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Strategies to alleviate the unusual effects of climate change on crop production: a thirsty and warm future, low crop quality. A review

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Climate change is one of the most common challenges in semi-arid regions, which are affected by such constraints as drought, heat stress, and decreased soil fertility. The most important consequences of climate change – rising temperature, decreasing rainfall, and deteriorating quality of some crops – are studied in detail in this review. The main future climate scenarios in semi-arid regions include decreased precipitation with highly irregular and unpredictable distribution patterns, with most rainfall concentrated over winter months, prolonged dry spells, early heat stress, exacerbation of edaphic constraints such as reduced soil moisture content, reduced soil organic matter, reduced soil biodiversity, reduced critical nutrient availability, and, ultimately, fewer crop yields. Due to the moisture and soil constraints caused by climate change, the cropping system, crop succession, and soil tillage techniques will need a major overhaul, and this requires modifying soil management and fertilisation, design of some new agro-climatic zoning, including neglected and underutilised crop species in rotations, optimised sowing time windows, expanded irrigation, design of multi-functional cropping systems, conservation agriculture, some changes in agricultural equipment, and the use of climate-smart agriculture practices. Rising carbon dioxide concentrations will decrease nitrogen metabolism by reducing photorespiration, and this reduces the protein content of the grain and worsens the quality of the staple crops. Selection of climate-smart varieties, application of agro-inputs at the right time, right place, and right amount (precision agriculture), and the use of leading technologies such as nano for designing the smart fertiliser should be considered to overcome the adverse effects of climate anomalies.

Keywords: abrupt climate changes; adaptation strategies; climate anomalies; nutritional quality; protein content; staple crop; yield improvement

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INTRODUCTION

Due to human activities (greenhouse gas emissions), the world has already been experiencing some climate change for a few decades. Data analysis in previous decades revealed that the global climate could indeed shift radically within a century, perhaps even within a decade. For example, increases in atmospheric carbon dioxide (CO_2) and ozone (O_3) levels were ubiquitous in many agricultural regions around the world (Wang et al., 2020). Furthermore, an abrupt increase in global temperature and extra heat are driving local and seasonal temperature extremes, shrinking snow cover and sea ice, intensifying the dry season, and changing habitat ranges for plants and animals (Hedlund et al., 2018). It has been estimated that warming trends are likely to reduce global yields by roughly 1.5% per decade. Although part of this decline is offset by technological and management improvements, the long-term decline in agricultural productivity due to climate changes is highly significant. Altogether, these changes can pose a serious threat to food security and it is important that assessments of global food security consider local and regional impacts in addition to those at the global scale. However, according to the latest estimates 9.2% of the world population was exposed to severe levels of food insecurity (Cafiero et al., 2018). This implies that food security can be further threatened by climate change, and it is one of the most important challenges to producing adequate food for the growing population (Kang et al., 2009). Roughly 83% of consumable food calories come from staple crops such as maize (corn), rice, wheat, soybeans, oil palm, sugarcane, barley, rapeseed (canola), cassava, and sorghum. It has been known that yields of some important global staples are already declining. For example, it is estimated that climate change is reducing global rice yields by 0.3% and wheat yields by 0.9% on average each year (Ray et al., 2019). In contrast, some more drought-tolerant crops such as sorghum in Africa, southern and south-eastern Asia have benefited from climate change and their yield has increased by 0.7–0.9% yearly due to climate shifts since the 1970s.

Farmers are used to dealing with weather, but climate change is making it more difficult by increasing temperature during the warm season, the occurrence of severe colds in winter and early spring, and altering rainfall distribution (Shah et al., 2021). Climate change is usually accompanied by changes in more than one meteorological parameter. That is why the interaction of several meteorological parameters and their changes have a more severe impact on crops than a single weather extreme event (Estrella, Menzel, 2013). Researchers tried to understand whether climate change was measurably affecting crop productivity and global food security (Ray et al., 2019). Due to the demographic pressure, it is very important to pay attention to this issue, and in some cases, it is necessary to use a new paradigm, change macro-instruction and long-term methods, collective responsibility, wisdom, and plans with government and international support (McMichael, 2014).

The effects of climate change on crop production may be direct or indirect. Direct effects include changes in temperature, precipitation, and moisture regime. Indirect effects include those that are induced by adaptations such as changes in irrigation, crop rotation, and tillage practices (Hamidov et al., 2018). Although all of these effects are sometimes evaluated and interpreted in terms of quantitative aspects of crop yield, climate change can have a more important effect on product quality and it can ultimately affect community health, which has been less studied. Although climate change has improved some aspects in some areas, this cannot be generalised to all areas, and efforts should be made to improve crop quality. Relying on the framework of a crop prediction model , statistical analysis of crop years during the last decades, and scenario building, it also provides estimates of climate change effects on crop yield and food security. This review focused on the effects of climate anomalies, i.e., decreasing rainfall, increasing temperature (drought and heat stress), and the reasons for the decline in the quality of agricultural products as well as strategies to improve production and maintaining food security under climate change. We are also reviewing the most important technological, strategic, and investment approaches leading to sustainable agricultural development for food security under climate change (Climate smart crop production).

CLIMATE CHANGE AND ITS IMPACT ON WATER RESOURCES

The hydrological cycle, water resources, and water supply for plants are undoubtedly among the greatest pressures of climate change. Along with climate change, population growth, and the development of the irrigated area with relatively low efficiency rates of irrigation have increased water demand significantly (Sherwood, Fu, 2014). Therefore, it is necessary to investigate the exact effects of climate change on water-soil-plant relations in order to design possible adaptation strategies.

Climate change can directly affect soil water balance, and it will lead to significant changes in soil evaporation and plant transpiration; subsequently, the crop growth period may be shortened and water productivity can be decreased (Kang et al., 2009). The prediction is that with the temperature increase and precipitation fluctuations, water availability and crop production are likely to decrease in the future. Studies show that precipitation decrease are possible in some regions of the world, and this means that water availability is under serious threat from the changing climate (Seung-Hwan et al., 2013; Azhoni et al., 2018).

This will be especially noticeable in semiarid areas, especially in the area of WANA (West Asia and North Africa), which was previously facing water shortages; it can pose a serious threat to the food security of this region with a relatively high population.

One of the most important reasons for water shortage in climate change is the rising temperature and, consequently, the increase in water loss and inefficient transpiration of the plant.

In recent years, relative humidity has been almost constant. However, the increasing temperature can intensify the vapor pressure deficit (VPD) between the plant and the air, which increases unwanted and uncontrolled leaf transpiration (Lobell, Gourdji, 2012). The increased VPD leads to reduced water-use efficiency because plants lose more water per unit of carbon gain. Plants respond to a very high VPD by closing their stomata, but at the cost of reduced photosynthesis rates and an increase in canopy temperature, which in turn may increase heat-related impacts. In fact, all the absorbed water from the soil enters the vascular system and, after their impact on the growth process or chemical activities, the bulk of the water is removed from the plant through transpiration (Bertolino et al., 2019). Certainly, most of the water released through the stomata is not functional, and it is likely that the plant will be able to grow normally with lower amounts of transpiration, which can result in improved water use efficiency without yield penalty (Chaves, Oliveira, 2004; Bertolino et al., 2019). Hence, it seems manipulating and modifying the operation, density, or morphology of the stomata so that they can absorb more carbon dioxide per unit of water could be one of the most important breeding measures to increase water use efficiency.

Previous evaluation of barley and rice showed that the decrease of stomata density by overexpression of the *EPF1* gene (epidermal patterning factor 1; preventer of stomatal clustering) could increase water use efficiency, despite small reductions in photosynthetic rate under well-watered conditions in some cases (Hughes et al., 2017; Caine et al., 2019). Some morpho-physiological properties such as the ability to prompt supply ions to guard cells, linear dumbbell-shaped guard cells, trichome (epidermal hair), thick cuticle (waxy or leathery leaf), sunken stomata, extensive plasmodesma connections with subsidiary cells, which exist in grass species, can improve water efficiency (Bertolino et al., 2019).

Another target point for breeders that should be seriously considered during climate change is root modification. Changes in the metrics of root-to-shoot ratio and sink and source relationships can partially improve water absorption and reduce inefficient water loss (Maseda, Fernández, 2006). Roots with small-diameter and large-diameter xylem vessels, the ability to penetrate at high depths, continuous vascular connections, and a high specific root length increase the contact surface of roots with soil and increase water absorption, with high hydraulic conductance. In addition, the decrease in root diameter also helps to enhance water access and increases the productivity of plants under water stress (Kim et al., 2020). Aquaporins are water channel proteins present in the plasma membrane, vacuolar membrane, and on the surface of nitrogen-fixing nodules in plants of the Leguminosae family (plasma membrane intrinsic proteins, tonoplast intrinsic proteins, nodulin intrinsic proteins, respectively). It has been revealed that increasing the expression of aquaporins under water stress conditions can be one of the options to improve water absorption (Kapilan et al., 2018).

Climate change and dry spells caused by it have led to more attention being paid to rainwater conservation/harvesting techniques (RWH). Harvesting the runoff and floods or temporary storage of precipitation out of the required intervals are the most important strategies for sustainable crop production in semi-arid areas (Tolossa et al., 2020). Rainwater harvesting methods for crop production are divided into three different classes basically determined by the distance between the catchment area and cropped basin (application area): in-situ systems, internal (micro) catchment RWH, and external (macro) catchment RWH (Ammar et al., 2016). Although each method has some advantages, micro and macro catchments are more considered, especially in semi-arid regions. In arid or semi-arid regions, most of the cultivated areas are often on the outskirts of cities, the pattern of rainfall is very irregular and unpredictable, and the collection of water from uncultivated areas is significant. In water-limited environments, adaptation measures such as reducing evaporation (by mulching, appropriate and square planting patterns, reduced tillage, planting into furrows, using plants or cultivars that have the respectable architecture to cover the soil quickly, etc.) and adjusting crop calendars, increased crop water use efficiency, and advanced irrigation technologies can further reduce crop water requirement (Figure). However, in some regions, climate change has led to increased rainfall and reduced yields. Examination of these areas has shown that higher rainfall amounts increase N leaching and subsequently reduce crop yield (Gérardeaux et al., 2018).

In some areas, climate change is such that changing the agro-climatic zoning, improvement of agrobiodiversity, and including neglected and underutilised crop species in rotations is undeniable. Some of the underutilised minor crops such as amaranth, mung bean, and winter grain legumes, which are well adapted to the spring precipitation pattern, are highlighted. These crops provide more options to build temporal and spatial heterogeneity into uniform cropping systems and will enhance resilience to drought stress (Ebert, 2014). The use and domestication of native and rangeland plants in any region that produces acceptable biomass despite water deficiency can be an effective way to improve food security in the coming years. However, it should not be overlooked that mild drought stress and deficit irrigation throughout the whole season with the condition of the proper observance of other management are more likely to improve water use efficiency (WUE) and yield concurrently (Yu et al., 2020).

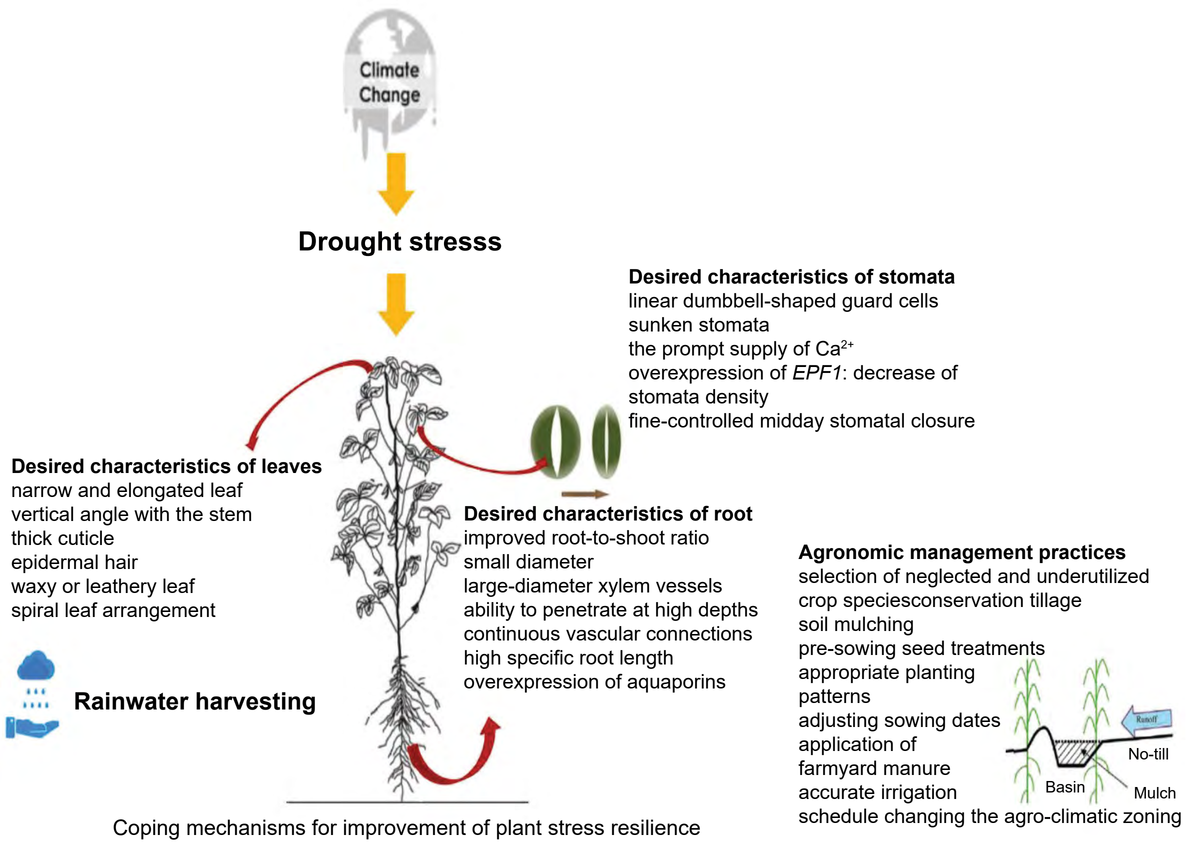

Figure. Some possible adaptation strategies, adaptive mechanisms, and management through cultural and molecular alternatives to mitigate drought effects on plants (adapted from Seleiman et al., 2021)

PLANT TOLERANCE TO HIGH TEMPERATURE IN A CHANGING ENVIRONMENT

Climate change is real, and it is caused by human activities. These changes affect different aspects of plant growth (Zhang et al., 2019). Among the changed atmospheric factors in recent decades, the rise in temperature and global warming are more evident than others (IPCC, 2014). Two-thirds of global warming has occurred since 1975, at a rate of roughly 0.15–0.20°C per decade (Lorenz et al., 2019). Temperatures rising due to climate change can reduce crop production in several ways. Firstly, higher temperatures cause faster crop development and thus shorter crop duration, which in most cases is associated with lower yields (Stone, 2001; Lobell, Gourdji, 2012). Secondly, a sharp rise in temperature (heat stress) can reduce photosynthesis and therefore may lead to a decrease in crop growth and final yield. However, crops with a C_4 photosynthetic pathway (e.g., maize and sugarcane) profit from this condition. It appears that C_4 plants benefit from climate change and increased temperatures due to the nature of their photosynthetic system; however, temperatures above 38°C inhibit photosynthesis (Zheng et al., 2022), whereas warming at night raises respiration costs without any potential benefit for photosynthesis (Sadras, Calderini, 2015). Thirdly, warming raises the vapor pressure deficit (VPD) between air and the leaf and increases transpiration and water loss. Finally, rising temperatures directly affect some intracellular processes and inhibit some of the mechanisms needed for cell growth, thereby reducing crop yield (Siebert et al., 2014). Unlike drought stress, the effects of heat stress have been less studied. It seems that the invention of new omics technologies and bioengineering such as genomics, transcriptomics, proteomics, metabolomics, phenomics, and ionomics have opened a new window for studying the cellular and molecular aspects of the effects of global warming on plants. By affecting the different aspects of crop physiology such as increasing evapotranspiration, disrupting the plant water balance, decreasing photosynthesis, increasing respiration, decreasing the root system growth, and disrupting phenological stages (pollination, flowering, root development, and root growth stages), heat stress can result in reduced growth of the whole plant and economic yield (Cho et al., 2018; Janni et al., 2020).

From cellular and molecular perspectives, heat shock factors and heat shock proteins have been considered important potential candidates to address the issue of heat stress. Heat shock proteins are a group of protective proteins that increase their expression and accumulation under stress conditions (Wu et al., 2022). They are involved in signalling, reactive oxygen species (ROS) scavenging, translation, protein folding, host-defence mechanisms, biosynthesis of compatible solutes, carbohydrate metabolism, energy-saving pathways (e.g., reduction in the expression of non-essential genes), and amino acid metabolism (Usman et al., 2014; Li et al., 2015; Reddy et al., 2016). Genetic engineering and increased expression of the encoding genes of the said proteins had a significant effect on pollen viability, stigma receptivity, and plant growth under heat stress (Alam et al., 2017).

The use and replacement of C_4 heat-tolerant plants such as sorghum and millet can be one of the undeniable solutions for some semi-arid regions. Compared to C_3, C_4 plants have higher photosynthetic rates and better tolerance to high temperature and drought. Under high temperature and high light, the C_4 pathway is more efficient than C_3 photosynthesis and this is due to the CO_2-concentrating mechanism (Taiz et al., 2018). The change in plasma membrane fluidity and its permeability are the first responses of plant cells to heat stress. Hence, the preservation of plasma membrane function under heat stress is necessary for continued and efficient photosynthesis and respiration systems (Guihur et al., 2022). It has been revealed that an increase in the expression of the fatty acid desaturase (FAD) family and, consequently, an increase in a number of double bonds within fatty acid chains play an important role in adaptation to high-temperature stress (Niu, Xiang, 2018).

Modulation of the antioxidant defence system through genetic manipulation or external stimulant treatments such as foliar application of salicylic acid, ascorbic acid, proline, and glycine betaine under heat stress conditions results in reactive oxygen species (ROS) detoxification and stabilises the photosynthetic system and related pigments (Hussain et al., 2019). Heat stress induces drastic effects by changing the ratio of phytohormones. As reported, the concentration of some phytohormone and growth regulators such as abscisic acid, salicylic acid (HOC_6H_4COOH), and ethylene increased under high-temperature stress, while others, such as cytokinin, auxin, and gibberellic acids, decreased (Wu et al., 2016). It appears that maintaining the phytohormone balance under stress conditions is a good research point to improve heat tolerance.

The reproductive growth stage has been recognised as highly sensitive to heat stress (Hedhly et al., 2009). The use of fast-growing cultivars or species (winter or spring ephemeral herb species) in areas with hot summers can be significantly effective. However, there is a negative correlation between early maturity and crop yield, and that remains an important challenge for breeders. The involvement of native and forgotten species in crop rotations should be seriously considered. Native species show certain changes in their growth patterns and a physiological process to cope with heat stress. Although some agronomic management practices, such as adjusting planting dates, accurate irrigation schedules, and, to some extent, the use of some foliar spraying treatments mitigate the effects of heat stress, significant emphasis has been put on molecular biology as the newest agricultural research tool to detect molecular markers associated with heat stress tolerance.

NUTRITIONAL QUALITY OF CROP PLANTS UNDER A CHANGING CLIMATE

Concentration of CO_2 as a by-product of respiration and burning of fossil fuels or decaying vegetation has been increasing rapidly since the beginning of the industrial period. Increased CO_2 concentration is expected to affect current and future ecosystems (Graven et al., 2020). This aspect of the climate trend generally enhances C_3 plant productivity, whereas other climate anomalies (heat stress and drought), generally elicit the opposite response. Estimates suggest that CO_2 trends in recent years resulted in increased global yields by roughly 1.8% (Zampieri et al., 2019). Simultaneously, it seems that increased temperatures resulted in a significant reduction in global yields by approximately 1.5% per decade (Neupane et al., 2022). However, all these estimates have been made in quantitative terms, and the question remains: what is the qualitative effect of the climatic trend on crop production? A few new studies have further quantified the impacts of climate change on crop quality. A meta-analysis of published data concluded that sulfur is decreased in grains grown at elevated CO_2 (Ainsworth, Long, 2005). However, there is still little information on how climate change and increased CO_2 concentration decrease nutrient concentration and qualitative aspects of the crops (Jobe et al., 2020). It appears that elevated CO_2 can stimulate carbohydrate production, especially in C_3 food crops and it may result in the dilution of other grain components such as iron, zinc, and protein (Dietterich et al., 2014). Previous evaluation revealed that elevated atmospheric concentrations of CO_2 affect plant phenology and they would have significant impacts on ecosystem productivity. Elevated CO_2 causes accelerated autumnal leaf senescence and significantly increases autumnal nitrogen desorption efficiency (Li et al., 2019). However, it seems that this increase is not enough to improve the quality aspects of the crop product.

Evaluation of mineral concentration in soybean seeds grown under elevated CO_2 showed that concentrations of K, Ca, Mg, P, and S increased significantly under elevated CO_2 at R6 growth stage (full seed size), while the concentration of Fe decreased significantly. The response of Zn and Mn concentrations to elevated CO_2 varied among cultivars. These findings suggest that elevated CO_2 is likely to benefit from the accumulation of seed fat and isoflavone but not from that of protein (Li et al., 2018). Previously, Bloom et al. (2010) reported that atmospheric CO_2 enrichment did not stimulate the growth of wheat plants by inhibiting the assimilation of nitrate into organic nitrogen compounds. However, the reactions of the organs were different so elevated CO_2 enhanced root nitrate assimilation in wheat and Arabidopsis while it inhibited shoot nitrate assimilation (Bloom et al., 2020). Altogether, previous studies showed that this could reduce the content of grain protein. This was particularly evident when the plants receiving NO_3^- as a sole N source: their protein content was similar to those receiving NH_4^+ (Rubio-Asensio and Bloom 2017). Elevated concentration of atmospheric CO_2 will disturb nitrogen metabolism by reducing photorespiration and ammonia production, and this can affect protein biosynthesis negatively and reduce the quality of the staple crops (Bloom et al., 2020). However, some high-yielding rice cultivars are able to maintain grain quality under elevated concentrations of CO_2 due to the lack of restrictions in the nitrogen source (Hasegawa et al., 2019). Therefore, these results promise that selecting new smart climate cultivars from the gene pool and transmission of effective genes can be a rational solution to prevent quality decline under climate trends. In addition, careful management of fertilisers, especially nitrogen, sulphur, and micronutrients should be considered, and appropriate fertiliser sources should be applied. Since high nitrogen utilisation can stimulate vegetative growth and can result in soil moisture depletion during the sensitive reproductive stages, their split application is highly recommended. The use of farmyard manure is critical for ameliorating the physicochemical and biological characteristics of soil and improving the accessibility of essential elements and nutrients

(Ewané et al., 2020). The accurate determination of an irrigation schedule has a significant impact on the uptake of nutrients by the roots and can improve the quality of the harvested product. Selecting the correct sowing date during the relatively wet period at the beginning of the growth season can also increase the availability of nutrients.

Under heat and drought stress, due to the inhibition of photosynthesis and stimulation of nitrogen remobilisation from leaves to filling seeds, the ratio of carbon to nitrogen was reduced, and this was accompanied by an increase in protein percentage (Taiz et al., 2018; Janni et al., 2020). Heat stress during grain filling markedly decreased starch accumulation in cereals (Yamakawa, Hakata, 2010; Yang et al., 2018). The levels of sugars such as fructose, sugar nucleotides, and hexose phosphate also declined under heat stress (Yang et al., 2018). The decrease in sugars may be related to assimilating utilization for purposes other than edible component production (Asthir et al., 2012; Janni et al., 2020).

Although in the early stages of drought or heat stress some plants can increase the concentration of compatible compounds, osmotic substances, and secondary metabolites, due to the high energy consumption for their production, reduced growth and biomass of the plant, the accumulation of these substances in improving the quality of the product is not so great. Agronomic biofortification – the utilisation of trace elements in soils or plant leaves to improve micronutrient contents in economic and edible parts of crops – is a reasonable, low-cost, and high-efficiency approach to improve quality (Gao et al., 2020). However, some nutrients and vitamins are still deficient and for this reason it seems necessary to enrich final products after harvest. The combined utilisation of micronutrients with macronutrients and organic fertilisers as well as the selection of suitable cultivars (climate-smart varieties) with high adsorption efficiency under limited soil moisture conditions can significantly increase the quality of the product. Favourable soil conditions that facilitate and increase the availability of essential trace elements in the rhizosphere and help crop uptake are the most important requirements for the success of biofortification methods (Dhaliwal et al., 2022).

CONCLUSIONS. FUTURE PERSPECTIVES

Here we have tried to evaluate some of the negative effects of climate change on crop production and provide some current and possible solutions to reduce their adverse impact on food security. The agricultural sector has been both ignored and a victim of climate change during the last decades. Hence, there is an obvious requirement for coping with climate anomalies (heat stress and drought) and mitigating the contribution of agriculture to greenhouse gas emissions. However, at the same time, the agricultural sector also has a serious responsibility to provide food security for the growing population in the coming decades. Therefore, identifying the impacts of climate change on crop production and finding logical solutions to alleviate their negative effects is an undeniable task. In this review, the effect of climate change on water scarcity and some strategies were highlighted. Improvement of stomatal properties, root and leaf morpho-physiological characteristics through genetic engineering based on omics techniques and plant architecture is an open breeding programme that can significantly increase WUE. Numerous cropping options are claimed to be climate-smart, with the incorporation of neglected and underutilised crop species in rotations, conservation tillage, mulching, pre-sowing seed treatments, appropriate planting patterns, adjusted sowing dates, combined application of organic and inorganic fertilisers, accurate irrigation schedule, and developing new agro-climatic zoning as powerful examples.

The increase of chaperone/heat shock protein, the reinforcement of ROS scavenging systems, changing the leaf angle to reduce the amount of solar energy loading, redirecting photosynthesis pathways to C_4, the increase in the number of unsaturated membrane fatty acids, phytohormone ratio adjustment, and inclusion of adapted native species in rotations are among the options that should be considered in improving heat tolerance. It is now clear that climate change will make our crops less nutritious, and it will impact our health.

The mechanism that causes certain crops to be less nutritious with elevated levels of atmospheric CO_2 is partly specified. Inhibition of photorespiration under elevated CO_2 concentration can reduce nitrogen metabolism and result in a lower amount of protein in the harvested crop. Application of fertilisers containing mineral nitrogen such as ammonium along with organic fertilisers increases protein production under elevated CO_2 concentrations. However, as can be seen from the above sections, a critical area of future research is how crop plants can be adapted to producing nutritious yields under climate anomalies. This is a very important yet under-researched area. The selection of plants with high adaptability to climate trends as climate-smart crops is very important for the breeders. In addition, farmers will need to use a combination of management approaches to alleviate the negative effects of climate change and develop resilient food production systems.

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KLIMATO KAITOS POVEIKĮ AUGALININKYSTEI MAŽINANČIOS STRATEGIJOS: SAUSA IR ŠILTA ATEITIS, PRASTA DERLIAUS KOKYBĖ

Santrauka

Klimato pokyčiai – vienas iš dažniausių iššūkių pusiau sausuose regionuose, kuriuose susiduriama su griežtais apribojimais. Šioje apžvalgoje išsamiai ištirtos svarbiausios klimato kaitos pasekmės – didėjanti temperatūra, mažėjantis kritulių kiekis ir pablogėjusi kai kurių pasėlių kokybė. Pagrindiniai ateities klimato scenarijai pusiau sausuose regionuose apima nereguliarų ir nenuspėjamai mažėjantį kritulių kiekį, kai daugiausia kritulių susikaupia per kelis žiemos mėnesius, užsitęsusią sausrą, ankstyvą karštį, suintensyvėjusius edafinius veiksnius, tokius kaip sumažėjusi dirvožemio drėgmė, sumažėjęs dirvožemio organinės medžiagos kiekis, sumenkusi dirvožemio biologinė įvairovė, sumažėjęs kritinių maistinių medžiagų kiekis ir galiausiai mažesnis pasėlių derlius. Klimato kaita verčia iš esmės peržiūrėti pasėlių sistemą ir dirvos įdirbimo metodus: būtina keisti dirvožemio įdirbimą ir tręšimą, suformuoti naujas agroklimatines zonas, įskaitant apleistus ir nepakankamai išnaudojamus sėjomainos pasėlius, optimizuoti sėjos laiką, išplėsti drėkinimą, projektuoti daugiafunkcines pasėlių sistemas, tausojančias žemės ūkį, atnaujinti žemės ūkio įrangą ir taikyti pažangią žemės ūkio praktiką. Didėjanti anglies dioksido koncentracija mažina azoto apykaitą, dėl to mažėja baltymų kiekis grūduose, prastėja pagrindinių pasėlių kokybė. Siekiant įveikti klimato anomalijų neigiamus padarinius, reikėtų tinkamu laiku, tinkamoje vietoje parinkti klimatui tinkamas veisles (tikslioji žemdirbystė) bei taikyti pažangias technologijas.

Raktažodžiai: staigūs klimato pokyčiai, prisitaikymo strategijos, klimato anomalijos, mitybos kokybė, baltymų kiekis, pagrindiniai augalai, derliaus gerinimas