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REVIEW PAPER

Climate change impacts on agriculture and food security; a global overview

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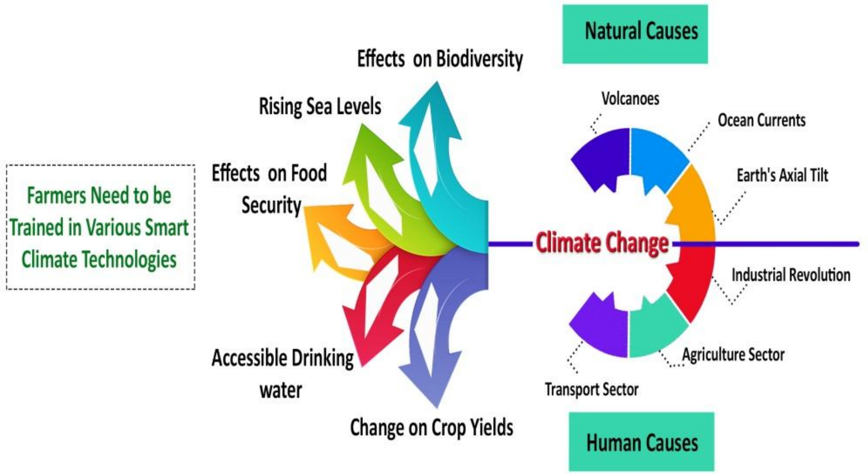
Highlights

- Climate change and rising temperatures are one of the most important environmental issues that can affect agriculture and water resources in an area.
- One of the important consequences of climate change can be on food security. Food security depends on climate change because any change in climate factors directly affects all food components.
- Due to the importance of climate change on the structure of the planet and its inhabitants, in recent years, as one of the most common topics, has been considered by scientific societies and many studies have been conducted to study its effects.
- In the present paper, the effects of climate change on agriculture and food security were studied.

Graphical Abstract



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Abstract

Climate change affects agricultural production and agricultural-related factors such as food security and economic well-being. Climate and its changes in recent decades have become one of the most important global issues and one of the major environmental problems. Agriculture is one of the first sectors to be affected by these changes; because farmers are unable to control the climate. However, management and change in factors such as crop cultivation and optimization of cultivation patterns under the climate of the region, can reduce the adverse effects of climate change on the growth and yield of agricultural products and play an important role in sustainable food production. The latest report from the Intergovernmental Panel for Climate Change (IPCC) estimates that the average global temperature rise for 2050 will be around 3 °C and at the end of this century around 4.5 °C, causing significant economic losses at becoming world level. This article collects information on the subject of climate change, its possible causes, its forecast in the near future, its impact on the agricultural sector as an impact on plants and its potential consequences for plant growth and productivity, plant breeding strategies and examines the adaptation of plants to climate change and the impact of climate change on food security.

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1. Introduction

According to its general definition, agriculture is an economic activity that is aimed at food production and as a result, the current and future food security of the world will depend on the success of this activity (Hatab et al., 2019; Rizal and Anna, 2019). Despite all the scientific and technological advances in increasing the yield and production of crops, agriculture is highly dependent on climate, therefore, climate diversity and its changes, both in the short-term (during the growing season) and in the long-term have a decisive contribution to the success of production (Aggarwal et al., 2019). For this reason, the impact of future climate change on agriculture and its products has been considered by the international scientific community (O'Neill et al., 2020). Crop production is projected to decrease in many areas during the 21st century because of climatic changes. This is illustrated in Fig. 1 which summarises average crop yield projections across all emission scenarios, regions, and with- or without- adaptation by farmers, showing an increasing trend towards widespread yield decreases (IPCC, 2014).

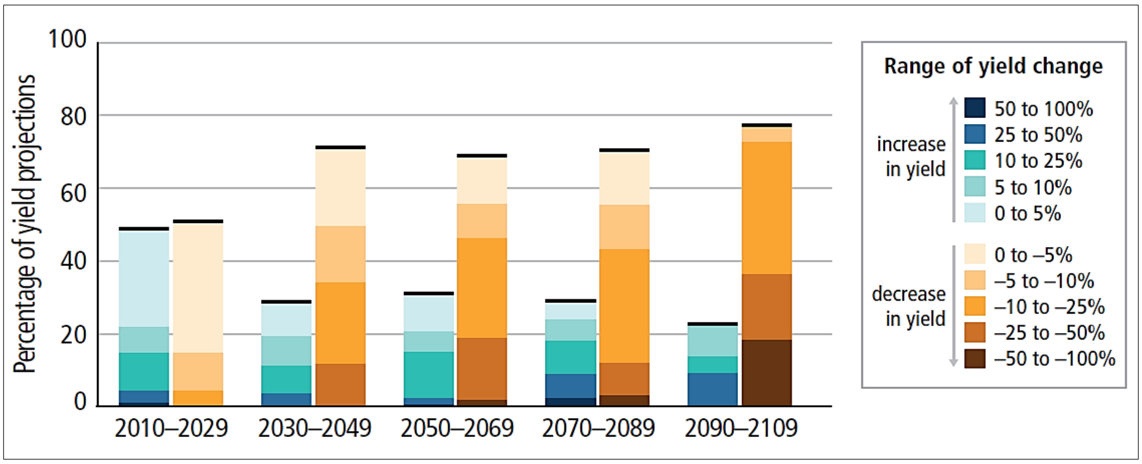

Fig. 1. Declining crop yields due to climate change during the 21st century (IPCC, 2014, 5th assessment).

Increasing carbon dioxide (CO_2) concentrations and proving the theory of the greenhouse effect, according to which the type and composition of gases in the atmosphere strongly affect the earth's temperature, are undeniable facts that have made future climate change possible. Existing scenarios for increasing greenhouse gas (GHG) concentrations in the atmosphere have provided different estimates of future temperature changes (Qin et al., 2020). Also, the latest report of the Intergovernmental Panel for Climate Change (IPCC) estimates the average global temperature increase for 2050 at about 3 °C and the end of this century about 4.5 °C (Sithara et al., 2020). If the concentration of greenhouse gases increases at the current rate (1.5 ppm per year), the approximation of most existing models for increasing the average temperature of the earth by 2100 AD is about 4.5-5.5 °C (Fig. 2) (IPCC, 2014; Rae et al., 2021). Despite the uncertainty in these predictions, it should be notedthat if the current temperature rises by only 1°C, the earth will reach its warmest temperature in the last 10,000 years (Gentilal and Miranda, 2020).

Accurate prediction of climate change requires the use of acceptable methods with minimal error (Zubaidi et al., 2020). In this regard, in climate studies, various methods have been used to predict climate change such as artificial intelligence and various climate methods (Zhang et al., 2021). Due to the importance of the subject, numerous studies and researches have been done in recent years in all regions of the world. A group of these studies has dealt with the impact of climate change on the growth and yield of variant crops, including the Impact of climate change on maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) (Brown and Rosenberg, 1999), rye (*Secale cereal* L.) (Chmielewski and Köhn, 2000), potato (*Solanum tuberosum* L.) and barley (*Hordeum vulgare* L.) (Holden et al., 2003), root and tuberous crops. Another group of studies focuses on the impact of climate change on agricultural production on a national scale (a specific country), examples of which over the past few decades in Germany (Chmielewski et al., 2004), India (Aggarwal et al., 2019), Egypt (El-Shaer et al., 1996; Yates and Strzepek, 1998), Spain (Hill et al., 2001), USA, Canada and Australia (Hill et al., 2001), China (Erda, 1996), Zimbabwe (Matarira et al., 1996), Kazakhstan (Mizina et al., 1996), Italy (Moonen et al., 2002), Saudi Arabia (Alkolibi, 2002), as well as larger-scale research in Europe (Ewert et al., 2005) or globally on arid regions (De Pauw et al., 2000).

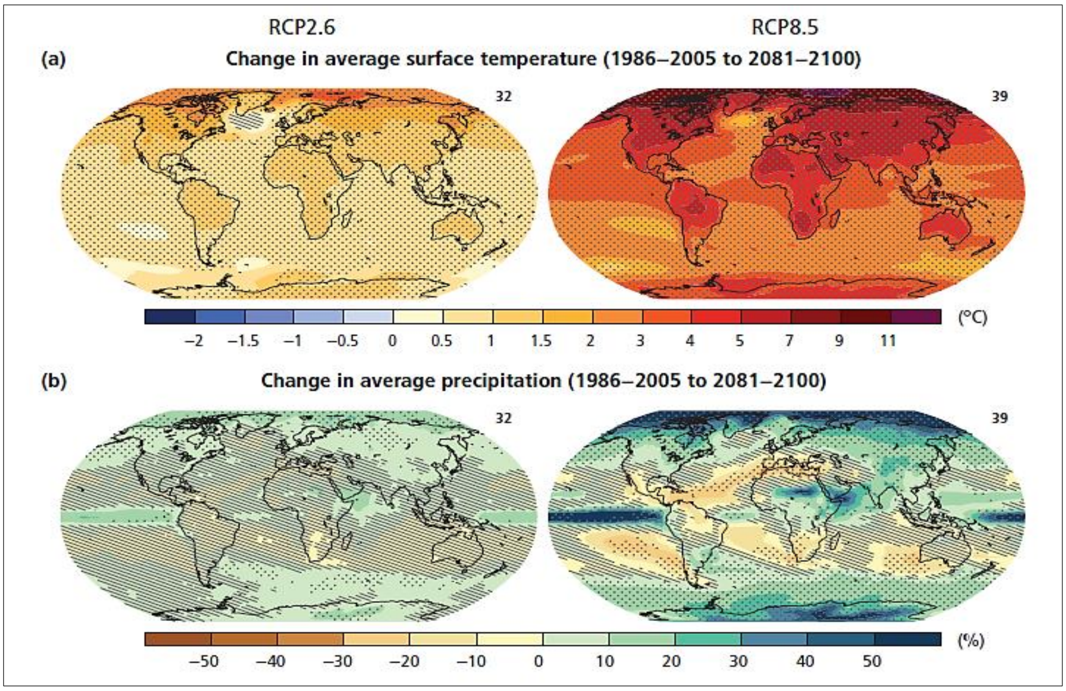

Fig. 2. Changes in average ground surface temperature (a), and changes in average rainfall (b), based on model predictions for 2081-2100 compared to 1986-2005 (IPCC, 2014, 5th assessment).

This article collects information on the subject of climate change, its possible causes, its projection soon, its impact on the agricultural sector as an impact on plants and its potential consequences for plant growth and productivity, plant breeding strategies and examines the adaptation of plants to climate change and the impact of climate change on food security.

2. Possible causes of climate change

Human endeavors to provide a luxurious and modern life have increased greenhouse gases such as CO_2, methane (CH_4), water vapor (H_2O) and nitrous oxide (N_2O) (Wecking, 2021). Today, greenhouse gases are naturally concentrated in the atmosphere (Mikhaylov et al., 2020). The human activities that produce greenhouse gases include the industrial revolution, agricultural activities, animal husbandry, explosions, etc (Jogdand, 2020). The causes of climate change can be classified into two categories: natural and human causes (Timpane-Padgham et al., 2017).

2.1. Natural causes

2.1.1. Volcanoes

Recent studies show that radiation energy from greenhouse gases is a major cause of global warming (Hu et al., 2020). Greenhouse gases also play an important role in understanding the earth's climatic history (Abdollahbeigi, 2020). According to studies, the greenhouse effect that generates heat by trapping heat plays a key role in regulating the earth's temperature (Abdollahbeigi, 2020). Human views of volcanoes are often seen as threatening human lives (Bassey, 2020). The dangers of volcanoes, including lava and volcanic gases, are always considered during their active phase, and less attention is paid to the positive effects of volcanoes in their inactive phase (Bankoff, 2021). Previous research has shown that the volcano has changed the climate of the region by increasing rainfall and decreasing the environmental temperature, and changing the climate has changed other environmental parameters of soil, vegetation, surface water and human (Roufou et al., 2021).

2.1.2. Earth's axial tilt

The earth's axis is tilted 23.5 degrees from the surface of its orbit around the Sun (Doran and Martin, 2021). The change in tilt is due to the change of seasons from summer to winter (Hart et al., 2019). The earth's axis seems to point to a North Star (Asmuni et al., 2020). The rotation of the earth's axis is very slow and is 0.5 degrees per century (Solheim et al., 2021). About 2500 BC (2500 years ago), the axis of the earth's pole was close to the Thubanstar (Ghosh, 2020). This gradual change in the direction of the earth's axis is one of the causes of climate change (Taheri et al., 2021).

2.1.3. Ocean currents

In almost a few decades, climate change can also result from changes within oceanic/atmospheric systems (Katelaris and Beggs, 2018). One of the most important climate regulators known is the ENSO (El Nino Southern Oscillation) phenomenon, which includes the El Nino and La Nina phases (Hayashi et al., 2020). In many regions of the world, ENSO is known as the most important cause of climate change, and this factor greatly overshadows the climate of regions of the world (Kundzewicz et al., 2019). A key sign of El Nino is the abnormal temperature rise along both sides of the equator in the Central and Eastern Pacific oceans (Tim et al., 2017). This current is accompanied by a huge and unusual warming every few years (Piatt et al., 2020).

71% of the earth's surface is covered by the ocean, which has a significant impact on the climate system (Mikhaylov et al., 2020). Ocean air currents carry huge amounts of heat and cold from one side of the earth to the other (Melikoglu, 2018). A large amount of heat is released from the ocean as water vapor, which often releases large amounts of greenhouse gases (Bozorgian, 2020). Undoubtedly, regions of the world are more affected by ocean currents than anywhere else (Trenberth, 2018). Ocean currents can have a huge impact on long-distance climates (Fraser et al., 2018). The Peruvian coast and other border areas are directly affected by the Humboldt current that blows along the Peruvian coastline (Wintersteen, 2021).

2.2. Humancauses

Human climate change occurs much faster than other factors (Cattaneo et al., 2019); the following are some of these factors.

2.2.1. Industrial Revolution

With the beginning of the industrial revolution in the early 19th century and the increasing growth of human evolution, various changes have taken place in human life (Tri et al., 2021). Human needs for energy and the consumption of fossil fuels such as coal, oil and gas have led to an increase in gases such as CO_2 in the atmosphere (Pareek et al., 2020). As shown in Fig. 3, the concentration of CO_2 in the atmosphere increased from 315.98 ppm in 1959 to 411.43 ppm in 2019, and Fig. 4 shows the increase in CO_2 emissions during the years 1850-2020 (Malhi et al., 2021).

CO_2 is a good carrier of sunlight, but it partially prevents the return of infrared radiation from earth to space due to severe cooling of the earth overnight (Chen and Lu, 2020). The increase in carbon dioxide in the atmosphere is exacerbated by greenhouse gases and is expected to lead to global warming. 57% of global warming is due to CO_2 (Yoro and Daramola, 2020). Methane is another important greenhouse gas in the atmosphere that is emitted during the drilling of oil wells and coal mines (Woda et al., 2020). Exploration, production, refining, transportation and storage of oil release methane (Sminchak et al., 2020).

Nitrogen oxides and chlorofluorocarbons are rising in alarm (Smurzyńska et al., 2018). Although chlorofluorocarbons degrade ozone, their effects are minimal given all the factors of global warming (Abas et al., 2018). Water vapor is another important greenhouse gas (Jalihal et al., 2019). Rising temperatures, increased evaporation and transpiration are other factors in increasing the rate of global warming (Kirschbaum and McMillan, 2018).

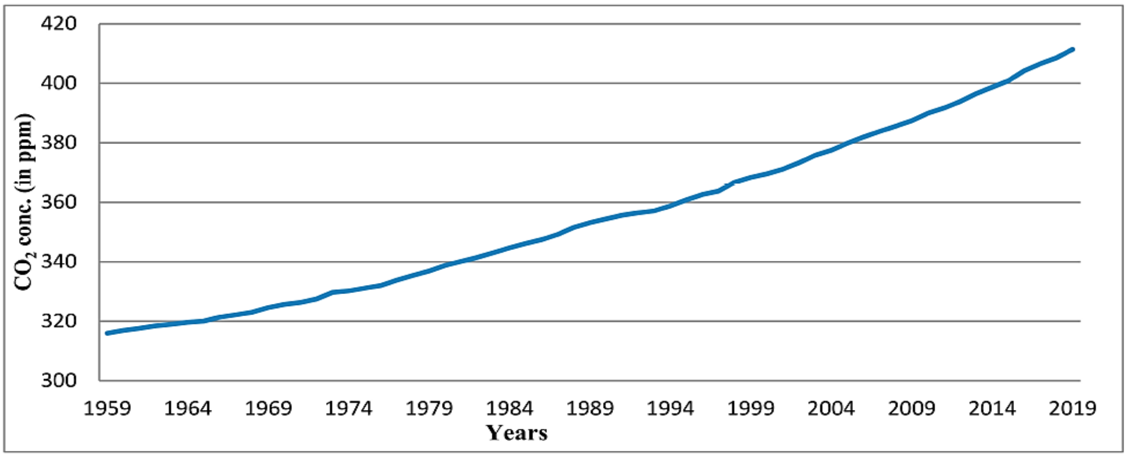

Fig. 3. Increased concentration of CO_2 in the atmosphere during the years 1959-2019 (Malhi et al., 2021).

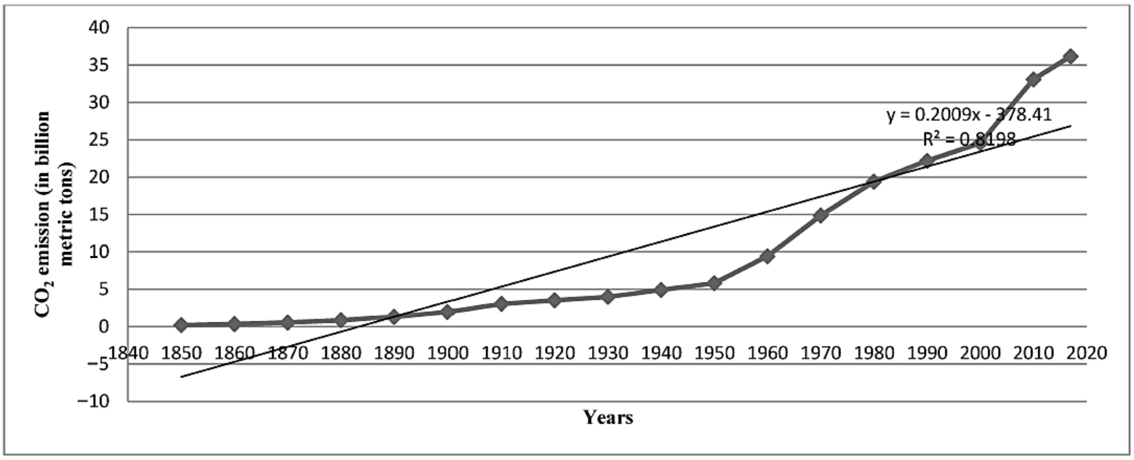

Fig. 4. Increased emissions of CO_2 into the atmosphere during the years 1850-2020 (Malhi et al., 2021).

2.2.2. Agriculture Sector

Agricultural activities play an important role in the production of methane and its release into the atmosphere (Singh et al., 2017). About 0.25 percent of methane emissions come from domestic animals such as dairy cows, goats, pigs, buffaloes, horses, and sheep (Yu et al., 2018). Methane is also released from rice fields that have been flooded during growing periods (Davamani et al., 2020). When the soil is flooded with water, it becomes anaerobic; under these conditions, methane is released into the atmosphere in three different forms (Conrad, 2020). 81% of it enters the roots and rises from the rice fields, the gas bubbles rise and spread in small quantities (Hussain et al., 2020).

2.2.3. Transport Sector

Cars, buses, trucks and other vehicles are petrol or diesel (Breuer et al., 2020). The combustion of fossil fuels leads to an increase in CO_2 and hydrogen sulfide into the atmosphere (Liu et al., 2020).CO_2 is a major greenhouse gas, mainly man-made and distributed, rising from 280 ppm before industry growth to 380 ppm today and is projected to reach 500 ppm by the middle of this century (Bernabeo et al., 2021).

2.2.4. Nuclear weapon

When large destructive weapons explode, a huge amount of energy is released, which immediately causes a fire (Crutzen and Birks, 2016). The pressure of sudden destruction causes the temperature to rise and is strongly affected by radiation (Li et al., 2018). In a nuclear bomb, a crack that occurs in atomic bombs can instantly create the conditions for high temperatures (Wang, 2020).

2.3. Effects of climate change

Since 1990, a group of scientists from all over the world has come together under the name of the Intergovernmental Panel for Climate Change (IPCC); They estimated that global warming is real and is happening today (Devès et al., 2017). Constant changes in climatic parameters lead to maximum and minimum climates such as high temperatures, floods and drought (Ali et al., 2017). Since the late 19th century, the average temperature of the earth has risen between 0.3-0.6 °C and over the past 40 years between 0.2-0.3 °C (Popov et al., 2018). Scientists estimate that emissions of man-made greenhouse gases will soon lead to an increase in global average temperatures of between 1.4-5.8 °C over the next 100 years (Jogdand, 2020). Predicting global warming may seem trivial, but it seems faster than anything in the last 10,000 years (Scher and Messori, 2018). The impacts of climate change are many and serious, including rising sea levels, changes in accessible drinking water, and an increased risk of severe weather such as floods, droughts, and hurricanes (Taylor, 2020).

2.4. Global warming and its effect on plants

Since the mid-19th century, temperatures have risen by 1.5 °C (Thompson et al., 2018). Increased heat has led to increased evaporation of the water surface; this increase increases moisture storage capacity, which will regularly affect water resources, forests, other natural ecosystems, agriculture, tourism, and health (Nowak et al., 2020). The average global temperature anomaly is shown in Fig. 5 and shows a significant increase in global temperature compared to the base period average temperature (1901-2000) (Malhi et al., 2021).

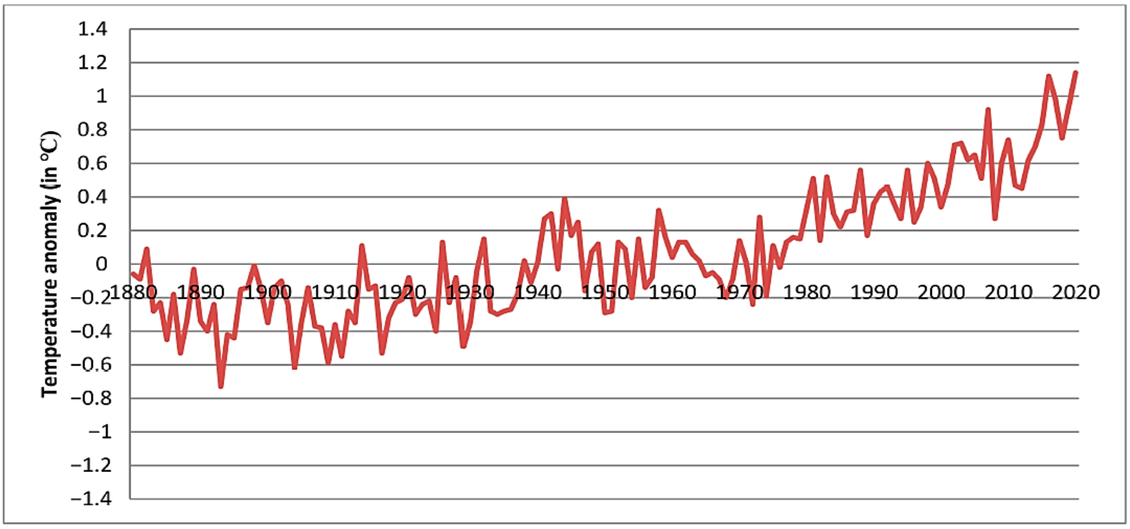

Fig. 5. Temperature anomalies on the surface of the earth and the oceans during the years 2000-1801(Malhi et al., 2021).

Many studies have been done to investigate the impact of climate change on evapotranspiration, water requirement and plant yield, and due to the different effects of this phenomenon on temperature and precipitation in different places, different reports have been presented, so that in some of them the decrease In others, increased yields and water requirements have been reported (Ahmadi et al., 2021). Studies have examined the effects of climate change on Legumes production in the Maldives, and the results show that climate change, which has increased global warming, will lead to drought during plant growth periods (Corobov, 2002). In a study examining the process of evapotranspiration in Taiwan's paddy fields, it was announced that by 2050, 3-5% will be added to the evapotranspiration of rice (Yu et al., 2002). A project was conducted to study the impact of climate change on potatoes in Northern Europe and the results showed that climate change will prolong the growing season of potatoes in this region (Haverkort and Verhagen, 2008). Most Iranian studies are devoted to the impacts of climate change on wheat production (Karimi et al., 2018). As shown in Table 1, except for chickpeas, other crops are expected to decline significantly under climate change (Karimi et al., 2018).

Table 1. A review of climate change on crop yields in Iran (Karimi et al., 2018).

Crop	Period	Study region	Impacts on yield
Potato	2050s	Iran	Without adaptation: Yield ↓ (~48.3%) With adaptation: Yield ↓ (~13.3%)
Chickpea	2100s	Gonbad (Gn), Kermanshah (Kr), Bojnurd (Bj), Maragheh (Mr)	With CO2 effect: Yield ↑ (~11.08–49.23%) T ↑ (2.0–6.0°C) → Yield ↑ (~12.59–59.37%) in Gn and Kr and Yield ↓ (~2.50%) in Bj and Mr
Maize	2100s	Khorasan Razavi	Yield ↓ (~6.4–42.15%)
Maize	2100s	Khorasan	Yield ↓ (~1.0–39.0%)

2.5. Effects of global warming on agriculture

Climate is a major determinant of agricultural productivity (Haro-Monteagudo et al., 2018). Concerns about the potential effects of long-term climate change on agriculture have sparked a wealth of research over the past decade (Garrett et al., 2021). According to historical evidence, climate change has had a profound effect on the earth in recent years (Abdollahbeigi, 2020). Climate change will directly affect agricultural performance and rotation in temperature and rainfall, and indirectly on changes in soil quality, diseases and pests (Costa, 2021). The effect of climate change on the productivity of different products estimated through different models is shown in Table 2 (Karimi et al., 2018).

2.6. The effects of climate change on biodiversity

Decreased biodiversity and adverse effects on plant and animal species are other consequences of global warming (Nunez et al., 2019). Animal migration and vegetation change due to drought and water scarcity cause changes in the food chain and adverse effects on the ecosystem of the region (Upadhyay, 2020). This problem also leads to changes in the biodiversity of the aquatic ecosystem in the seas (Mannino et al., 2017). Climate change also has direct and indirect effects on the lives of birds, which can severely disrupt their life cycle (Spence and Tingley, 2020). On the other hand, due to global warming, the time of flowering and growth of plant species has changed compared to the past (Rosbakh et al., 2021). Many animal and plant species are now extinct due to climate change, and many species of animals are forced to migrate, disrupting the entire ecosystem of the planet (Upadhyay, 2020). More than half of all living things have been extinct several times in the history of the planet, but it has taken hundreds of thousands of years to recover (Ceballos et al., 2020).

2.7. Adaptation of plants to climate change

Adaptation of plants to climate change, at different levels in agriculture within the temperature range of field levels, with changes in planting and harvest days, plowing and rotation of crops or species suitable for climate change, increasing fertility and use of pesticides and improving irrigation And drainage systems have been developed (Rivera-ferre et al., 2021).

2.8. Plant breeding for adaptation to climate change

Understanding the impacts of climate change on crops and their impact on crop yield, as well as identifying adaptation strategies in the agricultural sector in terms of water consumption, production and food security is important (Nhamo et al., 2019; Schneider and Asch, 2020). Among the methods of adaptation to climate change, changes in crop type and cultivation pattern and production of cultivars tolerant to environmental stresses play an important role (Hussain et al., 2020). Oilseeds are so important among crops that they are the second-largest food source in the world after cereals (Friedt et al., 2018). Camelina (*Camelina sativa* L.) is a plant that has been cultivated in recent years as an oilseed in Iran (Piravi-vanak et al., 2021). Although vegetable oil is mostly obtained from the processing of oilseeds such as soybean, sunflower, cottonseed, peanut and rapeseed, these plants have a high water requirement and their cultivation is limited in various aspects such as cultivation conditions and climatic conditions (Adeleke and Babalola, 2020). The most important advantages of the camelina oil plant, which is one of the plants that have attracted a lot of attention in recent years, Ability to plant in autumn and harvest in late April, low water requirements, better adaptation to climate change and excellent resistance to drought and spring cold (Rahimi et al., 2021).

Table 2. The effects of climate change on the productivity of various crops (Karimi et al., 2018).

Crops	Yield Variation	Cause	Model Used	Location
		Yield increase up to 29–32 °C		
Corn, soybean, cotton	–30–46% by 2100 –63–82% by 2100	Slowest warming scenario Rapid warming scenario	Hadley III model	United States of America
Cotton, sunflower, wheat	–2–9% by 2050	Medium-high and low GHG emissions	DAYCENT	California's Central Valley
Wheat	–6%			
Rice	–3.5%	Each degree Celsius increase in world's mean temperature	Global grid-based, local point-based, statistical regression and field warming experiments	Multiple sites of the world
Maize	–7.4%			
Soybean	–3.1% by 2100			
Rainfed corn	–23–34% by 2055	Increasing temperature and precipitation variability	Probability-based approach	Central Illinois
Wheat	–2.1%			
Barley	–9.1%			Eastern and northern Europe
Maize	–24.5%			
Maize	–5.8%	Increasing annual temperature	Multi method analysis with statistical regression	
Sugarcane	–3.9%			Sub-Saharan Africa
Drought-tolerant sorghum	+0.7%			Sub-Saharan Africa
Cassava	+1.7%			
Wheat	–9%			Oceania
Rice	–3.7%	1°C increase in mean growing season temperature	Regression, Kendall-tau statistic, Pearson correlation	China
Wheat	–10.2%			
	–10–22%			

2.9. Climate change and food security

Climatic elements and factors as well as climate change affect food security in various ways (Zavaleta et al., 2018). This effect may manifest itself through changes in temperature, precipitation patterns, and overestimation of climates, ocean warming and acidification, or even diversion in wind patterns that can alter the transport of pollutants (Pettersson et al., 2020). Rising temperatures and changes in precipitation patterns have a direct effect on the activities of bacteria, viruses, parasites, fungi, etc., which in turn will cause specific diseases in society (Braide et al., 2020). Climate change can also lead to floods and droughts (Watanabe et al., 2018). Both of these phenomena can destroy the food reserves of an area (Leeson and Harris, 2018). Scientists predict rising temperatures and unstable rainfall could reduce agricultural productivity in many vulnerable areas (Martinez-Feria and Basso, 2020). In developing countries, this can deprive millions of people of the ability to produce or buy enough food (Matemilola, 2017).

3. Conclusion

Population growth has put a lot of pressure on agriculture to ensure the world's food and nutrition security, which is getting worse with climate change. Despite uncertainties about the future climate scenario and its possible effects, various studies report that climate change will reduce agricultural productivity in the coming years. Key climate factors, namely temperature, precipitation, and greenhouse gases, significantly inhibit pest infestation, soil fertility, irrigation resources, physiology, and plant metabolic activities. The future of climate change and its effects are highly unpredictable, complicating planning for mitigation and adaptation. This requires the development of climate-resistant technologies that include an interdisciplinary approach to the region. Appropriate varieties must be developed that can adapt to climate change, along with planned crop management and crop pest control. Farmers need to be trained in various smart climate technologies and trained to facilitate their use at the field level.

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