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Drought's Harmful Effect on Crops Production and its Mitigation Approaches

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Abstract: *The biggest and most significant issue that seriously affects global food security for people is drought. Among all the abiotic factors, drought is likely to have one of the most detrimental effects on soil organisms and plants. The most catastrophic abiotic stress that has severely affected crop productivity worldwide is drought. Crops are particularly prone to drought because it reduces the amount of water and nutrients available, both of which are essential for plant survival and growth. The main abiotic limitations in the current and future climate change scenarios is drought stress. The most detrimental abiotic factor is drought, which affects many molecular, biochemical, physiological, morphological, and ecological aspects and processes during the whole growth and development process. Plants under prolonged drought stress have altered metabolic responses linked to growth and yield characteristics. One of the main issues with the current climate is drought, which is also one of the most serious abiotic stresses in many regions of the world. Drought is the single most important environmental stressor that negatively impacts crop productivity and quality worldwide. One of the main environmental variables influencing crop quality and productivity worldwide is drought. Drought stress diminishes a plant's capacity to yield by diminishing the size of its leaves, stem expansion, and root multiplication inside the soil. It also messes with plant water interactions and lowers water-use efficiency.More than 50 years of climate change and population expansion have forced agriculture into environmentally marginal areas in drier parts of the world. This is projected to have a major impact on agricultural production, particularly in sub-Saharan Africa. Among abiotic factors, drought is the leading cause of crop yield loss worldwide. Drought is a major global issue that causes food shortages and makes it difficult for small-holder farmers to grow enough crops when rainfall is erratic and low. Crop plants have evolved a variety of morphological, physiological, and biochemical mechanisms of adaptation to withstand drought stress. A plant, however, may display multiple coping mechanisms in response to drought stress.The mechanism(s) resulting in the least amount of yield loss during a drought are known as drought resistance. Some mechanisms of drought resistance include physiological factors, reduced transpiration, dehydration avoidance, and drought escape. Utilizing high-yielding, drought-tolerant cultivars that are well adapted is crucial to maximizing production potential while lowering the risk of climate change for as long as possible. Climatic-smart agriculture is ultimately the only approach that can reduce the detrimental effects of climatic changes on crop adaptability before they have a significant influence on global crop production.*

Keywords: *Food Security;Drought stress; Climate Change; Resistance; Yield Loss; Climate Smart*

1. INTRODUCTION

By 2050, it is predicted that there will be two billion more people on the globe, which will raise the demand for food to feed the expanding population (Mora *et al*., 2020; Zsogon *et al*., 2022). According to predictions from the Food and Agricultural Organization of the United Nations (FAO), in order to meet demand current levels of consumption, agriculture will need to produce 60% more food globally and 100% more in developing nations by 2050. Increasing the productivity of currently cultivated land is the primary means of meeting the world's food demand, as expanding agricultural lands comes with major implications for the environment. Therefore, an essential prerequisite for sustainable development is to encourage changes to more environmentally friendly production methods. However, the primary barriers to meeting the world's food demand are climate change and global warming, along with a growing population (Lowry *et al*., 2019). More significantly, the problem rests not only in feeding the world's expanding population, but also in producing food in a sustainable and safe manner (Kumar *et al*., 2012). Increasing agricultural productivity and guaranteeing sustainable food supply need improving resilience to environmental challenges, especially in the current period of global climate change.

One of the most severe abiotic factors that reduces the total crop yield of practically all agricultural crops is drought. By the end of 2025, 1.8 billion people worldwide are predicted to experience a severe water shortage, and over 65% of people on Earth will live in water-stressed environments (Nezhadahmadi *et al*., 2013). Plant growth, photosynthesis, and yield are all impacted by drought (Praba *et al*., 2009). According to Demirevska *et al*. (2009), the degree of drought stress, concurrent stress, plant species, and developmental stage all affect how sensitive a plant is to drought. Extreme climate conditions as droughts have detrimental effects on crop production both locally and globally (Zipper *et al*., 2016). Droughts between 1964 and 2007 resulted in a loss of cereal of 1820 million Mg, which was equal to the production of wheat and maize worldwide in 2013. The loss during the more recent droughts (1985-2007) was double that of the earlier droughts (1964-1984) (Lesk *et al*., 2016). Assessing the consequences of drought is essential for adaptation and mitigation, which is why it has garnered a lot of attention in recent years (Madadgar *et al*., 2017).

Abiotic stresses have the potential to cause large yield losses. For example, a drought on its own can reduce crop yields for several crops by 50-70% (Kumar *et al*., 2020). For instance, 40% yield losses in maize (Daryanto *et al*., 2016), 21% in wheat (Daryanto *et al*., 2016), 50% in rice (Daryanto *et al*., 2017), 27-40% in chickpea (Mafakheri *et al*., 2010), 42% in soybean (Maleki *et al*., 2013), and 68% in cowpea (Farooq *et al*., 2017) were documented because of drought stress. In many regions of the world, drought is becoming a greater threat to sustainable agriculture due to the effects of climate change, such as erratic rainfall and higher temperatures. Drought stress tolerance is a complex quantitative characteristic linked to various physiological and biochemical mechanisms (Wang *et al*., 2019).

Worldwide, abiotic stresses pose a serious threat to crop productivity. Drought can cause plants to respond in many different ways, the most prominent being modifications to their morphology and development. Historical evidence indicates that crop yields were severely lowered in the past. Crop development and growth are slowed by drought stress, which alters the crop's morphological, physiological, and biochemical characteristics (Tiwari *et al*., 2021). Drought stress can affect most crops, mostly during flowering and seed development (Anjum *et al*., 2017). Water scarcity affects even drought-tolerant plants when they are reproducing and developing seeds (Fang *et al*., 2015). Drought is caused by either excessive transpiration or limited water delivery to the roots of crops (Berger *et al*., 2016). Depending on their developmental stage and other factors, crops react to water scarcity in different ways (Berger *et al*., 2016).

Moreover, extensive drought forecasts have proven inaccurate in developed nations like the US (Anderson *et al*., 2018). The lack of a widely accepted definition of drought (Enenkel *et al*., 2015), the effects of climate change on worldwide drought patterns (Salami *et al*., 2022), and the uncertainty surrounding global food security (Purakayastha *et al*., 2019) all play a role in it. Concurrently, it is imperative to take into account teleconnections, such as the influence of variations in sea surface temperatures on drought episodes in Sub-Saharan Africa, which have contributed to the intricacy of models and evaluations that are already highly advanced. Furthermore, it is impossible to find a single physically measurable drought measure to determine for all of these situations because different forms of drought, such as meteorological, agricultural, and hydrological ones, have different socio-economic effects (Ekundayo *et al*., 2021). For instance, droughts can be made worse by other factors (including heat waves, floods, and violence) (Ropo *et al*., 2017) and are a common occurrence in Sub-Saharan Africa, especially in South Africa (Orimoloye *et al*., 2021a).

More effective adaptation strategies, policies, and innovative research may contribute to reduce the effects of the increased drought risk brought by climate change (He *et al*., 2019). This will help advance efforts to achieve the second Sustainable Development Goal (SDG; zero hunger). In order to effectively reduce the effects of drought on agricultural production and increase societal resilience to future drought-induced emergencies, policymakers and stakeholders must have a thorough understanding of the interactions between drought and food security. This understanding must be maintained while also meeting competing demands and enhancing environmental sustainability.

In an international context where food demand is rising due to population expansion, drought-tolerant crops are critical (Yu *et al*., 2022). In many parts of the world, drought is one of the most common stresses. It affects a wide variety of agricultural species, decreasing photosynthesis and encouraging the formation of reactive oxygen species (ROS) and cell membrane damage, all of which have a substantial negative impact on the quantity and quality of agricultural products produced (Kapoor *et al.*, 2020). Many morphological and physio-biochemical processes in plants are not significantly affected by drought stress. One of the abiotic factors that significantly reduces plant productivity worldwide is drought, whose frequency and severity have grown throughout the last 20 years (Begna, 2020). Numerous pathways involved in plant growth, development, and metabolism are hampered by severe drought stress (Ashour *et al*., 2010).

Breeding drought-tolerant cultivars is thought to be the greatest way to deal with the stress of drought and increase yields in shortages of water environments. In order to better understand the physiological and genetic basis behind drought tolerance, crop breeders rely on a multilayer approach to breed genotypes that are resistant to drought. They do this by phenotyping the traits associated with yield under water stressed conditions and characterizing the genetic diversity that is currently available (Mwadzingeni *et al*., 2016a). The most important benchmark for selecting breeding material resistant to drought is still phenotyping of morpho-physiological parameters, including as yield and yield components (Shaukat *et al*., 2021). In both ideal and water-deficient scenarios, crop yield has greatly increased due to selection based on characteristics such plant height, shortened days to anthesis and maturity, root architecture, and high root density (Ehdaie *et al*., 2012). A lower number of days to anthesis and maturity is necessary to prevent terminal drought, whereas a shorter plant height yields a higher harvest index (Lopes *et al*., 2023).

In order to adapt to drought stress, crop plants have developed a variety of morphological, physiological, and biochemical systems. When a plant experiences drought stress, however, it might use a number of coping strategies. Drought resilience refers to the method or mechanisms that cause the least amount of crop loss during a drought. Some strategies for surviving a drought include minimizing transpiration, avoiding dehydration, and adjusting physiological factors. Worldwide food security will eventually be threatened by climate change, making it harder than ever in the twenty-first century to feed the growing worldwide population. Using high-yielding, drought-resistant varieties that are well adapted is essential to maximizing yield potential while lowering the risk of climate change. Climate-smart agriculture is the only way to mitigate the detrimental effects of climate change on crop adaptability, and it can be implemented before the changes have a major influence on global crop production. The objective of the paper was understand the profound and grand impact of drought on the crop production and productivity under different production scenarios.

2. EFFECTS OF DROUGHT STRESS ON CROP PLANT SYSTEM

Reduced precipitation leads to drought stress, a devastating natural disaster that negatively affects plant growth, physiology, biochemistry, and reproduction from germination to maturity (Wasaya *et al*., 2021). Drought stress also poses a serious threat to global food security (Cheng *et al*., 2021). In general, plants adapt their morphological structure, physiological functions, biochemical reactions, and molecular mechanisms to drought stress and increase their drought tolerance in arid environments. These adaptations include slowing down the rate at which root, stem, and leaf tissues grow, massive accumulations of osmolytes (sugar, protein) in the cells, an increase in the activity of antioxidant enzymes like superoxide dismutase, catalase, and peroxidase, changes in the content of phytohormones, and modulation of gene expression (Mubarik *et al*., 2021; Raza *et al*., 2023a; Li *et al*., 2024).

One of the most damaging abiotic factors that reduces the total crop yield of practically all agricultural crops is drought. By the end of 2025, 1.8 billion people worldwide are predicted to experience a severe water shortage, and over 65% of people on World will live in water-stressed environments (Nezhadahmadi *et al*., 2013). According to Swelam *et al*. (2022), drought is an abiotic stress factor imposed by the environment that influences optimal performance. As a result, crop plants experience a drop and deviate from their ideal performance (Larcher, 2003). For agricultural scientists, the drought effect is a significant problem since it causes several physiological, biochemical, and molecular alterations in higher plants (Sial *et al*., 2022).Drought stress may worsen due to the diverse effects of global climate change and result in a significant loss of cereal crop yield (Kumar *et al*., 2020).

Abiotic stresses brought by different climate circumstances can be harmful to crop growth and yield. According to Ansari *et al*. (2017), plants experience morphological, physio-biochemical, and cellular alterations in response to a variety of abiotic stresses. One of the main challenges to crop production globally is drought since it reduces crop yield and severely impacts crop efficiency (Rai *et al*., 2021). Lack of water causes a range of reactions in crops at the physio-biochemical, molecular, and morphological levels, which in turn affects several processes and ultimately depresses crop productivity (Zlatev Z and Lidon F.C, 2012). A drought is a meteorological condition caused by a prolonged absence of water in the soil for a variety of causes, including low precipitation, intense heat, and human activity. One of the most common natural disasters that affect practically every climatic zone is drought (de Silva *et al.*, 2011).

Water makes up between 80 and 95 percent of the biomass of fresh plants (Nabizadeh *et al*., 2022). Water is essential for several physiological functions in plants, including water transport, nutrient intake, enzyme systems, growth, metabolism, and development (Seleiman *et al*., 2021). Through mass movement and diffusion, plants use water to absorb nutrients (McMurtrie and Nasholm, 2018). Water shortage brought due to drought impairs nitrogen uptake and delays plant growth in the rhizosphere zone (Elemike *et al*., 2019). According to a study done on big blue stem (BBS), corn, and barley, drought stress decreased the rate at which N and P were absorbed by the plants because of the nutrients' decreased mobility and decreased water uptake.After the drought, big blue stem, corn, and barley witnessed reductions in N uptake of 142%, 72%, and 84%, and P uptake of 88%, 80%, and 70%, respectively (Bista *et al*., 2018).

One of the biggest global factors affecting crop productivity is drought. Drought and flooding will occur more frequently due to climate change, especially in several African countries. There are hints that the frequency and intensity of drought occurrences may alter because of climate change. For example, 67% of the world's population is predicted to be affected by water shortages by 2050 (Ceccarelli *et al*., 2004). Drought can strike a crop at any point in its growth. Nonetheless, the likelihood of drought is highest at the beginning and conclusion of the growing season in the dry and semi-arid tropics. Early in the growth season, drought stress will have a negative impact on plant establishment.Drought can cause crop loss or a poorer yield if it strikes during the flowering or grain filling stages (Tumwesigye and Musiitwa, 2002).

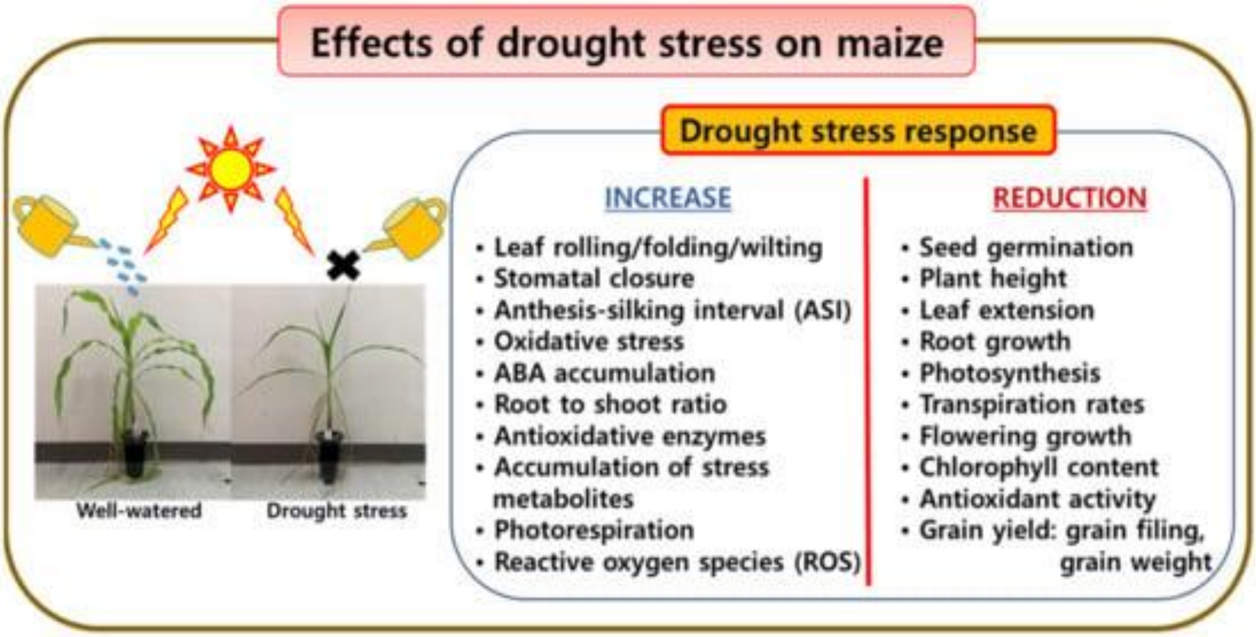

Figure1. *Effect of drought stress on maize growth and development.*

Drought is one of the main abiotic stresses limiting crop production globally because of continuing climate change events (Varshney *et al*., 2021a; Raza *et al*., 2023c). Agriculture, which is entirely reliant on nature, is the cornerstone of the economies of the majority of developing countries (Mendelsohn R, 2014). However, a variety of biotic and abiotic factors, including heat, salinity, drought, and waterlogging stress, have an impact on this crop (Jahan *et al*., 2019). Drought stress is one of these that has a significant impact on agricultural productivity (Li *et al*., 2013). Agriculture suffers huge losses worldwide due to water scarcity brought on by erratic and irregular rainfall (Ahmad *et al*., 2018).The frequency and length of drought stress are made worse by global climate change, which has a negative effect on crop productivity and quality (Begna, 2020). Major crop yields can be lowered by 50-80% during a drought (Lamaoui *et al*., 2018).

Drought restricts the effective use of land globally (Liu et al., 2016) and lowers crop productivity and quality (Waraich *et al*., 2011). When plants are stressed by drought, their metabolism, including physiological functions, is severely disrupted (Gupta *et al*., 2020). Drought stress is thought to be the primary abiotic factor that negatively impacts the production and quality of many field crops by changing plant physiology, growth, and metabolic processes (Alqudah *et al*., 2011; Lamaoui *et al*., 2018). Specifically, it inhibits a range of physiological and biochemical processes that affect plant growth, including osmotic adjustments, water relations, photosynthetic activity, and more (Mohammadi *et al*., 2016; Ma *et al*., 2016). As a result, flower production is reduced (Caser *et al*., 2019). One of the abiotic factors that significantly reduces plant productivity worldwide is drought, whose frequency and severity have grown throughout the last 20 years (Begna, 2020). Numerous pathways involved in plant growth, development, and metabolism are hampered by severe drought stress (Ashour *et al*., 2010).

One of the main challenges to crop production in rain-fed environments is drought stress. Furthermore, agricultural productivity is significantly impacted by drought stress during the reproductive cycle, which spans from the start of flowers to grain filling (Kumar *et al*., 2022a). Abiotic stressors such as drought lead to a number of impairments, including as elevated body temperature, reactive oxygen species (ROS) production that damages cells, and problems with metabolism. Each of them causes oxidative damage that worsens over time and eventually kills cells (Sasi *et al.,* 2021).The crops in dry environments have evolved various physiological and morphological responses to drought. These include decreasing the amount of specific leaf area, increasing the amount of photo-assimilates allocated to the roots, decreasing foliar biomass, decreasing stomatal conductance, reducing photosynthetic rate, decreasing transpiration rate and water loss, adjusting osmotically, decreasing relative growth rate, and lowering the maximum quantum efficiency of photosystem II (Fv/Fm) (Marinoni *et al*., 2020).

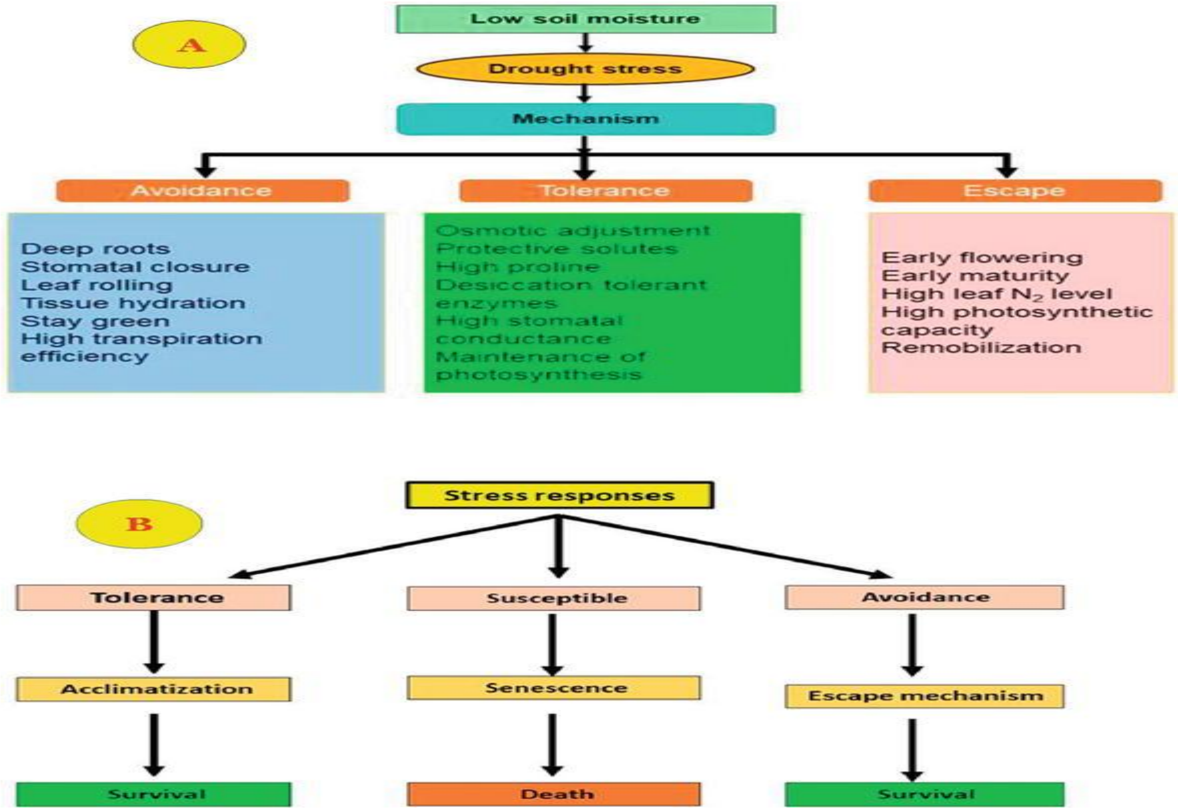

Figure2. *Mechanisms of drought stress and their responses to drought stress in crop. (A) Different responses and mechanism of the rice plants under drought stress; (B) Plant response mechanisms to drought stress.*

2.1 Drought Effects on Different Development Stages

Different stages of a plant's growth and development are impacted by drought stress. For example, water stress is particularly important during the development of the reproductive system. Rapid leaf transpiration lowers the water potentials in the xylem, which causes water loss in the fruits and can stunt the growth of grains and fruits. As a result, drought stress negatively impacts plant productivity and quality, particularly during the plant's crucial growth phases (Table-1).

Table 1: Drought stress in its critical phases affects major field and vegetable crops

Crops	**Critical Water Requirement Stage**	**Impact of Water Deficit**	**Reference**
Rice	Panicle initiation, flag leaf, and milky stage	Reduction in number of spikelets per panicle and grain yield	Pascual V.J and Wang Y, 2017
Wheat	Crown root initiation, tillering, jointing, booting, flowering, milk and dough stage	Kernel abortion decreased biomass and yield	Khan *et al*., 2019
Sorghum	Booting and flowering	Reduction in yield and quality of grains	Shenkut *et al*., 2013
Maize	Silking and tasseling	Delayed silk development, poor anthesis, reduced silk elongation and impedes embryo development	Udom B.E and Kamalu O.J, 2019
Pearl millet	Booting and flowering	Pollen shedding, reduced yield	Zegada-Lizarazu W and Lijima M, 2005
Finger millet	Flowering	Yield reduction	Tadele Z, 2016
Groundnut	Peg penetration and pod development	Reduced in number and size of pods	Roja *et al*., 2020
Sunflower	Head formation and early grain filling	Depletion in seed yields by reducing seed size and number	Yawson *et al*., 2011
Sesame	Flowering	Flower drop, decrease seed yield and seed oil content	Sarkar *et al*., 2010
Soybean	Flowering and pod filling	Floral abortion, reduced pod number, fewer seeds per pod, and reduced seed size	Singh *et al*., 2013
Blackgram and Green gram	Flowering and early pod development	Decreased seed protein content, reduced pod size, and seed yield	Baroowa B and Gogoi N, 2014
Cotton	Square formation and boll formation and development	Fewer and smaller bolls reduced Fiber length and strength	Wang *et al*., 2016
Sugarcane	Cane formation (Up to 120 days after sowing)	Low dry matter accumulation and low sugar yield	Verma *et al*., 2020
Potato	Early growth stage, initiation of stolon and the formation of tuber	Reduces total leaf area, poor tuber initiation, bulking, and tuber yield	Obidiegwu *et al*., 2015
Tomato	Flowering, fruit growth, maturation and fruit ripening stage	Flower drop, reduced fruit size, number and quality	Bahadur *et al*., 2011
Chilli and Capsicum	Flowering and fruit set	Flower and fruit drop, reduction in dry matter production and nutrient uptake	Bahadur *et al*., 2011
Cucumber	Flowering as well as throughout fruit development	Male sterility, bitter and deformed fruits	Kemble *et al*., 2006
Leafy vegetables	Throughout growth and development	Tough leaves, poor leafy growth and nitrates accumulation	Kemble *et al*., 2006
Okra	Flowering and pod development	Yield loss, fibre development	Konyeha S and Alatise M.O, 2013

Pea	Flowering and pod filling stage	Poor root nodulation reduced seed number	Maingi *et al*., 2020
Radish, turnip and carrot	Root enlargement	Deformed, pungent and poor root growth, harmful nitrate accumulation in roots	Bahadur *et al*., 2011

If a plant's physical adaptation to the drought is no longer sufficient, it may respond by producing a variety of chemical signals. Accumulation of proteins, genes, and osmolytes that are particularly engaged in stress tolerance are among the molecular signals (Goufo *et al*., 2017).

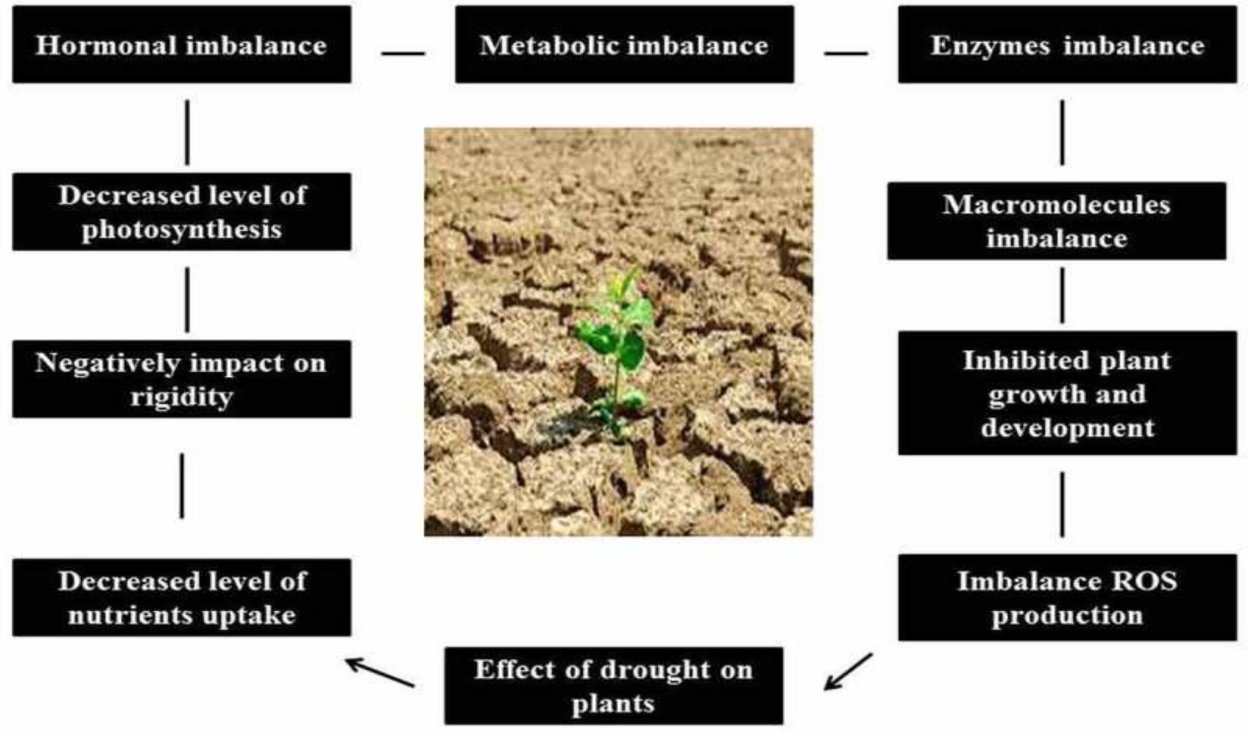

Figure3. *Drought stress significantly suppresses plant growth and development*

2.2 Factors Responsible For Drought

Drought is just one of the many negative effects of environmental change that have severely impacted agricultural systems. Due to extensive deforestation and overuse of fossil fuels, the atmospheric concentration of CO_2 has risen to 400 µmol-1 (Yang *et al*., 2019). The following are some of the many causes of drought:

2.2.1 Global Warming

Many ecosystems that depend on agriculture are in total chaos because of climate change. The globe is getting warmer from the North to the South Pole. Global air temperatures have risen by more than 0.9 degrees Celsius on average since 1906 (Brown *et al*., 2018). Furthermore, reservoirs hold less water when the temperature rises, which decreases the quantity of water available for irrigation in agriculture. This trend is becoming more noticeable with time. In many rain-fed agricultural regions across the world, global warming has resulted in a drop in the annual cumulative precipitation (Warner K and Afifi T, 2014). In this scenario, almost one-fifth of the world's population would be severely affected by water scarcity, assuming the predicted increase in air temperature of approximately 2°C over current levels by the end of the century (Ray *et al*., 2019).

2.2.2 Erratic Rainfall

Drought is frequently thought of as a prolonged catastrophic event that mostly affects places with less rain than usual. Comparing regions where agricultural production is only dependent on rainfall versus locations where the crop is irrigated by canals, rivers, and water channels reveals a greater degree of stress (Maliva *et al*., 2012). The distribution of yearly rainfall has a major impact on water stress during droughts in rain-fed areas (Konapala *et al*., 2020; Fatima *et al*., 2020). Three human activities—industrialization, deforestation, and urbanization have the greatest effects on rainfall patterns and plant water availability because of their effects on global climate change. Most of the time, there is a direct correlation between the intensity and distribution of rainfall both within and between years during periods of drought.

2.2.3 Changes in the Pattern of Monsoon

In many regions of the world, the monsoon season contributes significantly to the amount of rainfall, and its frequency is closely correlated with temperature. If current trends continue, summer precipitation in rain-fed areas is predicted to fall by 70% by the turn of the twenty-first century (Reddy P.P, 2015). The production of agriculture will unavoidably suffer from this. Remarkably, substantial seasonal variations in rainfall brought due to monsoon movements cause more than half of the world's population to experience food insecurity (Guo *et al*., 2015). Monsoon rains have had an impact on rhizosphere moisture levels and will continue to do so. In certain regions of the world, these variations in rainfall intensity, frequency, and duration affect plant yield (Aryal *et al*., 2020). Because of the shifting monsoon weather patterns, crop production requires a change in agricultural practices with an emphasis on sustainable crop production. Two strategies for dealing with monsoon patterns that alternate between excessive and insufficient rainfall and vice versa are crop preparation and management.

3. DROUGHT STRESS EFFECT ON PLANT

Drought has an impact on plants at every phenological stage of growth. Drought has an impact on both morphology and molecular structure. Below is a list of the various effects of drought stress on plants:

3.1 Plant Growth and Yield

Lack of water prevents seeds from absorbing and germinating since sufficient water is necessary for seed germination (Kaya *et al*., 2006). Similarly, for a variety of crops to be supported throughout their developmental stages, there must be enough moisture. A number of crops that are economically vital have been observed to experience stress due to drought, as listed in Table 2.

Table2. *Yield reduction (%) in various field and vegetable crops under drought stress conditions*

Crop	Average Yield Reduction (%)	Reference
Soybean	58.5	Samarah *et al*., 2006
Cowpea	60	Ogbonnaya *et al*., 2003
Chickpea	57	Nayyar *et al*., 2006
Pigeon pea	47.5	Nam *et al*., 2001
Canola	30	Din*et al*., 2011
Rice	72.5	Lafitte *et al*., 2007
Barley	50	Samarah N.H, 2005
Maize	75	Kamara *et al*., 2003
Wheat	22	Tack *et al*., 2014
Sorghum	87	Van Oosterom, E.J. and Hammer, G.L., 2008
Sunflower	60	Kasem,*et al*., 2015
Potato	13	Kawakam *et al*., 2006
Tomato	37.5	Patanè *et al*., 2011
Capsicum	99	Showemimo F.A and Olarewaju J.D, 2007

Plant growth is accompanied by the regular processes of cell division and elongation (Fathi A and Tari D.B, 2016). According to Sandalinas *et al*. (2017), there is often a correlation between infertility and drought during flowering because of a decrease for nutrients that reach the growing ear. By extending the anthesis stage and delaying grain filling, drought stress can drastically lower production in important field crops (Farooq *et al*., 2009). Reduced photosynthesis, ineffective flag leaf production, unequal assimilate portioning, and a diminished pool of vital biosynthesis enzymes including starch synthase, sucrose synthase, starch enzymes, and -amylase are only a few of the factors that could account for the yield drop (Plaut Z, 2004). Grain production in barley was greatly impacted by drought stress, as seen by reductions in tiller counts, spikes, grain per plant, and grain weight. Water scarcity decreased maize productivity, which caused a longer anthesis-to-silking duration and delayed silking (Table 1). Additionally, both worldwide and locally, the production of soybean seeds was decreased by drought (Frederick *et al*., 2001). It also affects other crops, such wheat.

3.2.Water Relation

It is crucial to comprehend the relationship between plants and water in order to forecast how agricultural systems will respond to severe weather conditions like droughts and how plants will grow in the absence of enough water (Lambers H and Oliveira R.S, 2020). Drought stress, for example, inhibits turf grass development primarily through disturbance of plant water relations and physiological activities (Saud *et al*., 2014). Different strategies are used by plants to withstand drought stress, such as improved water intake with deep root systems, decreased water loss through transpiration with smaller succulent leaves, and decreased water loss through greater diffusive resistance (Farooq *et al*., 2012). Relative water content in wheat leaves has been found to be higher during leaf development and to decrease as dry matter accumulated as the leaves matured (Siddique *et al*., 2022). The ratio of dry matter produced to water used is the definition of water-use efficiency at the whole-plant level (Monclus *et al*., 2006). According to Cantarero *et al*. (2016), wheat exhibited a higher water-use efficiency when faced with restricted resources as opposed to well-watered conditions. They connected the decreased transpiration caused by stomatal closure to this increased water efficiency.

Plants' water status and metabolic processes are significantly impacted by water loss (Mannocchi *et al*., 2004). As a result, high transpiration rates are encouraged by the ambient atmosphere's high temperature and low relative humidity. Reduced stomatal conductance was observed in plants with limited water availability as a result of rising leaf temperatures (Kogler F and Soffker D, 2017). The temperature of the leaf canopy rises in drought-stressed plants due to their hazardously low relative water content and transpiration ratios (Kutlu *et al*., 2009). The dry matter to water absorbed ratio indicates that they use less water. According to Lambers *et al.* (2019), cultivars that are resistant to drought utilize water more effectively than cultivars that are vulnerable, while susceptible cultivars had no effect.Wheat required less water when it was limited than when it was well watered. Stomatal closure, which lowers transpiration, is associated with increased water efficiency (Du *et al*., 2020). Thus, the main factor influencing drought-tolerant cultivars' increased water usage efficiency is reduced evapotranspiration because of stomata closure (Sharma *et al*., 2022).

3.3 Nutrient Assimilation

Lack of water lowers root nutrient translocation and total soil nutrient accessibility, which lowers the ion content of different plant tissues (Kheradmand *et al*., 2022). Plants absorb less potassium (K) when they are dry (Hu Y and Schmidhalter U, 2005). The decline in K was caused by decreased root membrane transporter activity, slower transpiration, and decreased K mobility. Reduced K levels were also seen in Malus hupehensis plants under drought stress (Qi *et al*., 2019). High salt (Na) content in Triticum durum genotypes was shown to be vulnerable, whereas high K content genotypes were found to be resistant (Karimpour M, 2019). Dehydration suppresses the expression of genes encoding K transporters (Li *et al*., 2009), and inner K channel activation is started by CIPK23, a protein kinase that functions similarly to calcineurin B in its interactions with calcium sensors. According to Cuellar *et al*. (2010), the K channel was active in leaves but inhibited in grapevine roots.

While the nitrogen (N) content of the leaves of drought-stressed plants did not alter, that of broadleaved lavender and Spanish marjoram plants did. These plants included peppermint, Spanish sage, Clary sage, and cone head thyme. Conversely, all species had a decrease in the amount of leaf phosphorus (P), with the exception of S. sclarea, which showed no change (Garcia-Caparros *et al*., 2019).It was previously believed that N shortage was the main factor causing the fall in the rate of photosynthesis and the senescence of leaves (Da Silva *et al*., 2011). Furthermore, it has been discovered that in the absence of water, K levels in Thymus daenensesis, Ocimum basilicum, and Ocimum americanum dramatically decrease (Sarani *et al*., 2014).

Table3. *Consequences of drought stress on plant nutrients*

Process Impacted	**Nutrient Depletion**	**Reference**
Soil integrity by erosion	Every mineral nutrient	Barber S. A, 1995
Transpiration driven mass flow	Calcium, magnesium, silicon, nitrates and sulfates	Barber S. A, 1995
Root growth	P and K	Lynch J.P and Brown K.M, 2001
Biological nitrogen	Loss of N	Ladrera *et al*., 2007

fixation		
Soil microbial activity	Loss of N	Schimel *et al*., 2007

3.4 Photosynthesis

Plant photosynthesis is severely impacted by water constraint, either totally inhibited or reduced (Nezhadahmadi *et al*., 2013). Due to a decrease in leaf area and photosynthesis rate per leaf area, photosynthesis is impacted by water scarcity (Sawant *et al*., 2021). The loss of CO_2 conductance through stomata and mesophyll limitations is the main cause of the reduction in photosynthetic processes in drought-stricken plants. This reduction affects Rubisco activity, nitrate reductase and sucrose phosphate synthase activities, and the capacity to produce ribulose bisphosphate (RuBP). Furthermore, it was shown that a shortage of water decreased the amount of leaf area per shoot, changing the architecture of the canopy (Deepak *et al*., 2019). According to Rahmati *et al*. (2018), this alteration in canopy design may have an impact on sink development (such as fruits or grains), gas exchange, water relations, and vegetative growth. As the length of water stress rose, so did the number of kernels and dry weight per 100 kernels of maize (Ge *et al*., 2012). Water dramatically changes the amount of chlorophyll, the most basic photosynthetic attribute, and is a unique indication of chlorophyll photooxidation and degradation (Anjum *et al*., 2011). Reduced photosynthetic activity, chlorophyll content, photosystem II photochemical efficiency, stomatal movement, and disruption of the water status have all been associated with lower plant production (Xiang *et al*., 2013).

Table4. *Drought stress affects photosynthetic enzyme activity in various field crops*

Crops	**Enzyme**	**Activity**	**References**
Maize	PEPCase	Increased	Jeanneau*et al*., 2002
Alfalfa	Rubisco	Unchanged	Medrano *et al*., 2016
Sugarcane	Phosphoenolpyruvate carboxylase (PEPCase), PPDK	Reduced	Du *et al*., 1996
Tobacco	Rubisco	Reduced	Parry *et al*., 2002

For instance, by reducing photosynthetic yield and disrupting the carbon cycle, drought stress decreased physiological and metabolic abnormalities in soybeans (Abdallah *et al*., 2018). For instance, the production of O_2 and H_2O_2, which eventually lead to lipid peroxidation and chlorophyll breakdown, is a significant indication of chlorophyll loss associated with drought stress (Du *et al*., 2020). In addition, a number of Calvin cycle proteins, including Rubisco, were down regulated in olives under drought stress.

3.5 Source-Sink Relationship

The byproduct of photosynthesis, carbohydrates, give non-photosynthetic tissues a substrate for growth and maintenance. Cell sugar partitioning and long-distance carbohydrate allocation in plants both depend on sugar transporters. The main process affecting plant development is the actual movement of sugars through plant organs via the phloem (Zhao *et al*., 2021). The source-sink interaction is impacted by a number of elements that influence sugar transport via the phloem, including the source, sink, and route between the two (Korner C, 2015). Assimilate export from source to sink is influenced by the rate of photosynthesis and the quantity of sucrose in leaves (Yu *et al*., 2017). Dry weather slows water transport by reducing sugar content and photosynthesis (Penella *et al*., 2016). Additionally, a drought makes it more difficult for the sink to efficiently use assimilates. Phloem loading and sugar metabolism are greatly impacted by drought (White *et al*., 2016). Gluconeogenic enzyme transcript abundance rises in drought stress (Cramer *et al*., 2007). However, a drought can alter the amounts of certain nutrients, like carbohydrates and amino acids. Additionally, by blocking ADP glucose pyrophosphorylase, drought stress enhances the synthesis of sucrose in sink organs (Suphia Rafique *et al*., 2020).

3.6 Respiration

Since respiration produces the energy and carbon skeletons needed for biosynthesis and cell maintenance, it is essential to the health and growth of plants. There has been much discussion about how drought stress affects plant physiology, signaling cascades, gene expression, and photosynthesis, but respiration is rarely examined as a result (Sanhueza *et al*., 2013). The process of respiration is carried out by the mitochondrial organelles. In addition to disturbing the plant's overall carbon balance, mitochondrial respiration plays a role in it because, according to Xu *et al*. (2015), 20% to

80% of the carbon fixed during photosynthesis is released again during respiration. The plant's metabolic efficiency is impacted by the carbohydrates lost during respiration (Lavania *et al*., 2016). Drought stress reduces the ability of ATP to interact with other enzymes by changing the electron partitioning between the cytochrome and the cyanide-resistant alternate pathway (Agrawal *et al*., 2015). There are two different routes by which electrons in plants' mitochondria go from ubiquinone to oxygen. The alternative route is distinct from the cytochrome routes, as Moore and Siedow (1991) showed, in that electrons are transferred directly to oxygen by alternative oxidase, as opposed to the reverse. It is unclear if the alternative pathway aids in the manufacture of ATP, however it has been shown that it is triggered when stress is applied or when the main electron transfer channels are blocked.

Lack of water stresses plants, causing them to release reactive oxygen species (ROS) that harm membrane components. Alternative oxidase activity preserves normal metabolite levels while reducing ROS generation, which makes it advantageous in stressful situations (Blokhina *et al*., 2003). In drought-stressed environments, plants therefore raise their respiration rate, which leads to an imbalance in the consumption of carbon resources, a decrease in ATP synthesis, and an increase in ROS generation (Baxter *et al*., 2014). The results of the study show that the ratio of respiration to assimilation (A) usually increases in response to increased water stress and lowers in response to re-watering, regardless of how respiration responds to increased water stress (Ayub *et al*., 2014). Many metabolic processes that are temperature-sensitive compose plant respiration.

According to Moroney *et al*. (2013), changes in substrate availability or variations in energy demand may lead to differences in heat response. Although it is widely acknowledged that droughts have a substantial impact on plants' carbon balances, it is still unclear how the metabolism of respiration is regulated in response to droughts (Watanabe *et al*., 2014). When environmental factors like dryness impede electron transport along the principal cytochrome-mediated oxidation pathway, ATP production is decreased. Under some circumstances, plants have a nonphosphorylating alternative pathway that allows electrons to go straight from ubiquinone to oxygen via a different oxidase enzyme (Way *et al*., 2015).

3.7 Oxidative Damage

Plants naturally release reactive oxygen species (ROS) that are harmful to the environment. These compounds are produced naturally during plant metabolism and can be found in the plasma membrane, mitochondria, peroxisomes, and chloroplasts, among other cellular compartments (Apel K and Hirt H, 2004). The body may collect potentially dangerous reactive oxygen species (ROS) such the hydroxyl radical (•OH) and peroxide anion (O_2•-), as well as non-radical molecules like hydrogen peroxide (H_2O_2) and singlet oxygen, due to an unbalanced oxygen metabolic route (Gupta *et al*., 2016).

The formation of superoxide and H_2O_2 or singlet oxygen in the photosynthetic electron transport chain is excessively reducedbecause of stress-induced stomatal closure, which restricts CO_2 uptake in the peroxisome and increases photo respiratory H_2O_2 generation in the peroxisome (Noctor *et al*., 2014). It is possible to enhance ROS production during a drought in a number of ways. A greater amount of CO_2 fixation reduces the amount of NADP+ recyclable via the Calvin cycle, which causes the photosynthetic electron transport chain to be overly reduced. During photosynthesis, plants under stress from drought lose more electrons to O_2; this phenomenon is called the Mehler reaction (Carvalho M.H.C, 2008).As previously reported, compared to wheat that has not been stressed by drought, wheat that has experienced drought stress exhibits a 50% greater loss of photosynthetic electrons to the Mehler process. It is useful to compare the quantity of ROS created by photorespiration and the Mehler reaction, even if the latter is harder to measure. In fact, the photorespiratory pathway speeds up during drought, particularly during the peak of RuBP oxygenation when CO_2 fixation is limited (Biehler K and Fock H, 1996).

Noctor *et al*. (2002) found that in drought conditions, photorespiration is predicted to contribute more than 70% of the total H2O2 generation. It is imperative to understand that an increase in ROS generation is extremely reactive and can have a variety of cellular, physiological, and biochemical effects (Mittler R, 2017). These effects can include disruption of the plasma membrane due to lipid peroxidation, protein denaturation, destruction of DNA and RNA, and degradation of enzymes and pigments (Choudhary *et al*., 2016). Lipid peroxidation and protein denaturation are linked to the most severe impacts of oxidative stress on plant cells (Gaschler M.M and Stockwell B.R, 2017). Ketones, aldehydes, and hydroxyl acids are examples of additional reactive molecules that can be produced by some of these reactions, while others can change

Protein function may be impacted by protein modifications such as glutathione, carbonylation, nitrosylation, and disulfide bond formation. Crop quality and productivity suffer as a result. According to Park et al. (2019), overexpression of OsCYP21-4 boosted rice biomass and productivity and increased seed weight by 10% to 15%. Delightful oranges' citrus fruit peels have an accumulation of reactive oxygen species and a rapid breakdown of chlorophyll due to overexpression of CitERF13 (Xie *et al*., 2017). Changes in gene expression in Arabidopsis have been shown to cause acclimation or PCD, as evidenced by the overproduction of singlet oxygen ($1O_2$) by flu and chlorina1 (ch1) (Shumbe *et al*., 2016).

4. RESISTANCE MECHANISM OF DROUGHT STRESS

Crops respond to severe drought stress scenarios by inducing various morphological, biochemical, and physiological responses that enable them to survive. According to Beck *et al*. (2007), drought stress disrupts water circulations at many levels, which leads to unfavorable reactions and ultimately adaption reactions. Suggested plants have defense mechanisms against drought stress in order to survive in such circumstances; these mechanisms should be thoroughly investigated. Crop plant yield and yield performance rapidly decline because of drought stress. Drought resistance refers to a distinct process that plants go through in order to withstand stress under specific circumstances and produce a larger yield than they would under normal water availability situations. Drought resistance is the process of minimizing the loss of economic yield in conditions of restricted water supply, as seen from the perspective of agriculture (Bohnert *et al*., 1995). According to Bohnent *et al*. (1995), there are three fundamental types of drought resistance: escape from a drought, avoidance of the drought, and tolerance to the drought.

4.1 Drought Escape

Drought escape is the process of reducing a plant's life cycle or growing season in order to avoid dry climatic conditions. Drought escape requires that the phenological development successfully coincide with times when soil moisture is available. This happens when the growth season is shortened and terminal drought stress is experienced (Araus *et al*., 2002). Different processes, including as early maturity, developmental plasticity, and assimilate remobilization, can be used to achieve drought and escape. Of all these variables, one of the most important ones for mitigating the effects of drought stress is the crop's early maturity. We must shorten the crop plant's developmental period at various growth stages in order to achieve early maturity.

According to Shavrukov *et al*. (2017), cutting short the flowering stage is considered to be one of the best times to avoid a drought among other stages. Different crop genotypes with early flowering behavior can be chosen, limiting their vegetative growth and allowing reproductive growth to occur prior to terminal stress (Bodner *et al*., 2015). Although early flowering and maturity can be viewed as a useful strategy for escaping drought, it has certain disadvantages and may reduce the potential grain yield because it takes less time for photosynthesis to occur and for seeds to accumulate nutrients, which are necessary for a higher grain yield.

4.2 Drought Avoidance

The plant is engaged in a multitude of ongoing physiological and metabolic processes that are not affected by drought stress and continue to operate normally even when there is a water deficit. Drought avoidance is the ability of a plant to retain a comparatively higher water content in its tissue in spite of the soil having a reduced water content (Levitt*et al*., 1980). By regulating stomatal transpiration, it aids in reducing water loss and preserving water absorption through a broad, deeply rooted root system. Condition wheat closes its stomata to preserve its water status during the drought. On the other hand, stomata shutting has certain detrimental consequences on respiration and photosynthesis. In addition, when a plant experiences a drought, the leaves roll in an attempt to preserve water, and they unroll again when the plant's leaf-water relations recover (Sirault *et al*., 2015).

According to reports, the grain's epicuticular wax layer, also known as glaucousness, is thought to be a crucial characteristic for avoiding drought since it keeps the leafwater relations intact during drought stress (Richards *et al*., 1986). A number of root characteristics, including root length, root density, and root biomass, also affect the ability to avoid drought (Kavar *et al*., 2008). Excessive water intake during drought stress is caused by larger root thickness, deeper roots, and more dense roots (Aina and Fapohunda, 1986). Therefore, a variety of plant characteristics, including stomatal transpiration, glaucousnessis, leaf rolling, and other structural and functional elements of the root, are in charge of helping the plant avoid dryness when under stress.

4.3 Drought Tolerance

Drought tolerance is the capacity of a plant to continue growing and developing in the face of a water deficit. Plants use a variety of physiological and biochemical strategies to combat water deficiency circumstances and preserve normal growth and yield potential. This intricate process is known as drought tolerance. Numerous studies have demonstrated the importance of antioxidant enzyme activity, osmoregulation, and osmotic adjustment in helping plants adapt to drought stress (Nemeskeri and Helyes, 2019). More sophisticated wheat-tolerant genotypes must be developed in order to meet the expanding population's need for food. Therefore, finding the genes that can be exploited in breeding to create new, more drought-tolerant genotypes is the primary goal of the research program on drought. Wheat varieties that can withstand drought have altered physiological and biochemical processes to enable them to thrive in environments where there is a shortage of water. Several physiological and biochemical mechanisms are activated at the cell, tissue, organ, and whole plant levels as part of the drought tolerance system.

5. CONCLUSION

In the natural world, plants are constantly subject to a variety of biotic and abiotic stressors. Drought stress is one of these stresses that has the worst effects on plant growth and productivity. It is also thought to pose a serious threat to agricultural production that is sustainable in the face of climate change. The definition of drought is an extended period of no moisture. As a factor that limits yield, drought has grown to be a serious danger to global food security. Plants react to drought in a multitude of ways, from altered cellular metabolism to altered growth rates and crop yields. Comprehending the biochemical and molecular reactions to drought is crucial for gaining a comprehensive understanding of plant resistance mechanisms in situations where water is scarce. The reduction of leaf size, stem extension, and root proliferation, disruption of plant water and nutrient connections, and inhibition of water-use efficiency are all detrimental effects of agricultural drought on crop productivity.

One of the main issues with the current climate is drought, which is also one of the most serious abiotic stresses in many regions of the world. Drought is the single most important environmental stressor that negatively impacts crop productivity and quality worldwide. Droughts, which are already negatively impacted by abnormal metabolism in crops, may become more frequent in many parts of the world in the upcoming decades due to climate change. This might potentially stunt agricultural growth and development. Water stress also hinders photosynthesis and the expanding leaves' ability to absorb nutrients, which has an impact on the crop's physiological activity. There is always a chance that crops may experience moisture stress and fail or produce less than expected, especially in areas where rainfall is the only source of crop production. Extreme moisture stress can cause the crop to fail entirely. Drought stress has a detrimental effect on yield and traits related to yield at different phases of growth, which lowers yield. The plant's developmental stage, the severity and duration of the stress, the species' genetic potential, and environmental interactions all have an impact on how drought stress affects a plant.

Improving drought tolerance in agricultural plants is a challenge for crop physiologists and plant breeders since it is a complex genetic trait involving multiple pathways. The best environmentally beneficial and long-term answer to the issues is to breed crop types that are tolerant of abiotic stress. A serious environmental problem, drought stress restricts the amount of water available to plants, which negatively affects their general health and stunts their growth. However, by employing every strategy at our disposal, creative solutions are required to safeguard plant production and health against this serious environmental problem. Breeding for drought resistance necessitates a thorough comprehension of the molecular mechanisms governing pathways responsive to stress.The plant uses four different strategies to deal with drought stress: avoidance, escape, tolerance, and recovery. In order to create a drought-resistant variety, breeding for drought resistance is a viable strategy that combines traditional and molecular methods. One of the primary tactics suggested for addressing the detrimental consequences of global warming in dry regions is the deployment of genotypes resistant to drought.

One of the main abiotic stresses that reduces crop productivity and undermines global food security is drought, particularly in light of the current climate change scenario and the rise in the frequency and intensity of stress factors. One of the main factors affecting crop productivity is drought, which can result in significant output losses. In the field, plants are subjected to a variety of abiotic stressors that can be fatal to their development and yield. Demand for drought-tolerant cultivars is considerable, suggesting that plant breeders have a difficult task ahead of them. However, obstacles to crop production based on physiological and genetic factors exacerbate the situation. The system or mechanisms responsible for a crop losing the least amount of yield in a drought-prone area while maintaining the highest yield in an ideal, drought-free climate are known as drought resistance. The demand for agricultural products worldwide, along with the effects of climate change such as global warming, has severely restricted crop yield and greatly inflated the market value of agricultural goods, resulting in severe inflation.

Despite many years of research, drought is still one of the most restrictive abiotic variables that significantly contributes to yield loss in arid and semi-arid environments. Plant breeders continue to face this difficulty. Crops that have been specifically designed for regions with limited moisture availability can help to mitigate this issue. Using high-yielding, drought-resistant varieties that are well-adapted is essential to maximizing yield potential while lowering the risk of climate change. Climate-smart agriculture is the only way to lessen the detrimental effects of climate change on crop adaptability, and it can be implemented before the changes have a major influence on global crop production. The plant's developmental stage, the extent and duration of the stress, the genotypic potential of the species, and environmental interactions all have a role in how drought stress affects a plant. Finally, climate change poses a threat to global food security, making it the hardest task of the twenty-first century to feed a growing global population.

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