool by fabric manufacturers. However, the use of natural wool in human clothing is very important considering the negative effects of synthetics. In this respect, it is necessary to ensure the continuity of wool production by considering the climate effects.

5. CONCLUSION

In the future, it is expected that the increase in temperature under the effect of global warming will negatively affect the yields obtained from animals. In this respect, it is recommended to select animals with high genetic tolerance to temperature stress (Finocchiaro et al., 2005).

Ensuring the continuity of yield and product quality in sheep and goats also affects the supply of human food resources. For this reason, it is necessary to determine the effects of global warming on ovine breeding and to take measures in this direction.

Mitigating the stresses arising from the effects of climate change on the production of meat, milk quality and other products worldwide and on the number and yield of sheep and goats requires further studies. Sheep and goats are the animals of the future, given their widespread availability, diversity, and ability to adapt to the most challenging climates around the world. Breeding, nutrition, health, and technological interventions are parameters that need to be addressed in mitigating the impacts of climate change. In order to obtain optimum yield from sheep and goats and for the safety and durability of the products obtained, animals should be protected from extreme stress factors.

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CHAPTER 13

GLOBAL CLIMATE CHANGE AND REFLECTIONS ON MEAT CONSUMPTION: THE CASE OF CULTURED MEAT

Asst. Prof. | Tuba ALBAYRAK[1]

[1] Yozgat Bozok University, Faculty of Agriculture, Department of Agricultural Economics, Yozgat, Türkiye. E-mail: tuba.albayrak@bozok.edu.tr, ORCID ID: 0000-0002-3745-8352

INTRODUCTION

In recent years climate change is one of the most important global problems and its impact is increasing gradually. Unnatural changes in the climate affect sustainability significantly by causing various environmental, social and economic problems. Agriculture sector is one of the sectors most affected by climate change. (Hayaloglu, 2018; Tiberius et al., 2019)

The world, which is approximately 4.5 billion years old, has experienced changes in its natural balance for various reasons. The changes have emerged with the deterioration of the interactions between the sun, atmosphere and earth. These changes emerged with natural factors until the 19th century. Along with natural factors, human has also started to cause these changes in the 19th century (Türkeş et al., 2000). Especially at the beginning of the climate changes occurring in the world, increasing air temperatures draw attention. It is estimated that this increase in air temperature will cause severe global climate change (Vurarak and Bilgili, 2015; Baş et al., 2021). Climate change is related to global warming, the rise of sea level, displacement of climate zones, more frequent occurrence of severe weather events, high-water and floods and the intensification of their effects, drought, erosion, desertification, epidemic diseases, agricultural pests, deterioration of natural balance together with wildlife species. It is estimated that the decline in human health will lead to important results by directly or indirectly affecting socio-economic sectors and ecological systems (Anonymous, 2001; Anonymous 2002; Bozoğlu et al., 2019).

In short, global warming affects the world and all sectors are affected by global warming. However, it is clearly seen that the effects of global warming on the agricultural industry are more than other sectors (Tıraşçı and Erdoğan, 2021; Tuomisto, 2021). Since agricultural production is mainly dependent on natural conditions, it is thought that changing climate and soil characteristics will cause changes in the yield and quality of farm products. Agriculture is a sector of great economic importance with its contribution to population and employment, national income, social nutrition and foreign trade. Therefore, it is clear that this sector will experience significant economic and social losses due to global warming (Yalçın and Kara, 2014; Choudhury et al., 2020).

Global warming has become a scientific and political issue that has recently caused long debates on the world’s agenda. Global warming in the world and our country causes many effects such as the change of rain regime and amount, seasonal temperature increases, problems in photosynthesis and fertilization in plants, water shortages, exposure of plants to abiotic stress conditions, and infertility of agricultural soils. Agricultural activities are also increasing in order to meet the food needs of the increasing world population. It is thought that as a result of this, difficulties will be experienced in agriculture, and therefore, there will be decreases in product yield and quality (Thinktech, 2021; Datar and Betti, 2010). The rapidly increasing world population and changing consumer habits have led scientists to search for edible food alternatives and alternative protein sources (Verbeke et al., 2015a; Verbeke et al., 2015b). Genetically modified organisms, insects, seaweeds, and in vitro meat or also named cultured meat are considered important alternative protein sources. In recent years, research on cultured meat has gained importance (Çakaloğlu Ebcim et al., 2021)

The aim of this book chapter was reviewing previous studies about cultured meat, which has been on the agenda recently. This chapter discusses the emergence of cultured meat production, the historical development and current situation of cultured meat, its development process, production methods and possible problems that may arise in the future and also evaluates the place and importance of cultured meat in halal certification, the studies of societies with different food cultures about cultured meat and as well as the technical and socio-cultural dimensions of the process (Fiala, 2008; Farhoomand et al., 2022).

1. GLOBAL WARMING REFLECTIONS ON FOOD SECURITY

The importance of sustainable solutions to the problems brought on by the increasing world population, such as global hunger, malnutrition and food security in the food industry, is increasing dayly (Van Der Weele and Tramper, 2014; Aydin, 2021). The concept of sustainability, which is defined as "to maintain the ability of future generations to have the same opportunities in this regard while continuing to live by using today's resources", first entered our lives with the report named "Our Common Future" presented to the United Nations General Assembly in 1987 (Anonymous, 1987).

When the concept of sustainability is considered within the framework of food, and agricultural production, are of strategic importance in order to provide nutrition, which is the most basic need of human beings. Many factors, such as adequate food supply, production of safe foods, and equal sharing of produced food, are related to food security and safety. FAO determines practical action recommendations for low-carbon livestock farming (Muslu, 2021; FAO, 2017).

As a result of the greenhouse effect caused by the gases given to the atmosphere by mankind, the increase in temperature on the earth's surface is called global warming. (Köknaroğlu and Akünal, 2010). According to the research, it has been determined that 360 million tons of methane and 10-17.5 million tons of nitrous oxide gases are released into the atmosphere annually as a result of human activities (Türkeş et al., 2000). Methane and nitrous oxide, which are greenhouse gases formed from human activities, respectively; 50% and 70% originate from agriculture. However, agricultural activities constitute 5% of the carbon dioxide emitted by humans (Yalçın and Kara 2014).

Animal husbandry, which has an important place in the world's activities, constitutes 18% of greenhouse gas emissions in terms of carbon dioxide equivalent and also 9% of carbon dioxide emissions. 37% of methane and 65% of nitrous monoxide emitted by human activities come from the livestock sector (Vurarak and Bilgili, 2015).

Table 1. FAO's five practical action recommendations for low-carbon livestock farming

1	To increase the efficiency of livestock production and resource use
2	Intensifying recycling efforts and minimizing losses for a circular bio-economy
3	Leveraging nature-based solutions for increase carbon offsets
4	Strive for healthy, sustainable diets and take protein alternatives into account
5	Developing policy measures to promote change.

Source: FAO 2022

Moreover, sustainable new protein sources, plants, insects and cultured meat, which have environmentally friendly production conditions and high nutritional values, come to the fore (Van der Spiegel et al., 2013).

2. ANIMAL PRODUCTION IN TURKEY

TUIK (2022) reported that red meat production has increased over the years. Accordingly, red meat production, which was 1 million 785 thousand 952 tons in 2020, was estimated to be 1 million 952 thousand 38 tons in 2021, with an increase of 9.3%. In this context, beef production increased by 8.9% compared to the previous year to 1 million 460 thousand 719 tons. On the other hand, sheep meat production increased by 11.7% to 385 thousand 933 tons, goat meat production increased by 4.5% to 94 thousand 555 tons, buffalo meat production on the other hand, increased by 28.6% and became 10 thousand 831 tons.

Table 2. Meat Production Amount in the Last 5 Years in Türkiye

	2017	2018	2019	2020	2021
Cattle	1 093 841	1 281 234	1 330 169	1 341 446	1 460 719
Buffalo	5 868	6 515	7 150	8 424	10 831
Sheep	262 825	291 179	316 170	345 639	385 933
Goat	77 794	82 839	87 126	90 443	94 555

Source: TUIK, 2021

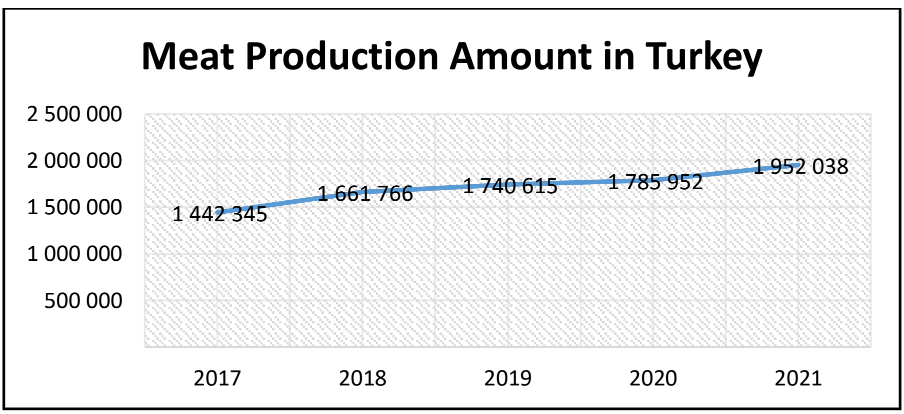

Figure 1. Total Meat Consumption Amount in the Last 5 Years in Turkey Last 5 Years (TUIK, 2021)

However, with this increase in red meat production, sufficient animal protein sources cannot be provided for population growth. According to the data for 2021, the current population of Turkey is 85 million. If we want a healthy society that receives daily animal protein, researchers and also the food industry need to review alternative protein sources.

3. NOVEL FOODS IN AGRICULTURE

It is expected that the world population will reach 10 billion by 2050 and in parallel with this increase population which the current food sector will double producing (Demirci, 2021; FAO, 2022). In parallel, the consumption of meat, which is one of the main sources of animal proteins, is expected to reach an average of 49 kg/person in 2050 and it is calculated that this corresponds to an increase of 40% when compared to the current production (Candoğan and Özdemir, 2021).

Agricultural lands that have been rendered unusable and contaminated water sources made it difficult to feed cattle, sheep, and poultry. Unfortunately, it has led to thereby to produce not a sufficient amount of animal-based proteins (Karapınar et al, 2020). Moreover, cattle cause carbon dioxide and methane emissions and this triggers global warming is evident. This verity has led academic and industry circles to find alternative protein sources. Cultured meat, microbial and insect proteins have gained interest in the novel food industry and can potentially be an alternative to the proteins obtained from meat and meat products. Especially insect consumption is a traditional food in some Asian, African and South American countries with as many as 2000 different insects. Most insects consumed are beetles, butterflies and caterpillars, crickets, grasshoppers, bees, ants, etc. Insect production on the farm, which is shown as a remedy for food shortage by FAO, is carried out in Asian and African countries. The most significant disadvantage of edible insect production their acceptance is difficult due to the factor/of disgust for regular consumers (Ekici et al, 2022). Additionally, by edible insect there are many biological and chemical health problems, especially allergies, which occur with the consumption of their proteins. People generally avoid insect consumption due to health, religious and ethical concerns (Yetim and Tekiner, 2020).

The most consumed insect species; Beetles including mealworms 31% (Coleoptera), butterflies and moths 18% (Lepidoptera), bees and ants 14% (Hymenoptera), grasshoppers and crickets 13% (Orthoptera), leafhoppers 10% (Hemiptera), termites 3% (Isoptera), dragonflies 3% (Odonata), flies 2% (Diptera) (FAO, 2013).

Figure 2. The most consumed insect species

Plant-based protein is a group of Sustainable Protein Sources. Plant foods have lower greenhouse gas emissions than animal foods, require fewer resources for production and are less harmful to the environment. Still, they cause a decrease in the productivity of the soil and adverse effects on the environment daily due to intensive agriculture with synthetic fertilizers and pesticides (Koyuncu and Akgün, 2018).

4. WHAT IS ACTUALLY CULTURED MEAT?

Sustainable food is defined as protective and sensitive to biodiversity and ecosystems, culturally acceptable, accessible, affordable, nutritionally adequate, safe, and healthy (FAO, 2022).

Cultured meat is one of the alternatives that emerged to prevent the negative environmental effects of traditional meat production. It is the production of cultured meat, also called “in vitro meat”, “artificial meat” or “clean meat”, “lab-grown”, “synthetic meat” produced from animal stem cells in a culture medium by cellular farming methods without slaughtering animals (Hocquette, 2015; Hocquette 2016).

Meat produced under laboratory conditions - the first meatball made of cultured meat (in vitro meat), which is claimed as a humane, safe and environmentally beneficial alternative food, was presented to the public in a restaurant in Singapore with the first legal approval by the Singapore Food Authority (Bhat et al., 2015; Bonny et al., 2015; Joshi and Kumar 2015; Kumar et al., 2017).

Tuomisto (2021) reported that under certain production conditions, artificial meat couldreduce energy consumption and land use by 99%, water use by 90% and energy consumption by 40% compared to conventional meat production. Artificial meats are in two different categories. The first is cultured meat or in vitro meat obtained from tissues and cells produced in a live laboratory environment. The second is artificial (synthetic) meat produced from genetically modified organisms or obtained by cloning (Bonny et al., 2015).

Stem cells are painlessly taken from a living animal by biopsy and placed in a bioreactor that provides the necessary nutrients and energy to reproduce. These cells turn into muscle and adipose tissue. Then, after processes such as colouring and adding spices, the final meat is created, so that edible meat is produced without slaughtering animals (Tuomisto, 2021). There are still uncertainties about the stem cells used in the cultured meat production process, the bioreactor design, and the best method for the procedure. Despite similarities with traditional red meat production, consumer acceptance of cultured meats is debatable, as animals whose genomes have been artificially modified in the laboratory are considered artificial or manufactured (Iyer et al., 2020).

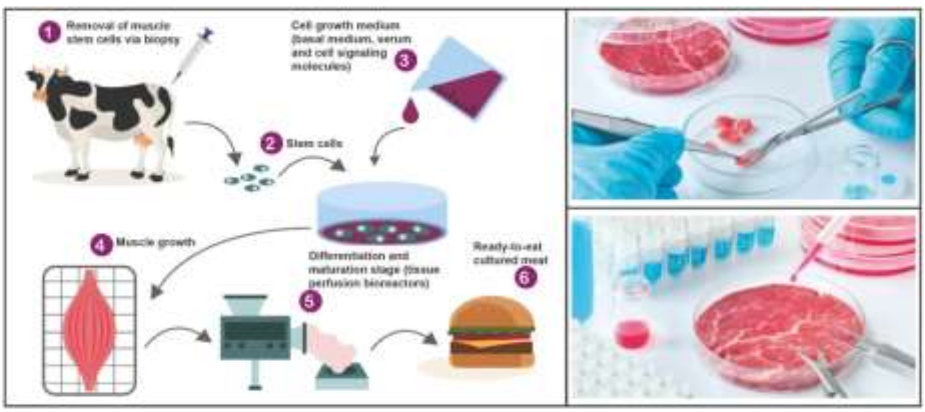

Figure 3. The production process of cultured meat (Modified from Anonymous source)

Looking at the historical development of cultured meat technologies, the table below can help us.

Table 3. Cultured meat technologies at the historical development process

In the1930s	The idea of cultured meat as an alternative to traditional meat was first conceived by Frederick Edwin Smith and Winston Churchill
1943	Rene Barjavel included cultured meat production in restaurants in his novel “Ravage”
In the 1950s	Willem van Eelen's came up with a new idea for using tissue culture for the production of meat products
1999	Patented tissue culture and stem cell concept by Willem van Eelen
2002	Acquisition and development of muscle biopsies from frog by SymbioticA*
2002	Development of muscle tissue from goldfish
2013	Production of the world's first *in vitro meat*-based burger by Dr. Mark Post
nowadays	Researching and developing process continues in the pioneer countries such as USA, Netherlands and Israel

Source: Arslan, 2022

* SymbioticA is an artistic research laboratory at the University of Western Australia's School of Anatomy and Human Biology.

4.1. Advantages and Disadvantages of Cultured Meat

4.1.1. Advantages of cultured meat

The study by Yetim and Tekiner (2020) reported that Environmentalists, in particular, strongly criticize the negative environmental effects of the livestock sector. Among the main criticisms, are greenhouse gas emissions 15%, excessive use of water and electric energy (20%), occupation of arable land (30%), adverse effects on biodiversity and living species (15%), environmental waste and pollution, zoonotic diseases, consumption of energy consumed in the world There are issues such as being responsible for 70% of the number of antibiotics and their role in the spread of antibiotic-resistant microorganisms (Tekiner et al., 2018).

Figure 4. The cultured meat

Moreover, it is seen as an advantage to meet the protein requirement of the ever-increasing population in a healthy and adequate way. It is seen as an advantage in terms of preventing land and forest destruction. There were many studies on the advantages. (Van Eenennaam, 2017; Gaydhane et al., 2018; Siegrist and Sütterlin, 2017; Sun et al., 2015).

- **Its design is healthy;** the culture medium, fatty acid, and nutrient composition can be changed to make cultured meat healthy. For example, replacing harmful fats with healthy fats such as omega-3 can prevent cardiovascular disease.
- **Fast production;** the culturing of cultured meat takes only a few weeks.
- **Reduction in resource use, environmentally friendly;** cultured meat production can reduce greenhouse gas emissions, energy use, and land and water use.
- **Availability of exotic meat;** since animal stem cells are needed for cultured meat production, cells from endangered animals or even extinct animal cell samples can be used to produce exotic meat.
- **Vegan meat;** People who are vegetarian due to moral and health problems can eat cultured meat, as it can be produced without killing animals.
-

4.1.2. Disadvantages of cultured meat

The first cell-based beef hamburger was created at a cost of USD 375 000 in 2013, and the first cell-based chicken nugget was for USD 50 in 2019 (Weinrich et al., 2020). Cell-based food products are also referred to as "cultured" or "cultivated" followed by the name of the commodity, such as meat, chicken or fish while the process can also be called “cellular agriculture”. Given the various terminology in use for this technology, internationally harmonized terms for the food products and production processes would facilitate understanding at global level (2020; Kılıç Ekici, 2011; Koyuncu and Akgün, 2018). Cell-based food production involves culturing cells isolated from animals followed by processing to produce food products that are comparable to the corresponding animal versions, such as meat, poultry, aquatic products, daily products and eggs (Lynch and Pierrehumbert, 2019; Muslu, 2021; Muslu, 2022; URL 1).

- **Control of the production process;** traditional meat contains anatomically diverse muscles, and in this context, regenerating muscle fibres with stem cells or muscle cells requires great care.
- **Obesity problem;** if produced meat proves to be cheaper and easier to mass-produce than conventional meat, some researchers think it could encourage overconsumption and increase obesity-related issues.
- **Commune problems;** It is considered to be a potential threat to livelihoods.
- **Environmental problems**; There are assumptions that the ecological balance may be disturbed.
- **Ethical Concerns;** Although the preference of serum obtained from animals in cell culture studies is a personal choice according to the choice of nutrition during consumption, the possibility of harming more animals with mass production in obtaining the serum (Aydin, 2021).

5. CONCLUSIONS

With the global climate crisis, cultured meat has been on the agenda intensively for the last few years in our country. The studies carried out in this chapter on cultured meat, which is predicted to enter our lives up to 10-15 years, are discussed in terms of the agricultural sector. In particular, it causes the emergence of different opinions in the public. Cultured meat; Due to commercial concerns, alternative food offers different views as an alternative agricultural product in the global crisis. Although it has come to the fore more with global warming today, studies on cultured meat date back to ancient times. With global warming, people's search for solutions to famine has made cultured meat a global issue. Agricultural economists have many studies on red meat. However, the literature on cultured meat and nature meat preferences on a global scale is very limited. Especially it causes the emergence of different opinions in the public. There are different views on many food products due to the spiritual values of Turkey. It is known that products with ethical and certificates, such as halal certified, halal slaughter are preferred. For this reason, it has emerged that it is important to deal with the issues in the consumer dimension.

The following is recommended in this chapter:

- It is important to reduce the cost of cultured meat in order to meet global needs.
- Halal certification should be provided in cultured meat as well as in red meat.
- It should not cause a decrease in agricultural livestock production.
- It needs to be proven in effective subjects such as sustainable agriculture, environmental protection, meeting consumer needs.
- It is important to determine the perceptions, reservations, positive or negative opinions of consumers against cultured meat. The perception of countries with different rules of food culture, especially Muslim countries, should be determined.

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CHAPTER14

IN GLOBAL WARMING AND AGRICULTURE CARBON FOOTPRINT

Lecturer | Selen ALNIAK SEZER [1*]

[1*] Yozgat Bozok Üniversitesi, Yozgat Meslek Yüksekokulu, Makine ve Metal Teknolojileri Bölümü, Yozgat, Türkiye, selen.alniak@bozok.edu.tr, ORCID ID:0000-0003-2832-4085

INTRODUCTION

The increasing world population, distorted urbanization, pesticides used to increase yield, unconscious fertilization, and polluted air, water, and soil by the chemicals used gradually, pollute the environment putting the life activities of living things at risk (MacCracken, 2001). Poverty, drought, destruction of biodiversity, global warming, climate change, deterioration of flora, and soil, and thinning of the ozone layer are the main problems encountered. These problems take time to arise but develop in a historical process.

From the moment people began to spread across continents to survive, the Interglacial Period (1.8 million-750 thousand years) and the Würm Glacier (10 thousand years to the present day)) and the ice ages saw overheating and overcooling on the earth with movements such as tectonics and volcanism, with the earth's rotation on the sun. Accordingly, many plant and animal species became extinct, while new taxa began to form (Galip, Başak, and Gültekin, 2004; Klein, Edgar, and Saltuk, 2003).

Figure 1. Earth glacial level (Anonim2022a)

18th century; with the developments in Europe, it has become one of the most important centuries. Humankind, who was skilled in using tools during the age of enlightenment; discovered how fossil fuels could be converted into labor through the invention of the steam engine. In this period called the industrial revolution, in addition to people's search for new resources (fossil fuels), industrial enterprises were established in various parts of the world.

Climates were beginning to change. Temperature increases, which seem to be small, have started to be felt in countries since there is an average increase. Winters were frigid and summers were arid and hot. The threat of global warming was first mentioned in 1896 by the Nobel Prize-winning chemist Svante August Arrhenius in his 'Report on Climate Change and Its Risks'. In his paper, Arrhenius claims that as the amount of CO_2 in the atmosphere increases, the surface temperature will increase, ultimately affecting the ice age, and leading to climate change (Anonim2022b; Appenzerler and Dimick, 2004; Ersoy, 2006).

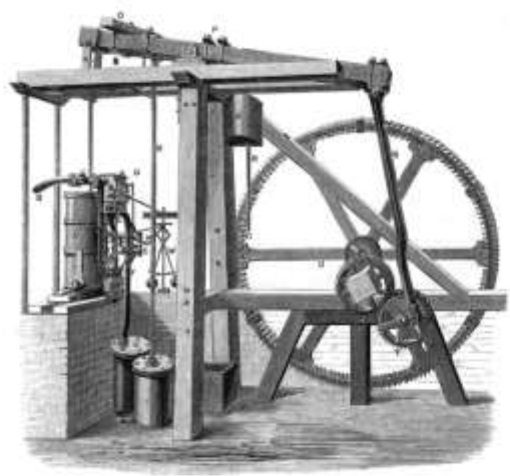

Figure 2. The steam engine was the starting power of the Industrial Revolution

After the 1960s, in addition to natural causes, the idea that humans and their various activities may have effects on the climate system comes to mind (Mitscherlich, 1995).

The research was supported by Arrhenius' report and it was determined and documented that climate change is related to the multiplicity of greenhouse gases. Countries such as the USA and Canada have observed the increase in greenhouse gases with their measurements every year and have predicted that the temperature increases in the 21st century will increase day by day (Anonim, 2022c).

In the late 80s, in order to reduce the negative impact and pressure on the climate system, in 1992, in Rio De Janeiro on an international scale; United Nations Conference on Environment and Development was held. In this conference, which consisted of five main topics, remarkable decisions on climate change were taken, and the United Nations Framework Convention on Climate Change (UNFCCC) was signed (Alada et al., 1993).

Rio summit; was followed by the Kyoto Protocol (KP) in 1997 and the Paris Climate Agreement (PA) in 2015. The Paris Climate Agreement has been the most important international agreement to date, surpassing the Kyoto Protocol and the UNFCCC to combat climate change (Pınarcıoğlu, 2018).

According to the UNFCCC, KP, and PA, while legal arrangements are being made to limit the greenhouse gas emissions emitted by people, it has also become increasingly active in international emissions trading, technology, and capital movements (Anonim, 2022d).

1. GLOBAL WARMING and GREENHOUSE GASES

Global warming has become an important topic that we often hear about recently, which has caused research and controversy.

99% of air we breathe consists of nitrogen (78.08%) and oxygen (20.95%) molecules. Approximately 1% is argon (0.93%) and carbon dioxide (CO_2, 0.0377%), which is a minimal but important greenhouse gas. The most important natural greenhouse gases are water vapor (H_2O) and CO_2, which have the largest share, methane (CH_4), diazo monoxide-nitrogen oxide (N_2O), and ozone (O_3), hydro-fluoro-carbons (HFCs), perfluoro-carbons, (PFCs), sulfur hexafluoride (SF_6), etc (Dellal, 2008).

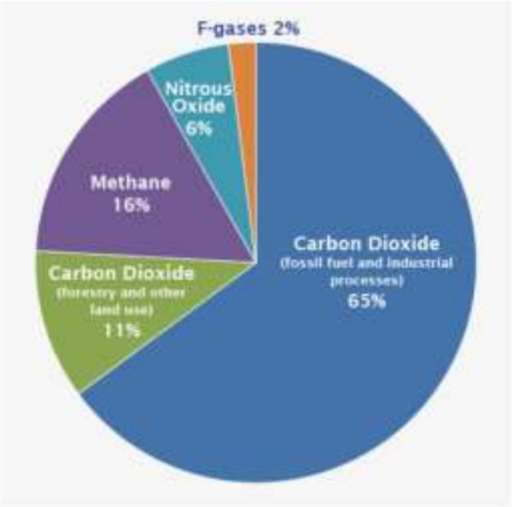

Figure 3. Shares of Greenhouse Gases in Global Warming(Change, 2014)

With the increase in the concentrations of these greenhouse gases in the atmosphere, the molecules compress the sun's rays and cause the temperature to increase. The effect of greenhouse gases on the emergence of temperature and climate on Earth is significant (Türkeş, 2003).

Greenhouse gases keep some of the rays from the sun to the earth and reflected, ensuring that living things remain at the temperature at which they can survive. This atmosphere heating and insulating effect are called the "Greenhouse effect." In the absence of greenhouse gases in the atmosphere, it has been calculated that the temperature of the Earth will be 30ºC cooler than it is now (Türkeş et al., 2000).

Although greenhouse gases contribute little to the earth's atmosphere, they play an important role in maintaining the atmospheric temperature of flora, fauna, and the ecosystem formed by humans.

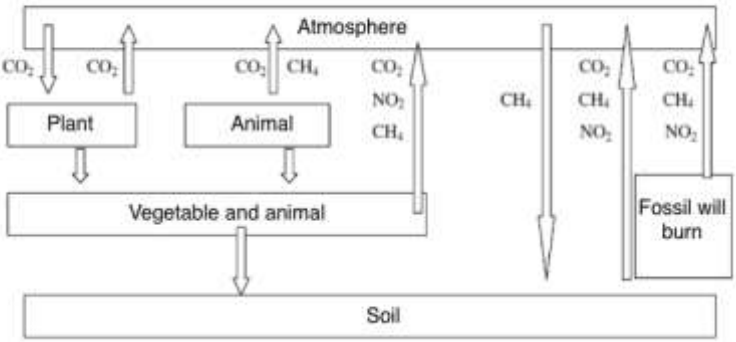

Figure 4. Greenhouse gas sources (Köknaroğlu & Akünal, 2010)

Greenhouse gases, precipitation, humidity, and weather movements with the increase in temperature create different weather conditions. Therefore, the humanity was faced with the danger of "global climate change" (Doğan, 2005).

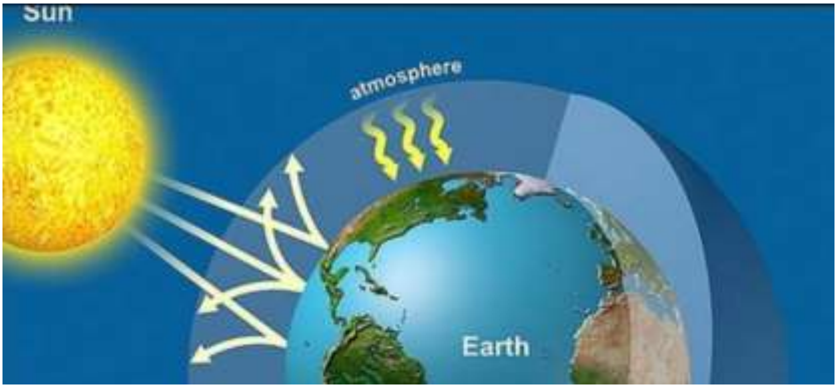

Figure 5. Occurrence of global warming with greenhouse gases (Anonim, 2022e)

Global warming is observed as an increase not only in air temperature but also in seawater temperature. With this increase, permanent damage is predicted to occur in the climate system. While drought occurs in some places, it is thought that some places will be affected by excessive rainfall and flooding, and rainfall periods, amounts, and types will change.

It is predicted that by the middle of the 21st century we will have a warm, humid, and rainy Earth (Kandil, 2008). Furthermore, according to the 2021 Global Risks Report, risks in a short period are illustrated in Figure 6 and Figure 7. In this context; The most important global risks are divided economically, environmentally, geopolitically, socially, and technologically (Anonim, 2022g).

Figure 6. Top Global Risks by Likelihood(Anonim2022g)

Figure 7. Top Global Risks by Impact(Anonim2022g)

2. CHANGES CAUSED BY GLOBAL WARMING

The main factors that cause climate change due to the effect of greenhouse gases are industrialization, energy production, urbanization, agriculture, and population growth. Climate changes caused by global warming are also closely related to societies, natural systems, and their socio-economic status. Human beings are faced with the choice of adapting to the global changing conditions or disappearing (Bayraç, 2010).

2.1. The Relationship Between Climate Change and Agriculture

Among the most important sectors affected by climate change is agriculture. Agriculture is an economic activity that is heavily dependent on weather and climate to produce the food and fiber necessary to sustain human life (Van Vuuren et al., 2009).

However, with climate change, differences are also observed in agricultural production. Climate change; with changes in average temperatures, rainfall, and floods that have a significant impact on soil erosion, drought, flooding, plant pests, diseases, changes in the atmosphere, and changes in the quality of some foods, agriculture affects agriculture in various ways.

With the increase in climatic and geographical problems, some disruptions in agricultural production also occur (Hitz and Smith, 2004).

A rise in temperature and CO_2 levels can increase crop yields in some areas. A study conducted in Japan shows that if the amount of CO_2 doubles, rice production will increase by 25%. CO_2 is an important source of nutrients for plants to maintain their vital activities. With other gases remaining constant and only the amount of CO_2 doubling, agricultural products are projected to increase by between 10% and 50% (Horie et al., 1996).

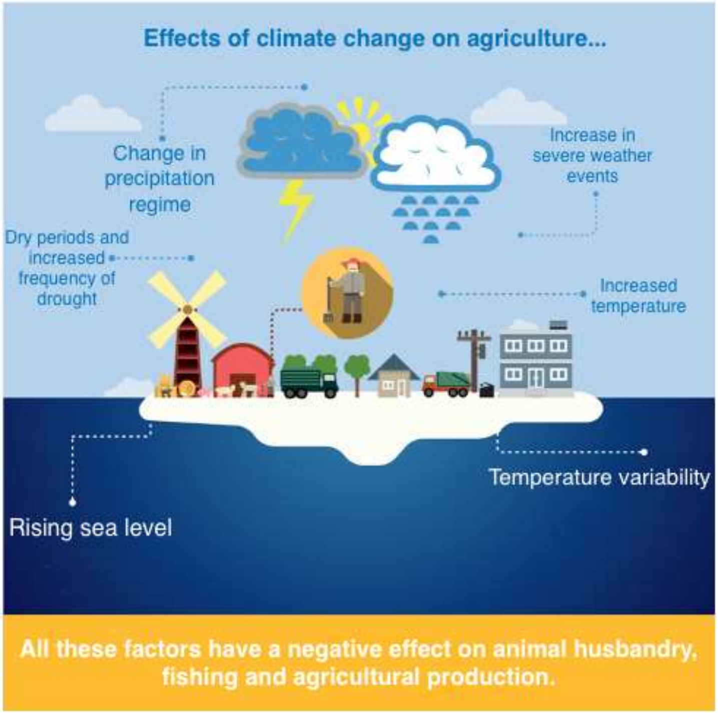

Figure 8. Impacts of climate change on agriculture

For yield increase, it is necessary to adjust the amount of micro-macro elements and water in the soil. Since these conditions depend on climate events, it takes some time and poses a great risk to food safety. It is now impossible to grow the same crops in the same region (Ziska et al., 2016).

According to the United Nations Framework Convention on Climate Change (UNFCCC), in the principle of "common but differentiated responsibilities" specified in Article 4.1(c), the obligations of countries to reduce greenhouse gas emissions are listed and expressed as a source of greenhouse gas emissions for agriculture.

In addition, climate change assessments of sustainable agriculture have been developed in Article 2.1(iii) of the Kyoto Protocol. In addition, in Annex-A part of the Protocol, agriculture is also included in the classification of sectors and resources that emit greenhouse gases.

In this context, the agricultural activities that need to be monitored are listed as Enteric fermentation (CH_4), Management of animal wastes (CH_4, N_2O), Paddy production (CH_4), Agricultural soils (CH_4, N_2O), Controlled incineration of meadows and pastures (CO_2, CH_4, N_2O), Incineration of wastes of agricultural products (CO_2, CH_4, N_2O) (Anonim, 2022f).

2.1.1. Greenhouse gases from rice (paddy)

Rice fields; contains carbon dioxide (CO_2), methane (CH_4), and nitrogen oxide (N_2O) from greenhouse gases (Tokay, 2018).

Since paddy is a product grown in water, methane (CH_4) is released into the atmosphere through paddy plants by leaving the organic material in the irrigated paddy fields in an oxygen-free environment (Nouchi et al., 1990; Şahin and Avcıoğlu, 2016).

By changing the irrigation pattern and soil treatment methods, managing the amounts of organic matter and fertilizer, and choosing the appropriate paddy variety, the number of greenhouse gases in paddy tars can be reduced (Hussain et al., 2015).

2.1.2. Greenhouse gases in animal husbandry

Methane (CH_4) is a gas that has a significant share in the atmosphere after CO_2 and has a high amount of insulation. Methane is seen in animal feces as it is revealed as a by-product of the digestive system of ruminant animals (Köknaroğlu and Akünal, 2010).

As a result of the studies conducted in Germany, it was stated that toilet training was started to be given to cows to minimize the effects of animal feces on global warming.

Fishing is also observed to be affected by climate change. Climatic change in streams, seas, and oceans also affects fisheries. These effects on fishing, in addition to prolonging the breeding and growing seasons of fish, adversely affect both the country's economy and people engaged in fishing activities.

2.1.3 Greenhouse gases from stubble burning

The most important source of CO_2, which causes global warming, is soil. In this sense, the retention of carbon in the soil within the scope of combating global warming is very important. CO_2, whose concentration in the atmosphere was 280 ppm a century ago, has reached its peak level by making 420 ppm in

April (Anonim, 2022h). Although contracts limit CO_2 emissions through agreements, they still cannot be prevented.

Burning stubble after harvest is known to reduce CO_2 emissions in the soil. Some reduction in CO_2 emissions after stubble burning is considered an indicator of a decrease in the number of soil micro-organisms. However, processing the soil to prepare for harvest again increased CO_2 emissions (Bulut and Çağlar, 2022).

2.1.4 The use of nitrogen fertilizers

The use of nitrogen fertilizers in agricultural lands has become mandatory in the face of the increasing population. Nitrogen, which is abundant in the soil, causes pollution of groundwater resources, air pollution due to evaporation and sweating, a decrease in biodiversity, serious problems for human health, and increases greenhouse gas emissions (Şahin and Avcıoğlu, 2016).

3. ECOLOGICAL FOOTPRINT

Mathis Wackernagel and William Rees defined the ecological footprint in the 90s as follows; fertile land and water areas where individuals and communities produce new resources with the resource management of technologies, and where the wastes generated are re-evaluated (Wackernagel and Rees, 1998).

The ecological footprint is very comprehensive and is combined into six groups - Carbon footprint, Agricultural land footprint, Forest footprint, Structured area footprint, Fishing field footprint, and Grassland footprint (Wiedmann and Minx, 2008).

The ecological footprint, which includes much more than greenhouse gases, measures the pressure we exert on nature, or in other words, a measure of the Earth's human demand on the ecosystem. It calculates how much of the natural resources we use and compares this with the availability of resources (Anonim, 2022ı).

The results are given in terms of the number of planets on Earth in terms of which we all follow our lifestyle. To learn about our ecological footprint;the https://www.footprintcalculator.org/home/en site, cold be used.

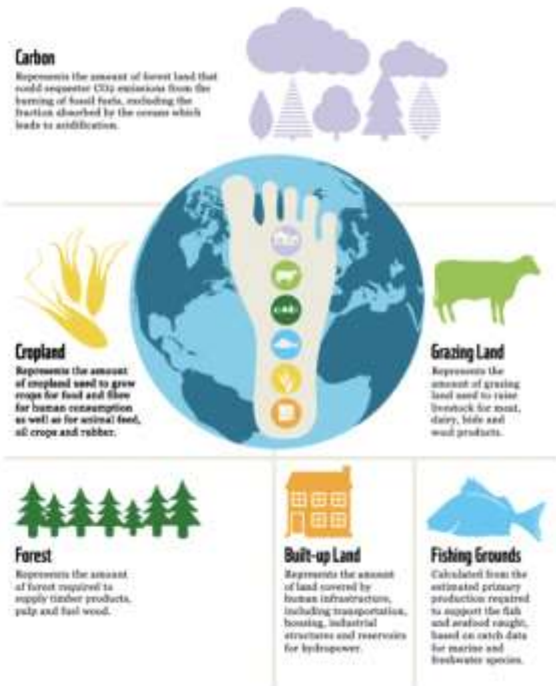

Figure 9. Exploring the Ecological Footprint (Deutschland, 2016)

3.1. Carbon footprint

The total amount of carbon dioxide emission that occurs directly or indirectly in all vital stages of a product is called carbon footprint (Şahin and Avcıoğlu, 2016). In other words, it is a measure of CO_2 emissions that occur at each step of the product life cycle (production, transportation, use, and disposal), which is also defined as the measure of the damage caused to the world by greenhouse gases produced by human activities and measured in terms of carbon dioxide (Wiedmann and Minx, 2008).

Terms used in the current literature as carbon footprint or synonyms are also referred to as embodied carbon, carbon content, embedded carbon, carbon streams, virtual carbon, GHG (greenhouse gases) footprint, and climate footprint (Courchene and Allan, 2008; Hertwich and Peters, 2009).

The term, commonly referred to as carbon footprint, is exactly what is referred to as "carbon weight" or "carbon mass" and refers to as "tons CO_2-equivalent" or kg CO_2-equivalent" (Jarvis, 2007).

In addition, the carbon footprint can be examined under two headings, personal and corporate as shown in Figure 10. In personal carbon footprint, the primary footprint is expressed as the amount of CO_2 generated from the combustion of fossil fuels that we consume daily in our homes, and the secondary footprint is expressed as the amount of CO_2 produced from the manufacture of the products we use to their decay.

In the corporate carbon footprint, Direct Carbon Footprint is expressed as the amount of CO_2 created by fossil fuels used by institutions to continue their activities, and indirect Carbon Footprint is expressed as the amount of CO_2 caused by the electrical energy consumed by the institutions and the amount of CO_2 due to steam, cooling or hot water purchased by the institution from another institution.(Bekiroğlu, 2011).

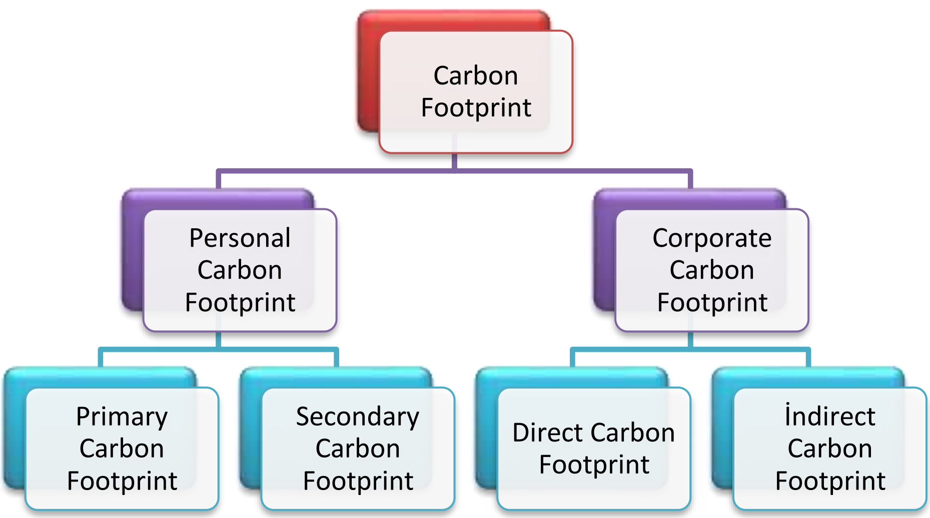

Figure 10. Carbon Footprint

The carbon footprint that occurs as a result of our activities in the world is accepted as an indicator in the assessment of greenhouse gas emissions that cause global warming (Standardization, 2006).

3.1.1. Calculation of carbon footprint

To calculate the carbon footprint, the number of greenhouse gases produced by the product throughout its life cycle must be estimated and added. The life cycle includes all stages from the production of a product to the final packaging, distribution, consumption/use of the raw material, and the final disposal stages.

Many of our daily tasks, such as electricity, heating, driving vehicles, or disposing of waste, cause the generation of greenhouse gases. With these greenhouse gases, the carbon footprint of a household is also formed. Everyone's carbon footprint differs depending on where they are located, their habits, and their personal preferences (Figure 11).

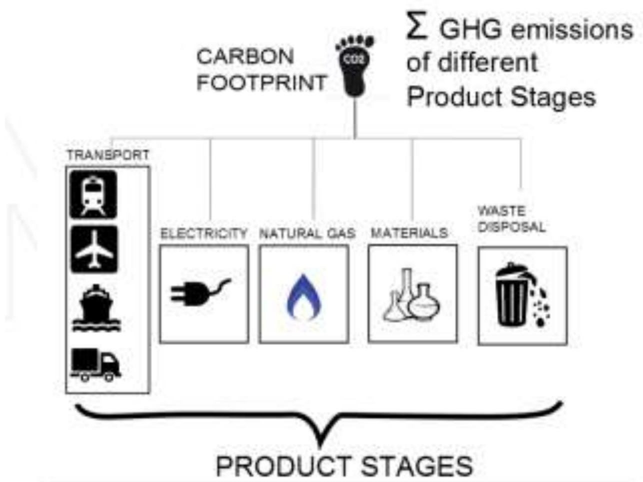

Figure 11. Carbon footprint calculation

4. CONCLUSION

We must live more sustainable lives by understanding our ecological and carbon footprints. We can start by making Earth-friendly choices and encouraging others to do the same. There are several ways to reduce our footprint and contribute to a healthier, more sustainable world. Major factor is to change the nutritional habits of the population as we may promote consuming more organic plant-based products and less animal protein. Food waste reduction is important part of the sustainable life strategy, followed by ensuring the reuse and recycling of waste, reducing energy consumption (using solar energy or renewable energy sources), plant trees by choosing the appropriate type and variety, raising awareness of producers about not burning stubble, producing biogas from animal wastes by anaerobic treatment method. Therefore, we aim to reduce greenhouse gas emissions by using the method of batch irrigation in paddy tars.

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CHAPTER 15

GREENHOUSE AGRICULTURE AND CLIMATE CHANGE

Res. Assist. Ph.D. | Adil Koray YILDIZ[1]

[1] Yozgat Bozok Üniversitesi, Kenevir Araştırmaları Enstitüsü, Yozgat, Türkiye. adilkorayyildiz@gmail.com, Orcid ID: 0000-0002-6472-5276

INTRODUCTION

Climate change is a significant problem that closely concerns the world regarding its effects and consequences. In the 5th Assessment Report of the Intergovernmental Panel on Climate Change, climate change is defined as "changes in the state of the climate that usually lasts for decades or longer" (IPCC, 2022). Global climate change is expressed as the increase in the average surface temperatures of the earth due to the rapid increase in the accumulation of greenhouse gases released into the atmosphere by human activities, such as the use of fossil fuels, land use changes, deforestation and industrial processes.

Greenhouse farming is an important area of food production. Since, it is grown independently of the climate, it increases access to food and has an important place in the economy. However, it requires more inputs in terms of energy, water, fertilizer and agricultural chemicals compared to conventional agriculture. This situation negatively impacts climate change in terms of direct environmental effects and indirect aspects such as energy usage.

In this section, the effect of greenhouse agriculture on climate change has been revealed through studies, and it has been discussed how an effective, efficient and sustainable production in greenhouses could be made in an environmentally friendly way.

1. CLIMATE CHANGE

The adverse effects and consequences of global climate change on human life are related to created damage to living species and deterioration of human health. All negative consequences were epidemics, drought, erosion, desertification, displacement of climate zones, increased severe weather events, rising sea level, and deterioration of natural balance. Thus, it directly or indirectly affects socio-economic sectors and ecological systems, leading to undesirable and unpredictable results. Despite all uncertainties, some potential severe changes could occur if global warming persists. The extremely high temperatures, floods, widespread and severe drought events, their natural consequence, bushfires, and forest fires, and human health and the functionality of ecological systems are highly plausible for some regions. (Türkeş et al., 2000). Even if all anthropogenic emissions are stopped, a 1–2°C increase in temperature is expected by year 2100. It is expected that tdoubling the CO_2

concentration, which causes the greenhouse effect, will cause global warming of 2.5°C (Aksay et al., 2005).

Many collaborative studies have been conducted against climate change in the international scientific arena. The United Nations Framework Convention on Climate Change (UNFCCC), which entered into force in 1994 under the umbrella of the United Nations; the Kyoto Protocol, which entered into force in 2004, and the Paris Agreement,which entered into force in 2016, are the most critical stages of the fight against climate change.

2. EFFECTS OF CLIMATE CHANGE ON AGRICULTURE

Agriculture creates conditions that cause the climate change and at the same time is affected by climate change. Generally, all crops need soil, water, sunlight and warmth to grow. The climate is a dynamic component that affects all of these. For this reason, the risk it creates for the agricultural sector is very high due to the unknown sections it contains. The risks posed by climate change have also changed the insurance approaches in agriculture. The increase in risks has increased the number of insured as well as the number of premiums (Çekici, 2009). It is estimated that sudden, extreme and drastic changes in the world climate system will significantly reduce the existence of soil for agriculture after 30–40 years and make the living conditions of plants and animals on it more difficult (Akın, 2006). Additionally, natural disasters such as fires caused by climate change directly and indirectly affect agricultural production (Deniz and Hiç, 2021). It has effects not only on the production but also indirectly on the price and consumption of agricultural products (Akalın, 2014).

Many studies have been conducted that reveal the effects of global warming and agricultural drought on agriculture (Tıraşcı and Erdoğan, 2021). The effects of climate change on agriculture can be listed as follows:

- Warmer and less rainy climatic conditions
- Increase in extreme meteorological events
- Reduction in water resources
- Increase in drought severity
- Deterioration of water and soil quality
- Degradation of the ecosystems and reduction in biodiversity
- Shifts in ecological areas

- Reduction in agricultural production and quality
- Increase in pests and diseases
- Fertilization and spraying problems
- Sustainable food safety issues

Agriculture is currently one of the economic sectors with the greatest environmental impact. The effects of climate change on agricultural activities have special importance due to the relationship between production and nutrition. In line with projected population growth and changes in eating habits toward greater meat consumption, global food demand is expected to increase by 70% in the coming years. Overall, meat and dairy products contain the highest proportions of global carbon footprints, raw materials and water per kilogram of any food. In terms of greenhouse gas emissions, livestock and animal feed production each produce more than 3 billion tons of CO_2 equivalent (Anonymous, 2022).

In the 4th Evaluation Report of the IPCC; it is stated that the contribution of agriculture to the total global greenhouse gas emissions is 10%-12%, and the same value is 15% in the 6th Evaluation Report of the IPCC. In the same reports, it is emphasized that the activities of paddy production, controlled burning of agricultural lands, meadows and pastures, burning of agricultural wastes that are the source of greenhouse gas emissions (IPCC, 2007; IPCC, 2022).

However, the increase in productivity and product quality in the field of agriculte may positively lead, to increase in macro variables such as employment and economic growth. Thus, climate change is a crisis and struggling situation to pass from an uncertain process to a certain process; it requires a collectively oriented, nature-based, and multidimensional perspective on the sustainability of agricultural production (Kara and Yereli, 2022).

3. THE RELATIONSHIP BETWEEN GREENHOUSE AND CLIMATE CHANGE

Greenhouses are production areas created to artificially provide conditions in places where plants do not have that. Plants are isolated from the external environment to a certain extent, and the desired conditions are provided. Thus, both regional and climatic negativities are eliminated, and the continuity of production is ensured. Greenhouses are classified according to the desired temperature, product growth time and usage purposes (Yağcıoğlu, 2009). Cold greenhouses are developed for plants that are affected by light frost but do not want heat, while hot greenhouses are used to cultivate equatorial or tropical region plants. Warm greenhouses are preferred for cultivating plants in the temperate climate zone. Greenhouses couldbbe installed in different ways. For example, they could be roofless, single-roof, multi-roof, low-roof greenhouses, or high-roof greenhouses. They are made of light-transmitting materials such as glass, plastic, and fiberglass. Greenhouses that meet the physiological demands of the plants in the most appropriate way are built and operated as the product of a multidisciplinary study such as construction, agriculture, mechanical, computer and electrical-electronic engineering.

Vegetables and fruit plants that can be considered small in size can be grown as early fruit by being covered with glass or plastic cover. Most vegetable and fruit that were grown only in natural conditions and at certain times of the year, could now have grown in greenhouses in earlier times and faster with the developing technology. This naturally increased the yield and quality in vegetable and fruit growing.

The needs of the plants produced are certain according to their life periods (Başçetinçelik and Öztürk, 1998). Providing these needs in the best way at every stage of production is a necessary condition for the most profitable production in greenhouse cultivation. Systems such as heating, ventilation and lighting must be present in order to achieve artificial air conditioning in the greenhouse. In addition, the irrigation and fertilization necessary for plant growth should be provided, and pesticide applications should be made against diseases and pests. In addition to the need for more energy, water, fertilizer and agricultural pesticides in greenhouse cultivation, it also creates conditions to produce a large amount of waste and carbon emissions (Baytorun and Gügercin, 2015).

3.1. Energy Consumption in Greenhouses

One of the important factors of global climate change is the applications made to meet energy needs. Mainly to provide climatic conditions, high energy consumption can be mentioned in greenhouse production compared to regular agricultural practices. The energy consumed in greenhouses has a linear relationship with crop yield (Canakci and Akinci, 2006).

Heating systems are responsible for most of the energy consumed in greenhouses. Depending on the desired temperature in the greenhouse, the required heat energy shows a non-linear increase. In other words, if the desired temperature is kept high in the greenhouse, the heat energy requirement increases proportionally (Baytorun et al., 2017). Heat energy varies depending on the type of greenhouse, its equipment, the desired temperature values in the greenhouse and external climatic conditions. The heat energy requirement in the greenhouse is generally determined by the average temperature values and the heating time. Additionally, although it is uncommon, optimum results can be obtained with expert systems created to meet this need (Baytorun et al., 2016). Especially in the winter months, the heating system gains great importance. Generally, water heated systems are used in greenhouses. Pipes through which hot water flows are used as heaters. The pipes are placed under the grow tables, under the ground, on the greenhouse floor, along the side walls, near the bottom, and along the greenhouse walls, close to the floor and ceiling (Titiz, 2004).

The most effective method for heating greenhouses is natural gas. However, since the natural gas infrastructure is insufficient in rural areas where greenhouses are located, heating is carried out with coal, negatively affecting both carbon emissions and costs (Boyacı, 2018). Fossil fuels are generally used for the heating of greenhouses. Still, among the natural energy sources that can be used, solar energy, geothermal energy, and biomass (biogas) energy are used (Kinirli and Çakmak, 2010). Photovoltaic cells can be used in lighting and/or heating systems. These cause more environmentally friendly results in terms of energy compared to fossil fuels (Allardyce et al., 2017). Although they support energy saving, they are uncommon due to problems in meeting the desired energy and high installation costs.

The most efficient heating source in terms of carbon emissions is the use of renewable resources. An important renewable resource used for heating greenhouses is geothermal energy. A significant portion (55%) of geothermal fields in Turkey are suitable for residential and greenhouse heating. For this reason, heating applications with geothermal resources, which are a very economical and clean energy source in today's conditions, continue to spread rapidly. In the studies conducted in greenhouses, it has been concluded that using geothermal energy in greenhouses is feasible (rentable) by evaluating the operating income and expenses obtained during the service life according to the benefit/cost ratio method (Cebeli and Kendirli, 2013). Heating greenhouses with geothermal energy sources will not only provide an economical aquaculture opportunity that will minimize heating costs but will also help increase our greenhouse areas (Karaman, 2004). Additionally, if geothermal resources are used in greenhouse heating without harming the environment, geothermal regions will have great advantages over cultivation in other regions in terms of CO_2 emissions (Baytorun et al., 2016b).

The conservation of energy in heated greenhouses is as important task. Because of the calculations, it has been determined that 40% of the heat energy can be saved depending on the heat protection measures in the heated greenhouses (Baytorun and Gügercin, 2015). The most used method conserving heat energy in greenhouses is application of thermal curtains. Its use is crucial as the share of high heating costs in greenhouses in production costs can be reduced due to the conservation of energy. Önder and Baytorun (2016) reported a temperature difference of 3 K in an unheated glass greenhouse and 2 K in a plastic greenhouse, with the help of a thermal curtain. With the help of the imported LS17 thermal curtain used in the heated glass greenhouse, 63% fuel savings were achieved, and in the plastic greenhouse, 36% fuel savings were achieved with the help of a white colored thermal curtain made of dense-textured polyethylene produced in Turkey.

To keep the heating costs at a minimum level while providing an optimum climate environment, the producers must establish a balance between production and energy costs by predetermining the amount of fuel required for the unit area depending on the different cover materials and internal temperature values. Additionally, necessary measures should be taken at the planning stage for measures to reduce the share of heating in production costs for economical agriculture. Some precautions should be taken during the planning phase, such as installing the greenhouses as blocks, reducing the surface area of the cover where heat losses occur, choosing the correctly assembled cover materials with low heat transmission coefficient and high resistance, usage of thermal curtains, placing the heating system pipes close to the greenhouse floor, and installing automation systems (Boyacı and Kılıç, 2020).

Cooling in greenhouses can consume as much energy as heating. Particularly in greenhouses established in regions with hot climates, cooling is needed in summer. There are various cooling methods in greenhouses (Boyacı et al., 2017). If these systems are operated with an effective control system, cooling can be achieved at the lowest cost.

3.2.Evaluation of Greenhouse Waste

Agriculture is responsible for the use of energy and water inputs, chemical fertilizers and pesticides, as well as many plastic materials. In addition to the pollution that occurs during the production of plastic, the plastic materials used for greenhouse, high or low tunnel cover material, mulching, irrigation and drainage pipes can become a source of pollution when left in open areas or burned at the end of their life. Instead, if agricultural plastic waste is collected correctly, it can be used as a new secondary raw material or an energy source. Adequate waste management can prevent economic losses and environmental damage (Vox et al., 2016).

The solutions offered by Boyacı and Kartal (2019) regarding greenhouse waste are given below:

- Extending the service life of plastic materials by increasing the additives added to plastic materials,
- Creating suitable collection areas for agricultural plastic wastes like expired plastic cover materials, drip irrigation laterals, etc.

in agricultural regions and taking the necessary measures for the recycling of these plastics by the authorities,

- Supporting scientific studies to produce biodegradable plastic materials,
- Creating a collection center for plant residues, makes the plant wastes useful for the soil by composting, thus preventing the spread of chemical fertilizers,
- Producers should be supported by government incentives for the facilities to be established to bring the vegetable wastes into the economy as biomass energy.

By evaluating organic production wastes as biomass and using them in energy production, both energy savings can be achieved, and carbon emissions can be reduced by 90% (Karaca, 2017).

3.3. Use of Water, Fertilizer and Pesticide in Greenhouses

Water consumption, which has an important place in agriculture, is directly related to climate change. A major consequence of climate change is drought. Alternatively, unplanned water consumption causes climate change (Kılıç, 2011). In addition to the deterioration of ecological balance and biological development, chemical residues in agricultural products have threatened human health. The intensive use of fertilizers and pesticides often causes significant hazards to humans and the environment. While approximately 3% of the total pesticide amount used in Turkey is used in the GAP region, about 30% is used only in Antalya and İçel (Topbaş et al., 1998). Considering the production areas, this difference arises directly from the greenhouses.

The study by Atılgan et al. (2021) has revealed that producers mostly only use pesticides and fertilize by considering the amount of production, do not attach importance to criteria other than yield, and do not consider possible environmental problems at all. Because of incorrect fertilizer applications, problems occur, such as soil salinization, heavy metal accumulation, nutrient imbalance, deterioration of microorganism activity, eutrophication and nitrate accumulation in water, introduction of nitrogen and sulfur-containing gases into the air, greenhouse effect, etc. (Sönmez et al., 2008).

4. CONCLUSION

While nitrogen fertilizers cause 75% of global warming as the most important effects, respectively, when the use of fuel for heating purposes is included, the use of coal takes the first place in terms of environmental pollutants. Among the factors that cause eutrophication, it could be concluded that the use of fertilizers containing 60% P_2O_5 and nitrogenous fertilizers with 70% cause acidification (Yelboğa, 2016).

Data obtained from the studies, showed that in order to ensure the correct nutrition for the plant growth in greenhouse cultivation, it is necessary to establish laboratories that make plant and soil analyses in close proximity to the producers and at affordable prices. Since the most important problem that the producers cannot solve in greenhouse vegetable cultivation is plant nutrition or fertilization, it is necessary to train qualified agricultural engineers who can help them with the nutrition programs of greenhouse plants according to the analysis results. Farmers also need training from public or private institutions on these issues.

The modernization of greenhouses, their access to renewable energy and the realization of their controls with effective information-automation systems enable efficient production while making it possible to save with an environmentalist attitude. For this reason, it is a necessity for sustainable greenhouse agriculture to make the necessary calculations at the planning stage and to take the required precautions by bearing the increase in the installation costs.

Reducing greenhouse gas emissions from agriculture and harmonizing the food production system is necessary. However, climate change is just one of the many pressures felt on agriculture. Food production should be evaluated in a broader context, and links should be established between agriculture, energy, and food security.As long as the environment and its components are environmental awareness subjects, climate change will become routine. The emergence of severe effects due to climate change, which affects almost everywhere in the world, reveals the need to increase and expand adaptation actions.

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