Abiotic stresses and vegetable production in the era of climate change: A review

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Abstract

Global warming has been recognised as a critical hazard to natural ecosystem existence. Changing climate is a continuous, multidimensional process of changes in climatic conditions that affect the abiotic and biotic aspects. This causes changes in climatic circumstances including extreme heat, rainfall amount, and temperatures, which leads to an increase in novel parasites, vegetation, and diseases, while vegetables crops must employ specific methods such as physiological, biochemcial and molecualar process to ensure optimal development during stress situations. The synthesis of hormones (phytohormones) and osmolytes is one of these processes. Plant hormones are natural materials which influence the physiological processes of plants such as growth, development, and cell differentiation. Under normal and stressful situations, plant hormones regulate essential physiological activities. Phytohormones, which come in a variety of forms, serve a significant role in plants, either on their own or in concert with one another. The type and concentration of such substances in plants have a significant impact on plant activities and functions. The current study describes phytohormones' possible involvement in fostering plant growth and development during stressful conditions.

Keywords: Abiotic Stress, Climate Change, Vegetable Production.

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Introduction

The word "vegetable" includes any form of plant life or plant product in its widest definition. In a more limited definition, it alludes to the fresh, palatable component of an herbaceous plant that is ingested raw or processed (Ward, 2016). Minerals, carbohydrate, calcium, and proteins are abundant in vegetables. Vegetables are the greatest assets for alleviating micronutrient malnutrition, and they give substantially greater revenue as well as more opportunities per hectare to small scale farmers than agricultural foods (Kumar *et al*., 2011). Vegetables, on the other hand, are vulnerable to environmental fluctuations, therefore extreme temps and insufficient moisture levels are the leading reasons of low yields, as they have a significant impact on various physiological and biochemical processes.

Climate change can be defined as changes in the average of several climatic factors like temp, precipitation, humidity levels, and atmospheric gas compositions, among others, over a longer period of time and across a wider geographic region. Changes in climatic factors such as air temperature, precipitation patterns, excess UV radiation, and increased occurrence of extreme weather events such as droughts and floods are playing a dominant role risk to tropical vegetable production (Tirado *et al*., 2010). Vegetable crops are extremely susceptible to climate fluctuations, and rapid temperature increases and also erratic precipitation at any stage of agricultural production can disrupt normal growing, blooming, pollination, and fruit development, leading to a drop in crop production (Afroza *et al*., 2010).

Changing climate as well as its unpredictability are key concerns impacting agricultural productivity, particularly vegetable crops. Fruit and vegetable yield is expected to be reduced resulting in a short growth period, that would have a detrimental influence on development and growth, especially due to final extreme heat and limited water accessibility (Venkateswarlu and Shanker, 2012). Global warming and unpredictability have created more ambiguities and dangers, putting additional limits on vegetable production environments. Vegetable crop prices may rise as a result of climate change (Abdelmageed *et al*., 2014). Furthermore, changes in climate are promoting pathogen proliferation and the emergence of new types of pest species, as well as fungal, bacterial, and viral illnesses. As a result, the aim of the article is to evaluate the consequences of climate change on various vegetable production.

Climate change and Abiotic stress

Plants are subjected to a variety of abiotic challenges as a result of global warming and changing climatic circumstances. Droughts, excessive salinity, harsh temps, micronutrient deficiencies, and metals sensitivities are among abiotic factors that affect crop growth (Newton *et al*., 2011). Such variables might even have a detrimental impact on soil fertility and contribute to

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increased soil erosion (de la Pena and Hughes, 2007).

Cold stress and vegetables

Cold stress is a primary abiotic stress that reduces crop yields by reducing the quality and longevity of the crop after harvest. Cold stress has an influence on all aspects of cellular activity in plants. The metabolic process of plants is hindered by cold temperatures. Several tropical and subtropical crops, mostly vegetables, might suffer acute freezing harm and even mortality if subjected temperatures of 1–10°C. Plants physiological process such as nutrition, photosynthesis, water potential, and respiration, among others, are significantly harmed (Jouyban *et al*., 2013). It could harm plant cells and induce yellowing leaves, mitochondrial dysfunction, apoptosis, alterations in enzyme concentration, and variations in cytoplasmic fluidity in vegetable. As a result, cold stress has a significant influence on plants, producing chilling injury, cellular membrane degradation, and a decrease in net photosynthetic, as well as a devastating effect on vegetable crop output. Reduced plant growth, irregular fruit development, interior discoloration (vascular browning), increased sensitivity to decay, and plant mortality are all symptoms of cellular damage and altered metabolism. Freezing stress reduces photosynthesis performance and improves leaf electrolyte leakage in watermelon seedlings (Shirani Bidabadi and Mehralian, 2020).

Heat stress and vegetables

Since 2021, the globe temperature is projected to climb by 1.4–5.8°C result of climate change (Arora *et al*., 2005). Heat stress lowered photosystem II activity and water holding capacity (Li *et al*., 2014). Reactive oxygen species (ROS) are produced in cells amid heat stress, and oxidative stress, together with increased hydrogen peroxide, malondialdehyde, and superoxide anions, is a major hazard to vegetable production (Yuan *et al*., 2016). Even though the nutrient composition has a variable influence, a 4°C rise in temperature is anticipated to lower the production of vegetables and legumes by 31.5 percent, using 20°C as the baseline temperature (Scheelbeek *et al*., 2018). A large change in temperature due to global warming over time would result in decreased rainfall, air velocity, and snowpack, reducing the duration of the growth period for plants and significantly impacting crop quality and agricultural output. Increased temperature also can contribute to drought conditions by increasing water loss through transpiration and evaporation. Extreme temps also affect germination of seeds, plant development, and maturation, as well as cause permanent drought stress that can result in mortality (Takahashi *et al*., 2013).

Salinity stress and vegetables

In several salt-affected places, salinity is a severe concern that limits the development and yield of vegetable crops. The most vegetable crops possess

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lower salt tolerance, especially in the range of 1–2.5 dS/m, although this diminishes when saline water is used for irrigation (Machado and Serralheiro, 2017). Salt-tolerant vegetable plants reduce salinity stress by altering leaf growth and perspective, improving root progression to get accessibility to lower waterbodies, producing osmolytes, and triggering a range of stress genetics and antioxidant (Tuteja, 2007). Salinity has an impact on plant morphological development, physiological state, and production, and it impacts a large amount of arable land. Salinity causes tomato plants' leaf area and dry matter content to decrease. Furthermore, the leaves were shown to be significantly vulnerable to salt stress than the fruits because they had higher proline and Na+ (Babu *et al*., 2012). Under salt stress, there was an elevation in protein, mineral, dietary fibers, vitamin c, phenolic content, and flavaoids in the leaves (Sarker *et al*., 2018). Salinity increased the nutritional content of radish seedlings, and its sprouting under environmental salinity stress resulted in the development of beneficial substances in the plant food (Yuan *et al*., 2016). Salinity affects dry matter production, leaf area, relative growth rate, and net assimilation rate, according to Lopez *et al*. (2011). In bean plants, salinity stress causes growth and photosynthetic activity to be suppressed, as well as alterations in stomata conductance, quantity, and size. and also lowers transpiration and the cell water potential (Kaymakanova *et al*., 2008).

Flooding stress and vegetables

Flooding seems to be another significant abiotic stress that has a major impact on the operations and productivity of vegetable crops, that are often regarded as flood-prone crops (Parent *et al*., 2008). Flooding usually results in an oxygen (O_2) deficit, that is caused by the sluggish exchange of gases in water and O_2 use by microbes and plant roots. Certain plants, especially tomatoes, are extremely susceptible to floods, and genetic diversity in this trait is restricted. Flooding damages plants in general because it reduces oxygen in the root zone, inhibiting aerobic activities. Endogenous ethylene accumulates in flooded tomato plants, causing harm to the crops (Drew *et al*., 2009). Onion is also susceptible to floods at bulb growth, with production losses of up to 30%. The plant responses to environmental factors are dependent on the growing period as well as the duration and intensity of the stimuli (Kumar, 2017) These challenges are the leading cause of reduction in yield of much more than 50% globally.

The physiology of vegetable plants is affected by flooding. Reduced stomatal closure is one of the first physiological reactions of plants to soil flooding (Folzer *et al*., 2006). Flooding has an adverse influence on plant vegetative and reproductive development because it affects physiological functioning (Pautasso *et al*., 2012). Floods facilitate the spreading of water-borne diseases, severe droughts expose plants to infections, and storms aid spores' distribution by the wind (Gibbs and Greenway, 2008). Root respiration is

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hampered in waterlogged conditions as soil air is substituted by water, resulting in poor nutrient absorption and an increased risk of soil borne illnesses.

Drought stress and vegetables

Drought is defined as a state of stress caused by a lack of water. Drought is a climatic term that refers to a period of time when there is less rainfall or water availability. Drought stress occurs in plants if environmental circumstances cause a decline in the total of soil water, resulting in continual water loss via transpiration or evaporation (Ashkavand *et al*., 2018). Drought is the most significant result of global warming, and it is accountable for the world's worst mass starvation in the last century. Drought affects over % of the world's agricultural regions (Bot *et al*., 2000). Also has an impact on the soil ecosystem's functionality, form, and fertility (Liu *et al*., 2010). Due to increased evapotranspiration, reduced precipitation, and lowered soil microbial activities, significant water stress combined with an increasing temperature will affect vegetable crop productivity and quality. This will result in an increase in solute concentration and eventually a sinking of the water content, interrupting membranes and photosynthetic activity processes, and ultimately cell death (Yusuf, 2012). Numerous vegetables (cucumbers, melons, pumpkins, squashes, lima beans, snap beans, peas, chili, sweet corn, and tomato) are susceptible to water stress through blooming and fruiting. Potato tubers are extremely drought-sensitive, and even mild water shortage has a negative impact on production capacity (Luoh *et al*., 2014). Under water stress, the development of vegetable seeds such as onion, okra, and potato tubers, as well as the sprouting of potato tubers, are adversely affected. Under water deficiency conditions, productivity and quality in tuber, root, and bulb vegetable crops are considerably reduced because the transfer of carbohydrates from the leaves to the storage organs is inhibited (Kusvuran *et al*., 2016).

Role of phytohormones for stress tolerance

Stress has a significant detrimental influence on agricultural output because it disrupts plant processes caused by hormonal and nutritional irregularities. Plants, being sessile creatures, are subjected to harsh environmental circumstances. Droughts or floods, rainwater flooding, excessive salt, higher or lower temp, toxic substances, and radiation from the sun are only a few of the environmental variables that are harmful to plant growth and development (Raza *et al*., 2020; Hossain *et al*., 2021). To deal with these harmful pressures, plants have developed effective detecting, communication, and response systems. The PHs, that could be identified as cellular signal molecules which function as signalling molecules in crops under trace levels and have crucially important activities in the regulation of plant responses to abiotic stresses, are one of the most visible examples of these response mechanisms

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exerted by plants (Williams, 2011). Plant hormones are determining factors that help plants control their growth and survival functions. The proportion of hormones produced depends on a variety of biotic and abiotic conditions. Such hormones can have a significant influence on plant growth and development even at extremely low concentrations. Auxins, the very first phytohormone revealed (Darwin and Darwin, 1880), salicylates (SA), ethylene (ET), cytokinins (CKs), gibberellins (GAs), brassinosteroids (BRs), jasmonates (JA), abscisic acid (ABA), and strigolactones (SL), the last PHs to be found (Su *et al*., 2017), are among the nine types of PHs (Gomez-Roldan *et al*., 2008). ABA, SA, ET, and JA are among the PHs that were identified as having a critical role in the plant's response to environmental challenges (Peleg and Blumwald, 2011; Wasternack, 2014). Phytohormones such as ABA, BRs, CK, ET, GA, JA, and SA, according to Yadav *et al*. (2021), play a critical role in drought stress tolerance in plants by regulating cellular processes at the molecular level through cell signaling. According to significant participation in the responding to the challenges such as severe temperatures and drought, the SL and BR form a novel plant hormone of rising relevance (Nolan *et al*., 2020).

Phytohormones

Ethylene

Ethylene is a gaseous hormone that plays a role in a variety of morpho-physiological plant functions, including the threefold response in germinating seeds, forming flowers, ripening fruits, and stimulating plant reactions to external stimuli (Awan *et al*., 2017). It's important for changing how plants react to pathogens, external mechanical injury, Ultraviolet rays, and nutritional shortage. Numerous incidences of ET accumulation have been documented in reaction to mechanochemical injury (Abeles *et al*., 1992; Kendrick and Chang, 2008). Ethylene is a growth regulator, the more of it is produced, the slower the plant grows and the sooner it reaches maturity (Nadeem *et al*., 2010a). Ethylene, which is involved in a variety of plant activities, has a deleterious influence on plant growth and development when levels are high, especially under stressful situations (Nadeem *et al*., 2010a). Root growth stimulation at low concentrations while the suppression of root elongation has been seen at high concentrations (Mattoo and Suttle 1991; Belimov *et al*., 2002). Ethylene has a considerable influence on rhizobial infection in legumes and plays a crucial role in legumerhizobia interaction (Penmetsa and Cook, 1997). Ethylene was shown to prevent nodulation either administered immediately as a gas or in the form of its precursor, such as ACC (Yuhashi *et al*., 2000). It also has a detrimental impact on plant growth by inducing a variety of problems including leaf abscission, senescence, epinasty, and chlorophyll degradation (Shibli *et al*., 2007; Nadeem *et al*., 2010b).

The gaseous hormone ethylene (ET) and the oxylipin-based hormone

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jasmonate (JA) work together to help plants respond to biotic and abiotic challenges in a variety of ways (Zhu, 2014). ET is capable of activating and has increased heat stress tolerance (Clarke *et al*., 2009). Crop seed development is severely threatened by extreme temps during the reproductive period. ethylene production is variably controlled in floral and fruit tissues in pea during heat stress to maximize resource allocation in reproductive tissues (Savada *et al*., 2017). Ethylene confers thermostability and mitigates heat-induced negative effects in rice (Wu and Yang, 2019). As a result, plant species and tissues differed in their physiological, biochemical, and molecular activities of ET in response to heat stress. Further research is needed to have a better understanding of ET's involvement in plant thermotolerance. ET is required for the initiation of the anti-necrotrophic pathogen innate immunity.

Gibberellins

The GAs is a long-standing and quite well class of regulating hormones that are involved in several plant physiological processes including as seed germination, inter-nodal elongation, induced blooming, and fruit formation (Islam *et al*., 2021). There are around 250 GAs representatives documented, however only a couple of them are physiologically active and play various functions in plant growth. GA's receptor protein is nucleus confined GID1, and binding of GA to receptor protein aids in interaction with the repressor DELLA protein. GA regulates signaling by disintegrating repressor proteins, which result in a wide variety of biological and physiological responses (Lo *et al*., 2017). GA regulates redox homeostasis in H. vulgare by increasing electron mobility (Mark *et al*., 2016). The phytohormones communicate with one another, and this association can be detrimental, as shown with gibberellins (Heinrich *et al*., 2013), where a high amount of jasmonic acid inhibits gibberellin production. *Nicotiana attenuata* stem elongation is inhibited due to a reduction in gibberellins. Researchers observed that the total quantity of jasmonic acid was responsible for the suppression of gibberellins (Fleet and Sun, 2005). Gibberellins are vital in growth and development of plants because they influence seed germination, root/shoot elongation, flowering, and fruit patterning (Fleet and Sun, 2005; Shani *et al*., 2013). The use of gibberellins has been shown to improve wheat production in salty conditions (Parasher and Varma, 1988). Afroz *et al*. (2005) demonstrated that the use of gibberellins improved the photosynthetic rate and nitrogen fixation of salt stress mustard plants. Plants subjected to extreme heat stress exhibit elevated acidification of extracellular solution and reduced proteolysis, which may be controlled by the administration of gibberellins (Aleksandrova *et al*., 2007).

Auxins

Auxins, like CKs, are natural plant growth hormones that are usually

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engaged in root/shoot development and comparative growth (Sachs, 2005). Auxins collaborate with CKs in a variety of cellular and physiological functions, including cell cycle regulation, cell growth, apical domination, leaf growth, and embryonic development during seed maturation (Tromas *et al*., 2009; Jurado *et al*., 2010). The Auxin Response Factor (ARF) group has been discovered as transcriptional regulators which regulate auxin's effects; for instance, several ARFs have been shown to play an important role in lateral root formation (Wilmoth *et al*., 2005). According to research by (Marin *et al*., 2010), the collective activity of micro RNAs impacted the amount of lateral root development, miR390 and TAS3-derived transacting short interfering RNAs, and Auxin Responsive Factors constituting an auxin-responsive regulatory network. When soil water tension is low, auxins accumulate in root system and are transferred to the leaves. When soil water tension is low, auxins accumulate in root system and are transferred to the leaves. These auxins bind to receptors on the surface of the cell membrane of stomatal cells, resulting in increased stomatal conductance (Babu *et al*., 2012). Auxins are well-known phytohormones that help plants cope with environmental stresses such as salt, underwatering, and soil acidity (Salama and Awadalla, 1987; Ribaut and Pilet, 1991).

Salicylic acid

Salicylic acid is among the most important phenolic natural growth factors, and has been identified in practically all plant species belonging to diverse groupings. It has been discovered that it regulates a variety of physiological and biochemical processes in plants. It has been extensively explored in plants to aid in the development of systemic acquired resistance to a variety of diseases (Misra and Saxena, 2009; Kolaksazov *et al*., 2013). Nevertheless, depending on the amount and period of osmotic stress, the SA involvement in plants treated to salt and osmotic stressors remained relatively equivocal in many plant species. Similarly, SA exogenous treatment reduced salinity-related effects (Horváth *et al*., 2007). Cold stress causes a rise in the quantity of jasmonates and salicylic acid in wheat (Kosova *et al*., 2012; Kolaksazov *et al*., 2013). Furthermore, plants that are engaged in many developmental processes such as seed germination, root growth, and senescence have been shown to contain jasmonic acid and salicylic acid (Chen *et al*., 2009b; Wasternack and Hause, 2013).

Abscisic acid

The plant hormone abscisic acid was identified in the early 1960s and was determined to be capable of breaking seed dormancy (Cornforth *et al*., 1965). It was eventually discovered that it may have a function in plant growth and stress adaptation responses (Guschina *et al*., 2002; Iqbal, 2015a). Abscisic acid (ABA) is the most researched stress-responsive hormone in plants, and it is implicated in a variety of stressors such as osmotic, drought, and cold stress (Peleg and Blumwald, 2011; Wasilewska *et al*., 2008). Seed development and seed dormancy, as well as water management in the plant body via stomatal opening and closure, and plant responses to external challenges, are all affected by ABA. When there is a lack of water, ABA is mainly synthesized in the roots and transferred to the leaves through the xylem, resulting in a rise in leaf concentrations. That rise in ABA functions as a stimulus in guard cells, triggering a signalling pathway that regulates guard cell turgor (Danquah *et al*., 2013; Awan *et al*., 2017). The production and translocation of ABA in the abiotic stress response causes stomatal conductance and a reduction in transpiration rate, limiting cell development (Peleg and Blumwald, 2011). Dar *et al*. (2017) found that ABA upregulates hormone-responsive transcription factors and that phosphatases and kinases in ABA signaling mediate quick responses to diverse abiotic stressors. Furthermore, ABA not just to mediates physiological reactions by its own signaling, but it also regulates physiological responses in plants subjected to abiotic stressors by connecting with other PHs (He *et al*., 2018). It's important to note that ABA activates and galvanizes a variety of physiochemical defence mechanisms, including proline biosynthetic pathway, antioxidants, ROS detoxifying enzymes, heat shock proteins, and unsaturated fatty acids, as well as the strengthening of cuticular waxes, all of which help plants to mitigate the negative effects of abiotic stress (Liu *et al*., 2018; Yin *et al*., 2018.

Jasmonates

Jasmonates are a large category that includes a variety of substances such as jasmonic acids (JAs), jasmonic acid methyl ester (JAME), and others. Jasmonates are distributed all through plant, but levels are particularly high at the stem apical, root tips, immature fruits, and young leaves, which are fragile growth portions (Wasternack, 2007). JAs are thought to play a role in embryo and reproductive organ development, sex determination, seed germination and seedling development, root growth, fruit ripening, leaf movements and senescence, gravitropism, trichome formation, and tuber development (Wasternack and Hause, 2013; Wasternack, 2014). Because of their strong protective potential on plants against stress (Takeuchi *et al*., 2011), research have focused on JAs, which play an important role in abiotic stress tolerance. Furthermore, plant motions associated to adapting seasonal and circadian cycles are influenced by JAs-mediated secondary metabolites synthesis (Chen *et al*., 2006). It is well-established that jasmonates have a role in abiotic stress control in *Carica papaya* (Mahouachi *et al*., 2007), citrus, and *Arabidopsis thaliana* (*A. thaliana*) (Arbona *et al*., 2010; Brossa *et al*., 2011).

Strigolactones

Strigolactones (SLs) are carotenoid-derived PHs that are released by 80% of

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plants that claim to have a symbiotic interaction with arbuscular soil mycorrhizae (Akiyama and Hayashi, 2006). Such PHs were first recognized as an "ecological signal" for parasite seed development and a symbiotic link between helpful bacteria and plants. Those substances were generally dubbed strigolactones because this obligatory hemiparasite plant requires a live host for germination and initial growth (Cook *et al*., 1972). Numerous strigolactone analogs, including GR5, GR7, and GR24 (the most active), were produced synthetically in several plants, and subsequent descriptions had also characterized one ‘s fully functioning roles in a variety developmental stage, such as root development, shoot branching, leaf senescence, reproductive development, and controlling the architectural style of plant organs (Gomez-Roldan *et al*., 2008; Kapulnik *et al*., 2011). Additionally, SLs have an effect on the quantitative growth of the symbiotic nitrogen-fixing bacteria in root nodules (Rochange *et al*., 2019). SLs are important in controlling many physiological and morphological activities throughout plant adaptation to abiotic stressors such as salt, drought, nutritional deficiency, temperature, and pathogenic assail, according to several studies (Marzec *et al*., 2013). SLs were also shown to have an important function in nitrogen and phosphorus deprivation, causing changes in root and shoot architecture and encouraging rhizobial bacteria and AM fungus symbiosis (Marzec, 2016).

Cytokinin

The CKs are important plant PHs that act as ABA opponents and auxin antagonists/synergists in a range of methods that affect plant growth, development, and tolerance to abiotic stressors (Pospilová, 2003; Danilova *et al*., 2016). The usage of cytokinins has also been found to be beneficial in modulating the plant's sensitivity to external stress (Ha *et al*., 2014). Whenever a plant is subjected to salt stress, CKs are triggered. CKs can improve salt stress resistance by associating with other plant hormones like auxins and ABA (Iqbal *et al*., 2006). Because the photosynthetic system is destroyed in suspectable plants under low photosynthesis settings, there is a higher drop in photosynthesis in susceptible plants than in stress tolerant transgenic plants during water stress. As a result, CKs may preserve photosynthetic systems in transgenic plants, adding to stress tolerance (Rivero *et al*., 2010). Plant intrinsic CKs are nucleotide derivative with isoprenoid or aromatic side chains that are present in lesser amounts in plants (Sakakibara, 2006). Cytokinin is thought to improve wheat salt tolerance by interacting with other plant hormones and regulating and detoxifying harmful ions and reactive oxygen species. It is also shown that tobacco can withstand dryness by accumulating cytokinin Rivero *et al*. (2007). Cytokinin has been found to alter nitrogen metabolism in plants by increasing nitrate reductase activity (Sakakibara., 2006; Sykorova *et al*., 2008). Plant resistance to salt and

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drought was also found by Barciszewski *et al*. (2000) owing to cytokinin buildup. Other authors have found on the role of exogenous cytokinin application in plant stress tolerance (Gupta *et al*., 2003; Yang *et al*., 2005), which is regarded as a cost-effective and simple strategy for inducing stress tolerance in a variety of crops (Torres- Garcia *et al*., 2009). According to Ketabchi and Shahrtash (2011), cytokinins can help protect plants against infections. The use of cytokinin lowers the deleterious effects of *Fusarium moniliforme* on maize seedlings significantly.

Melatonin

Melatonin is a differentially expressed chemical that has a wide range of effects on plants. For the first time in 1995, two groups of researchers discovered melatonin (N-acetyl-5-methoxytrytamine) in vascular plants (Wang *et al*., 2017). It is regarded as an antioxidant with considerable anti-oxidant properties in the management of reactive oxygen species (ROS) (Raza *et al*., 2020). Plant melatonin is also engaged in a variety of physiological functions, including growth, roots, seed germination, photosynthesis, and stress resistance (Arnao and Hernández-Ruiz, 2015). The discovery of the first plant melatonin receptor has paved the way for this regulating molecule to be classified as a novel plant hormone. Melatonin has also been considered as a plant master regulator due to the range of its activities. Additional activities regulated by it include ripening or senescence, the internal biological clock, and parthenocarpy. Lastly, melatonin is an endogenous plant bio-stimulator that protects plants from abiotic and biotic stresses (Sun *et al*., 2015). The absence of a recognized sensor is among the most significant constraints in research on melatonin in plants. Growth stimulation, roots induction, tropism, seed germination promotion, photosynthesis, efficiency optimization, and leaf water/CO_2 exchange are all affected by melatonin (Sharif *et al*., 2018). Phytomelatonin, like other plant hormones, regulates H_2O_2 synthesis by controlling stomatal closure via the CAND2/PMTR1-mediated signaling pathway (Arnao and Hernández-Ruiz, 2019).

Brassinosteroids

Brassinosteroids, a novel class of plant hormones, affect plant development processes such as seed germination, blooming, and senescence (Rao *et al*., 2002). Brassinosteroids are found in plants at extremely low concentrations, and their concentration fluctuates in plant tissues, with young tissues containing more brassinosteroids than mature tissues. *Chlorella vulgaris*, a unicellular green alga, has also been found to contain brassinosteroids (Bajguz, 2009; Stirk *et al*., 2013). Over than 50 naturally occurring brassinosteroids were discovered by Kim *et al*. (2005) across the whole plant kingdom. Brassinosteroids are essential for a wide range of plant developmental activities; include shoot and root elongation, seed development and germination, and the formation of vascular tissue, according to Schumacher and Chory (2000). When green algae are subjected to heat stress in the presence of brassinosteroids, the level of ABA increases (Bajguz, 2009). Cell elongation, cell division, photomorphogenesis, xylem differentiation, growth, and reproduction are among the physiological and biochemical processes regulated by them in plants (Nolan *et al*., 2020). Auxins are intimately connected to BRs because they modulate their transport, coordinating the tropic responses of plant organs and encouraging lateral root primordial initiation during lateral root growth (Li *et al*., 2005; Bao *et al*., 2004). BRs, unlike other PHs, are employed near synthesizing cells rather than for long-distance transport. BRs do, however, have a long-distance effect when they interact with PHs like auxin (Symons *et al*., 2008; Vriet *et al*., 2013).

Polyamines

Small aliphatic nitrogenous bases generated by cellular metabolism are known as polyamines (PAs). The PAs are not hormones, but they have been proposed as a novel category of plant growth regulators because of their role in regulating many growth and development processes as well as plant responses to abiotic stress (Liu *et al*., 2007; Chen *et al*., 2019). PAs also have a role in plant embryogenesis, organogenesis, reproductive development, leaf senescence, and fruit maturity, among other physiological processes (Igarashi and Kashiwagi, 2010; Childs *et al*., 2017). Additionally, PAs have been shown to defend against environmental stressors in a number of investigations (Minocha *et al*., 2014; Chen *et al*., 2019).

The H_2O_2 generated by PA oxidation is implicated in signal transduction and plant responses to biotic and environmental stressors (Freitas *et al*., 2017; Mellidou *et al*., 2017; Sariyev *et al*., 2020). The PA biosynthesis process is intertwined with the ethylene biosynthetic pathway, since they both use the same precursor (Sadenosylmethionine) and compete for it. Furthermore, PA metabolism is linked to nitric oxide production (Pál *et al*., 2015).

Impact of abiotic stresses on vegetable production

Abiotic challenges are currently a key stumbling block for worldwide agricultural crops. A large portion of the community in developing nations whose agricultural production still persists is continually endangered by biotic and abiotic stressors. The problem is projected to worsen as a due to global warming. With the expected increase in global population and food supply, this will be vital to identify strategy to enhance crop resistance to abiotic stress conditions in order to increase agricultural productivity and food security (Calanca, 2017). Drought, waterlogging, heat, cold, and salt challenges are reviewed, as well as their negative effects on vegetable production.

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Abiotic stress and Onion

Salinity Stress

Around the year 2050, it is projected that significant soil salinity would have damaged 50% of cultivated land (Wang *et al*., 2003). One of the primary abiotic factors that restricts agricultural growth and results in economic loss is salinity, which is induced by excessive NaCl concentrations (Capiati *et al*., 2006). In comparison to other vegetables, onions are the most vulnerable to salinity, as per the United States Department of Agriculture (USDA). Onion growth and photosynthetic metabolism are affected by soil salinity (Beinşan *et al*., 2015). Salt stress has a number of effects on plant development and output. Salt stress has two major impacts on crops: osmotic stress and ionic toxicity. Assimilate synthesis, decreased cell growth and membranes functionality, and reduced cytosolic metabolism are all secondary effects generated by the fundamental effects of salt stress (Gull *et al*., 2019). High salinity generates a scarcity of water in the rhizosphere, resulting in a greater salt content, as measured by the concentration of Na^+ and Cl^- ions (Tuteja *et al*., 2012). The number of bulbs per unit area, size, and fresh weight of onion bulbs are all affected by salinity in irrigation water. It has an impact on bulbing and the quality of harvested bulbs. The fresh weight of onion bulbs at harvest is also affected by salt at various development stages (Sta-Baba *et al*., 2010). The flavor production and minerals content of onion bulbs are also affected by salinity. It is yet to be revealed whether or not utilizing NaCl at specific developmental stages will impact taste accumulation and growth (Chang and Randle, 2004). H_2O_2 application increases chlorophyll content, which helps in reduction of salt stress in onions (Semida, 2016).

Drought Stress

Onion is an irrigated crop that requires a significant quantity of irrigation water to grow. Low productivity is caused by a lack of water. Onions require a lot of soil moisture to generate a lot of yield (Kadayifci *et al*., 2005). Onions are a shallow-rooted crop, with most penetration up to 18 cm and only a few roots extending up to 31 cm, extracting relatively little water from depths more than 60 cm. According to Srinivasa (Rao *et al*., 2016), the top 30 cm of soil absorbs the majority of the water, thus it's critical to maintain the soil wet to ensure the plant gets adequate water.

Onion production is increased by a constant supply of water in the needed amount. Drip irrigation is the most effective way to distribute water in drought-prone locations. Bagali *et al*. (2012) discovered that drip watering at shorter intervals resulted in a much larger bulb production. Onion growth phases that are subjected to soil drought stress have a significant influence on bulb output and quality. Onion bulbs' weight and size are also affected by drought. At the first stage, non-stressed and water-stressed plants generated the greatest average bulb weights of 102g and 91g, respectively, with significant differences at the 0.05 level of probability (Zayton, 2007).

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Heat stress

Rising global temperatures are becoming a big worry, hurting not just plant development but also crop yield. The severity, duration, and rate of temperature rise characterize high temperature stress. The amplitude and scope of stress increase fast when the temperature rises over a specific threshold, resulting in complicated acclimation effects that rely on temperature and other environmental parameters (Wollenweber *et al*., 2003). When a plant is stressed by heat, the rate of seed germination decreases, lowering photosynthetic efficiency and performance. Incredibly high temperatures during the reproductive period might impact pollen viability, fertilization, and grain or fruit production (Hatfield *et al*., 2011). Heat-related impairment to crop generative tissues is a major source of yield reduction in agriculture across the world (Suzuki *et al*., 2003). Tapetal cells lose its functionality and become dysplastic under heat stress during reproductive growth. Due to a fast temp spike during the winter period, the crop matures early, resulting in smaller bulbs. Temperature increase has been associated to lower net photosynthetic and, as a result, lower agricultural output (Mathur *et al*., 2011).

Cold stress

Abiotic stressors such as cold and freezing are prevalent environmental abiotic stresses that impact plant growth and development. Crops in various parts of the world are subjected to periods of exceptionally low temperatures. Plant development is hampered and production is harmed when plants are exposed to freezing and drought at the same time (Wang *et al*., 2016). Cold stress, that comprises temperatures as low as 20°C and as high as 0°C, impairs plant development and output while also limiting agricultural productivity. Plants are prevented from developing its full genetic potential by cold stress, which slows metabolic activities both directly and indirectly through osmotic, oxidative, and other stressors (Tommasini *et al*, 2008). Cold stress can result in poor germination, stunted seedlings, chlorosis, decreased leaf growth, and wilting, as well as tissue death (necrosis). Plants' reproductive development is also harmed by cold stress. Cold stress causes significant membrane damage, which is mostly produced by the severe dehydration that occurs as a result of freezing during the cold stress (Yadav, 2010). Plants undergo a variety of physiological and biochemical changes as a defense strategy against cold (0–15°C) and freezing (0°C) conditions. The average bulb weight per plant increased after being exposed to low temperatures for brief periods of time (Khokhar *et al*., 2007).

Waterlogging stress

Waterlogging is a significant abiotic factor that crops experience. Heavy and irregular rainfalls, as well as poor soil permeability produced by granular soil from the use of heavy agricultural machinery, are to blame (Hirabayashi *et al*., 2013). Waterlogging reduces the

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oxygen supply to submerged tissues, affecting plant growth, development, and yield (Barickman *et al*., 2019). Because of their shallow roots, onions are very vulnerable to waterlogging stress. In a pot experiment, the response of onion genotypes to waterlogging stress was investigated (Dubey *et al*, 2020). Waterlogging stress can prevent assimilates from moving from the source to the sink, lowering bulb yield (Prasanna and Ramarao, 2014). Waterlogging has a substantial influence on bulb output and yield at various development stages. Waterlogging at early development phases following transplanting and bulb initiation affects bulb quality and marketable bulb size, according to Ghodke *et al*. (2018).

Abiotic stress and potato

Water stress

Water stress is the most significant factor affecting agricultural output and quality. Potatoes are known to be extremely water-stressed. Water stress has different impacts on plants depending on when it occurs, how long it lasts, and how severe it is. Modifications to a lack of water cause changes in a variety of morphological, biochemical, and physiological features, the majority of which are detrimental to plant production (Minhas *et al*., 2018). Shoot height, root depth, leaf area, and other morphological characteristics show the impact of water stress on potato crop growth and development (Kumar *et al*., 2015). Nilsen and Orcutt (1996) state that one of the strongest markers for evaluating plant responses to environmental or abiotic stress is shoot growth. Water stress produces a substantial decrease in shoot height at all growth stages, according to Kumar *et al*. (2017), although it is most noticeable at the tuber start stage. Reduced cell size in shoots is caused by a decrease in cell expansion rate. Water shortages have a significant impact on leaf production, reducing the number, size, and length of leaves (Kumar *et al*., 2015).

Under water stress, the tuber initiation stage of the potato plant is the most vulnerable, while the tuber maturity stage is the least sensitive, resulting in a drop in overall biomass output (Kumar *et al*., 2017). Resulting from water stress, the quantity of non-marketable tubers rises at the expense of marketable tubers (Kumar *et al*., 2015).

Drought

Soil dehydration changes the morphology of the potato root system, leading to increased adventitious root proliferation, decreased root elongation, increased root thickness, and the production of root hairs that maintain root-soil contact in soil that shrinks away from roots during drying (Wishart *et al*., 2013, 2014). Drying the soil enhances the flowability of the roots at first. However, prolonged water withdrawal reduces root hydraulic conductivity (to avoid soil losses), and these changes are attributed to aquaporin activity and control (Maurel *et al*., 2010). Xylem embolism, a phenomenon in which air enters the xylem vessels and interrupts the sap flow, can significantly diminish root hydraulic conductivity in the plant

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during extended durations of dryness (Cruiziat and Cochard, 2002). Plant roots are also thought to sense soil dryness biochemically, causing the phytohormone ABA to be synthesized and transferred to the shoot via the xylem, inhibiting leaf growth and inducing stomatal closure (Dodd, 2005). Reduced stomatal density may also cause lower transpiration rates in response to drying soil (Yan *et al*., 2012; Sun *et al*., 2014).

Salinity

Salinity raises the osmotic pressure of soil pore water, limiting root water intake, and has a negative impact on soil structure, lowering water infiltration, soil aeration, and oxygen delivery to the roots. Some components that are connected with salt have a higher absorption. Toxicity is caused by elements such as sodium, chlorine, and boron (Levy and Veilleux, 2007). Significant osmotic stress in the tissues is among the main effects of salinity, and it causes adverse alterations in cellular function that impede amino acid synthesis, protein metabolism, respiration, and photosynthesis (Koyro *et al*., 2012). Lower CO_2 absorption is another result of the combined effect of salt and drought, which increases the generation of reactive oxygen species (ROS), which are particularly destructive to nucleic acids, lipids, and proteins (Koyro *et al*., 2012).

Heat stress

The first factor that defines a location's potential for potato growing is temperature. Potato tuber output is lowered by high temperature stress because assimilate availability is reduced and assimilate partitioning to tubers is reduced (Joseph *et al*., 2006). High night temperatures have a large impact on carbon partitioning across plant parts, with temperatures above 18°C favoring carbon diversion to above-ground portions at the expense of tubers, causing plants to grow very tall and lowering harvest index (Minhas *et al*., 2018). Tuberization in potatoes is a morphogenetic shift from stolon development to tuber production that is influenced by both external and endogenous factors (Singh *et al*., 2015). In warm areas, heat tolerance in potatoes entails strong growth, tuber initiation and development, concurrent and balanced glucose partitioning to the haulm and tubers, and starch buildup in the tubers (Kumar *et al*., 2007). Under heat stress, several secondary metabolites, including antioxidants with known nutritional benefit, alter dramatically (Kumar *et al*., 2013). Without adaptation, climate change is expected to reduce world potato crop by 18% to 32%, or by 9% to 18% with adaptation (Hijmans, 2003).

Abiotic stress and Tomato

Heat stress

Tomatoes are susceptible to high temps, and extreme heat can cause floral stomatal closure and reduce fruit output (Camejo *et al*., 2005; Driedonks, 2018). Increased temperature had a deleterious impact on pollen grain growth, especially in the early stages, resulting in

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poor pollen germination and pollen tube formation (Raja *et al*., 2019). Photosynthesis is similarly affected by high temperatures (Nankishore and Farrell, 2016). According to Pressman *et al*. (2002), heat stress in tomato produced male sterility, although male sterile plants grown at 29°C were able to yield fruits after receiving pollen created at 25°C. Temperatures above 30°C limit pollen germination and pollen tube formation in tomato (Vasil, 1987). According to Kakani *et al*. (2005), the ideal temperature for pollen germination in vitro was 15–22°C, while the optimal temperature for pollen germination in vivo was 25°C (Dempsey, 1970).

High temperatures have an impact on the physiological activities of roots as well as the development of aboveground plant components like fruits. The heat stress changed the architecture and physiological metabolism of tomato blossoms, as well as the synthesis of substances including carbohydrates, polyamines, and proline (Alsamir *et al*., 2017). Increased temperature to inadequate temperature circumstances has a considerable impact on tomato reproductive development, producing proportionally more harm to anthers than to female organs (Xu *et al*., 2017).

Drought

According to Rao *et al*. (2016) abiotic stressors have been associated to altered shoot, root, and leaf development, as well as crop-season life cycle and duration. Khan *et al*. (2017) investigated morpho-physiological variations in tomato crop metrics during drought stress. During drought stress, the plant body's relative water content drops due to a decrease in water supply. According to the findings, reduced water inhibited photosynthetic capability, impact on energy output and, as a consequence, poor growth. For up to 6 days, moisture stress reduced the weight of tomato seedlings' shoots and roots (Zhou *et al*., 2019). Drought stress causes the amount of solute in the soil solution to rise, allowing water to move osmotically from plant cells. This causes a rise in solute concentrations in plant cells, lowering water potential and disrupting membranes and cell functions including photosynthesis (Rao *et al*., 2016). Stomatal closure in tomato cultivated under non-irrigated settings ranges from 14 percent to 73 percent, depending on the climatic conditions and cultivars (Nemeskeri and Helyes, 2019).

Salinity

Salts dissolved in soil solution come into intimate contact with roots and may impair plant development because the osmotic action reduces water intake from plants, lowering the water potential of leaves and tissues. In many species, salt has the impact of not only decreasing the proportion of seeds that germinate, but also prolonging the time it takes to complete germination. At low NaCl concentrations, tomato seed germination is inhibited (Petretto *et al*., 2019). Plant roots are subjected to fast osmotic stress as a result of salinity stress, which results in a decrease in leaf and shoot growth. Salinity stress causes an ion imbalance, which causes necrosis and early mortality of older leaves (Munns and Tester, 2008). Because of the reduction in plant water potential and chlorophyll production, salinity has an impact on photosynthesis (Parihar *et al*., 2015). Roots are unable to ingest water directly from the soil under high salinity stress conditions, resulting in hazardous salt and chloride concentrations, plant nutritional problems, and oxidative damage (Rouphael *et al*., 2018). Under salt stress, the tomato variety Shed displayed impacted stomatal features such stomatal density, stomatal breadth, leaf stomatal area, and leaf stomatal area index, but the Alam variety remained unharmed (Guo *et al*., 2018).

Conclusion

In the last few years, there has been a significant shift in the climate, that has an immediate impact on the production, productivity, and quality of vegetable crops. As per studies, it appears that it will have a significant influence on global food and nutrition security in the coming years. As such, to ensure that the quality and quantity of vegetables, the effects of climate change can be mitigated by adopting appropriate approaches/strategies such as developing improved cultivars tolerance to biotic and abiotic stresses; conserving forests, soil, and water; utilizing renewables, and protected cultivation.

To adapt to the changing environment, plants evolve many techniques, one of which is the synthesis of hormones. Such plant hormone contributes in growth and development of plants by speeding up processes in plants. Also, it is clear from the foregoing section that all these plant hormones communicate with others, and so this engagement can be good or detrimental. The majority of unfavorable reactions to plant hormones are caused by large concentrations, which directly impact the specific plant process. It had an influence on both the vegetative and reproductive stages of plants, and its influence varied depending on the species. Furthermore, consistent with earlier study findings, it is discovered that extreme drought stress encountered by diverse plant species impeded the photosynthetic process in plants, resulting in lower plant growth and output. Under various abiotic conditions, several species of plants showed a rise in ROS, RNS, and proline content, as well as a decline in development and a drop in photosynthetic pigments. Plants have been observed to lose dry matter, pigmentation intensity, and phenolics as a result of saline condition. Phyto regulators such as plant hormones, osmolytes, bio stimulants, and others have been found to give plant tolerance to various abiotic stimuli by boosting protein, proline, and antioxidant metabolism in many plant species.

The research from a community of scholars mentioned that the presence of a hormone, its use for a clear objective, through the use of a phytohormone producing strain are some of the most important aspects to be considered when trying to improve plant growth and development under normal and stressful conditions. There is a large deficit in the knowledge of such features that has to be

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covered by finding out information at the vast system level. The quantity and frequency of plant hormones administration must be studied.

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