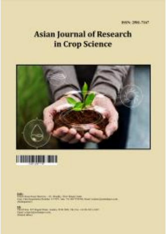

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Crop Responses and Strategies for Mitigating Cold, Salt, and Drought Stress in Vegetables: A Review

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Author's contribution

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The demand for vegetables has increased significantly over the past few decades, due mostly to the world's rising population. Cold, salt, and drought are all key abiotic variables that might jeopardise vegetable production. Many vegetables, including cauliflower, carrot, tomato, okra, pea, eggplant, lettuce and potato, are sensitive to cold temperatures, excessive salt levels and dry circumstances. Researchers have extensively studied the plant's defence systems against cold,

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salt, and drought stress in both model plant species and field crops. To increase food production, it is critical to produce crops that are resistant to stress and can survive in salty and dry areas. Vegetables play an important part in the human diet owing to their nutritional value, which includes vitamins, carbohydrates, protein, and minerals. Several vegetable crops have substantial local relevance worldwide, while others are widely cultivated. Each of these vegetable crops experiences varied levels of biotic and abiotic stress, resulting in changes in their molecular, physiological, and morphological responses. This review paper focuses on the major abiotic stresses that influence essential crops such as okra, cauliflower, tomatoes, peas, chilies, and eggplant. The review also examines a variety of methods for promoting growth and development in these vegetables in stressful environments.

Keywords: Significantly; abiotic stresses; threats; extensively; nutritional value; physiology; morphology; strategies.

1. INTRODUCTION

Increased incidence and severity of biotic (insects, illnesses) and abiotic (drought, flood, salinity, heat, cold, nutrient imbalance) adverse circumstances endanger agricultural productivity [1]. To sustain metabolism and development, plants have many stress-resistant systems [2]. Vegetable crops may respond to varied environmental pressures, but rapid climate change may outweigh these adaptations [3]. The response systems involve various factors such as species, stress severity, stress duration, phenological stage, and tissues or organs. Reversible or irreversible abiotic stressors modify plant physiology and metabolism [4]. These variables affect abiotic stress-prone vegetable crops [5]. To meet the world's vegetable demand, we need new growth methods and resistant genotypes to address drought and salt challenges [5].

Antioxidants, vitamins, minerals, and dietary fibres make vegetables an important part of the diet [6]. People eat vegetables for their flavour, texture, and religious significance. Global vegetable output rose 65% in 2019. Of the almost 8 billion people on Earth, about 770 million are undernourished [7]. Scientists and producers are working to boost vegetable output and nutrition under stress [8]. Environmental variables, including solar radiation, evapotranspiration, and soil moisture retention, affect drought and salt stress [9].

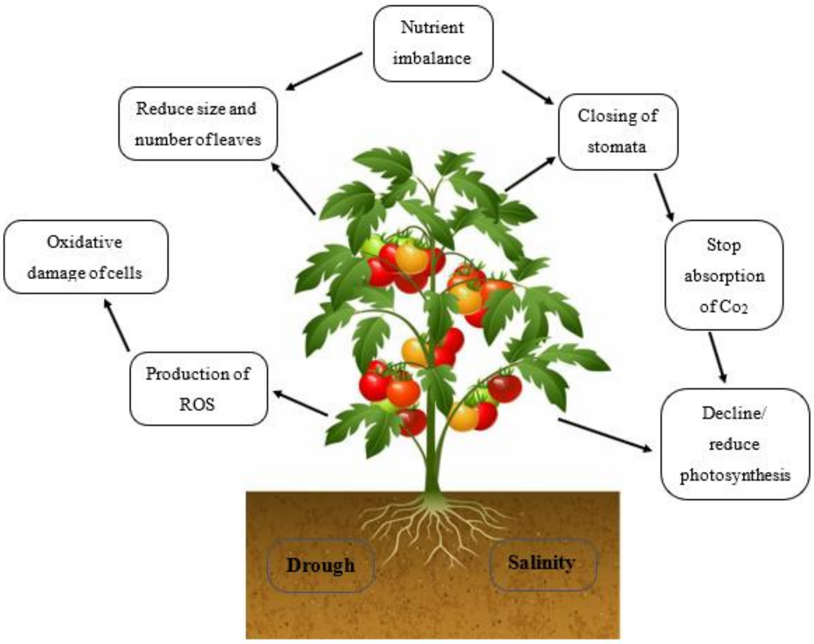

Fig. 1. Effect of salinity and drought on physiological process of plants

Salt and drought affect vegetable yields and quality. Salt (EC~ 2.5 ds m−1) and drought pose threats to vegetables [10]. Safdar et al. [11] report that drought and salt induce osmotic, ionic, and oxidative stresses that slow down plant growth. As stomata close, CO2 absorption, carboxylation, and internal CO2 levels drop, which leads to more photorespiration [12] (Fig. 1). Reactive oxygen species (ROS) produced in response to salt stress and drought accelerate damage to plant cell organelles.

Some unanswered problems with plant responses to salt and drought persist after decades of research on vegetables. Possible methods for increasing yield are discussed, along with the chemical and physiological reactions of plants to salt and drought. Several methods to enhance vegetable output under drought and salt stress conditions Munns et al. [13].

2. COLD STRESS IN BRASSICA VEGETABLES

Nevertheless, for Brassica plants to reach their full potential, certain environmental constraints must be satisfied. Upon surpassing these limits, Rodriguez et al. (2015) report that plants undergo various forms of stress, leading to a reduction in their development and production. At a certain point in their vegetative development cycles, broccoli and cauliflower stop responding to extreme heat by transforming their meristem into an inflorescence. This happens before the plant's edible blossom head forms (Siomos et al., 2022).

According to Zhang et al. [14], plants may experience physiological stress and developmental delays due to low temperatures. We classify the temperature strains as either chilling or freezing stress. Plants normally chill out between 0 and 15 °C, but when temperatures drop below 0 °C, they experience freezing stress. The precise freezing stress threshold is species- and tolerance level dependent [15].

In order to improve the longevity and yield of Brassica vegetables, it is crucial to comprehend the physiological and morphological effects of cold stress on these crops [16].

- **Vegetative changes in cold stress**

Morphological change refers to the observable alterations in plants that take place either in the initial or severe phases of exposure to low temperatures [17]. Cold stress may hinder the germination and development of Brassica crop seeds. The duration of cold stress negatively correlates with the length of the plantlet's radicles and plumules. After 288 hours of exposure to low temperatures, the germination rate of Brassica rapa decreased. Brassica rapa seedlings are unable to germinate when exposed to temperatures lower than 12°C, which negatively affects their early vegetative development Rodríguez et al. (2015). Low temperatures reduce roots' capacity to assimilate nutrients, such as food and water [18].

Cold soil inhibits root growth due to reduced tissue nitrogen concentrations [19]. Cold temperatures inhibit the development of lateral roots [20].

- **Reproductive changes**

Brassica plants' metabolism determines the amount of food they produce during their reproductive life cycle. Cold stress during the reproductive period causes plants to reduce metabolic activity, which in turn lowers yields. Low temperature stress has a negative effect on a plant's reproductive phase, especially on the vulnerable section of the process Thakur et al. [21]. There are several separate stages in the reproductive phase, such as flowering, head development, micro- and mega-sporogenesis, pollination, gametophyte formation (including pollen grains and embryo sacs), fertilization, and seed development. The net yield drops because of a cascade of unfavorable responses that occur at each level of cold stress [22].

Cabbage heads may be negatively impacted by cold stress, which can cause delays in development and start. Cabbage bolting happens when the plant experiences early blooming in response to certain environmental factors Manasa et al. [23]. As a result, the cabbage head's overall quality and market worth may suffer. Cold temperatures may reduce the nutritional content and antioxidant activity of cabbage heads [24].

The inflorescence is composed of the flower buds of a mature broccoli plant. The consistency in size and form of these buds is vital in guaranteeing that the curds will be of good market quality. The temperature during the seedling period can alter the growth of the broccoli inflorescence Grabowska et al. [25].

Buttoning continues all the way until infancy. Low temperatures significantly affected the quality of broccoli heads when they were seedlings, specifically between 8 and 10 weeks old Kału Żewicz et al. [26]. The disruption of the anticipated uniform morphology of the flower buds resulted in an uneven distribution and shape [25]. Fig. 2 shows how cold stress affects the reproductive and vegetative parts of Brassica crops.

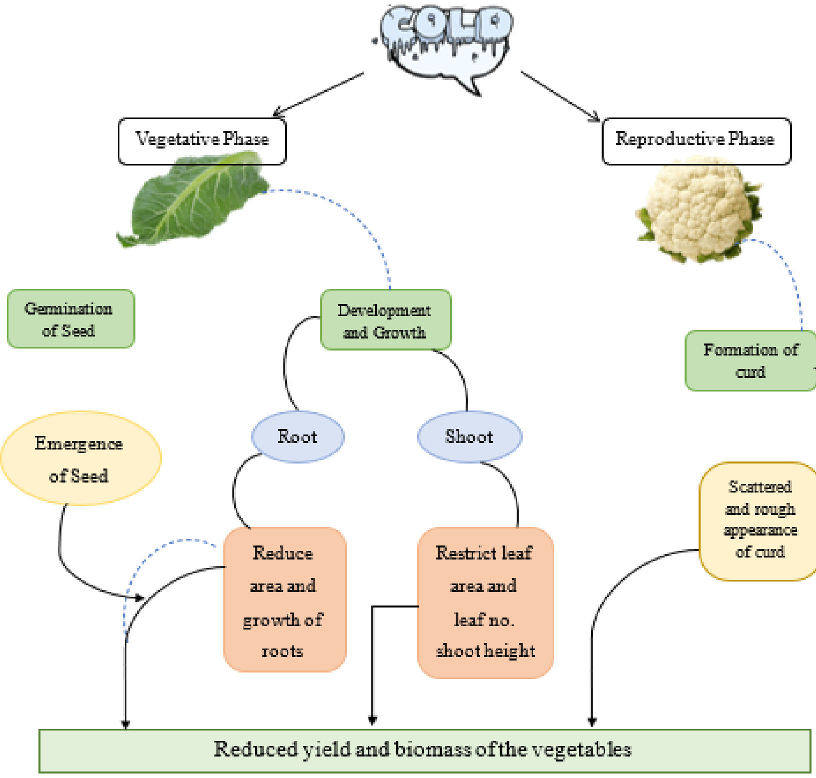

Fig. 2. Effect of cold stress on vegetative and reproductive phase of vegetable

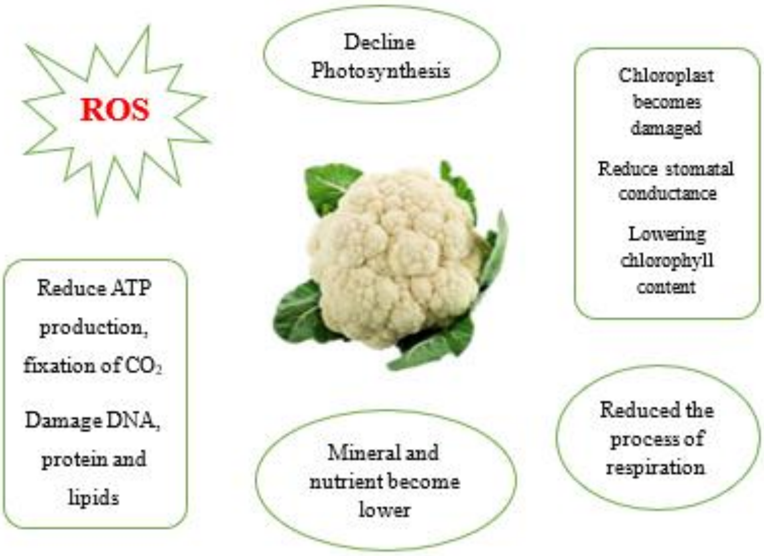

Fig. 3. Impact of cold stress on the physiology of vegetables

- **Nutrient Uptake**

Low temperatures may decrease the presence of essential nutrients, including nitrogen (N), phosphorus (P), and potassium (K), in the soil, as well as the effectiveness and amount of nutrient-absorbing proteins in plant roots [23]. Cold temperatures can impede the growth and development of roots by reducing their length and diminishing their overall bulk. Due to the considerable decrease in root volume, there is a reduced chance for roots to find new water and nutrient sources, leading to a significant decrease in mineral absorption. In addition, cold stress may lead to inadequate absorption of water by plant roots, hence affecting the uptake of nutrients by roots and their subsequent transport to the shoots [27] **(**Fig. 3).

3. SALINITY

We can categorize soil salinity as either primary or secondary salinity. The principal cause is the natural process of rock disintegration, which releases soluble salts such as sodium, calcium, and magnesium chlorides, sulphates, and carbonates into water. Wind and rain then deposit these salts in the soil solution. In this procedure, the most readily transportable salt is sodium chloride. Secondary salinity, in contrast, arises from human activities such as the substitution of perennial crops with annual crops, the utilisation of irrigation water containing high levels of salts, and the imprudent application of chemical fertilisers. These factors collectively contribute to the escalation of soil salinity [28].

- **Salinity effect on pea (*Pisum sativum*):**

People generally consider peas, along with other legumes like broad bean, common bean and soybean, to be highly susceptible to salinity. However, among these legumes, pea is particularly sensitive to salt. The growth of medium salinity has a negative impact on almost all morphological, physiological, and molecular characteristics of peas (Ahmad and Jhon, 2005).

Pea shoot growth is severely decreased at low salinity levels, whereas root development is not affected. However, both shoot and root growth are negatively impacted at greater saline conditions [29]. The study, conducted by Rao et al. [30] found a positive correlation between the rise in saline levels and the inhibition of growth and loss in yield in pea plants. According to Okcu et al. [31], when exposed to salinity levels between 6 and 10 dS m−1, a salt sensitive crop has a 50% decrease in production. The study, conducted by Najafi et al. [32] found that pea plants did not experience a significant loss.

The amount of free proline in plants significantly increases when they are under salt stress. They observed a drop in the rate of photosynthesis in pea plants, which they linked to a decrease in the concentration of photosynthetic pigments. Additionally, researchers claimed that the buildup of sodium ions in high salinity circumstances caused the loss of chlorophyll content in the leaves.

- **Improve pea growth and yield in salinity**

Bonilla et al. (2004) found that adding boron (B) and calcium (Ca) to the nutritional medium may effectively reduce the negative effects of salt stress on pea plants in saline circumstances. Adding Ca or B to pea plants increased the number of seeds that germinated and their vegetative growth when they were exposed to 75 mM NaCl, but not when they were exposed to 150 mM NaCl [33]. By applying B and Ca, the damaged nodules caused by salt stress were able to recover and exhibited increased activity in nitrogen fixation.

El-Hamdaoui et al. [33] demonstrated that externally applied boron (B) and calcium (Ca) can resolve the salt-induced deficit of potassium (K) and iron (Fe). Salt stress harms the structure of the cell wall in pea plants, leading to changes in the pectin component. However, studies have shown that administering both calcium (Ca) and boron (B) positively enhances the integrity of cell walls (Bolalos et al., 2003). In salty environments, nitrogen fertilizers significantly enhance the development of pea plants. Figueira and Caldeira [34] found that the application of NO3 successfully promoted the development of pea plants under mild salinity conditions (Fig. 4).

- **Okra (*Abelmoschus esculentus* L.)**

Okra is a semi-tolerant or moderately resistant crop; however, salt stress might reduce its development and production [35]. At 6.7 dS m−1, okra fresh produce production decreased by 50%. Salinity has several negative effects on crop development. High salinity negatively affects okra's morphology, physiology, metabolism, and enzyme activity, thereby reducing crop output [36]. Saleem et al. [37] identified many okra cultivars. In contrast, saline medium enhanced okra leaf chlorophyll a and a/b ratio (Ashraf et al., 2003). Salt stress has no effect on chlorophyll b and carotenoids.

- **Improve salt tolerance in Okra**

It seems that a practical and workable way to improve okra's salt tolerance is to apply organic chemicals like humic acid and exogenous potassium (K) Fig. 5.

- **Tomato (*Solanum lycopersicum* L.)**

Some authors consider tomatoes to be fairly susceptible to salt stress [38]. According to Campos et al. [39], the development of both the vegetative and fruit parts of tomato plants significantly decrease in salty environments. Nevertheless, the decrease in growth is more noticeable in genotypes that are sensitive to salt compared to those that are resistant to salt [40]. Refer to Fig. 6.

The saline environment has a negative impact on tomatoes' physiological efficiency. Leaf water and tomato plant osmotic potential declined, whereas endogenous ABA concentrations rose when exposed to saline conditions [41]. Katerji et al. [42] reported a significant reduction. Tomato plants experience an ionic imbalance and osmotic shock due to the presence of a high quantity of salt [43].

- **Improving salt tolerance in tomato**

While tomato output decreases significantly in salty environments, the majority of commercially available tomato cultivars are fairly resistant to salt stress at all stages of development, including seed germination, vegetative growth, and reproductive growth [44]. Adding extra potassium and Calcium to the root growth medium improved tomato growth and development under saline regimes [45] and salicylic acid from outside the plant greatly improves its growth and other physiological traits when it is exposed to salty conditions. When tomato plants were exposed to high salt levels, adding salicylic acid from outside the plants greatly increased glucose, fructose, and proline levels [46]. Grafting tomatoes have demonstrated a significant increase in their salt tolerance [47].

Fig. 4. Salt stress on pea plant

Fig. 5. Salinity impact on Okra

Fig. 6. Salt effected tomato plant

Fig. 7. Salt effect on cauliflower plant

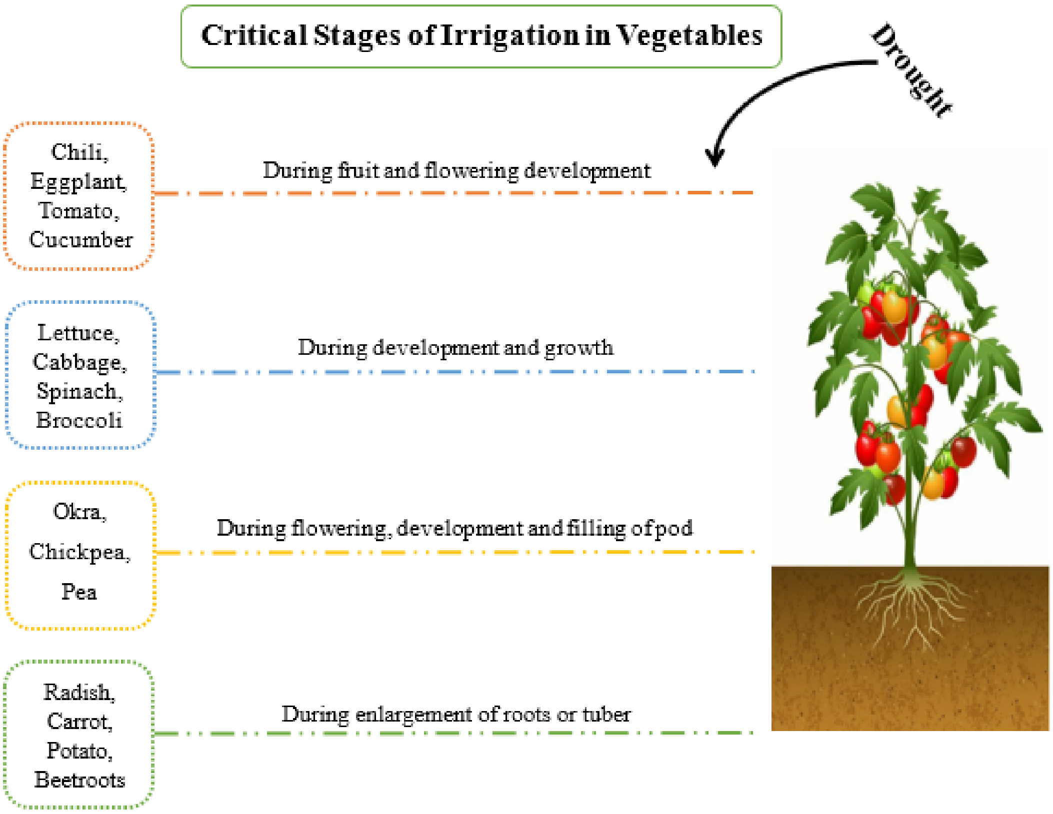

Fig. 8. Critical stages of irrigation

- **Cauliflower (*Brassica oleracea var. Botrytis* l.)**

Cauliflower has a modest level of tolerance for salt. However, the literature only provides a limited number of quantitative findings about its tolerance. Jamil et al. [48] demonstrated that soil salinity reduces the percentage of seed germination in cauliflower. The roots' development was significantly impaired compared to the shoots' growth. The presence of salt stress significantly decreases the cauliflower yield [49]. It is necessary to investigate the specific reactions of cauliflower to salt stress due to its global popularity as a vegetable [48] (Fig. 7).

- **Salt tolerance in cauliflower**

There is a single study on how to improve salt tolerance in cauliflower. Shahbaz et al. [50] suggests that adding nitrogen to the growth medium could significantly boost cauliflower's yield under salt stress.

4. DROUGHT AND VEGETABLE PRODUCTION

We define drought as a condition of strain caused by insufficient water. Drought is a meteorological phenomenon characterised by a prolonged period of reduced precipitation and limited water resources. Drought, a consequence of global warming, is responsible for the most severe famine in the last century. Drought impacts more than % of the global agricultural areas [51]. Additionally, it affects the functioning, structure, and fertility of the soil ecosystem [52]. The combination of increased evapotranspiration, decreased precipitation, and reduced soil microbial activity will result in substantial water stress. This, coupled with rising temperatures, will have a negative impact on the production and quality of vegetable crops. As a result, the concentration of solute will rise, causing a decrease in the amount of water. This will disrupt membrane function and activities related to photosynthesis, ultimately causing cell death [53].

Potato tubers are very susceptible to drought, and even a small water scarcity significantly reduces their production capability [54]. Water scarcity significantly reduces the production and quality of tuber, root, and bulb vegetable crops [55].

- **Physiological changes in drought**

A drought is an environment under stress due to a water shortage. The greatest mass famine in world history was caused by drought, which is the most significant effect of global warming. More than a percent of the world's agricultural areas experience drought [51], which has an effect on fertility, shape, and functioning of the soil ecosystem as well [52]. This will cause the concentration of solutes to rise and eventually cause the water content to sink, disrupting the processes involved in membrane permeability and photosynthetic activity, and finally leading to cell death [53].

A wide range of vegetables may experience water stress during flowering and fruiting. Even a small water scarcity negatively impacts potato tubers' ability to produce due to their greater sensitivity to drought [54]. Due to the inhibition of the transfer of carbohydrates from the leaves to the storage organs, vegetable crop yield and quality are significantly decreased in situations of water scarcity [55].

- **Molecular changes**

Plants produce more ROS in their cell organelles because they must close their stomata to obtain water. Increased ROS generation will lead to oxidative stress. Major metabolic processes, including the production of reactive oxygen species (ROS), occur in subcellular compartments such as the chloroplast, mitochondria, and peroxisomes [56]. Photorespiration in peroxisomes, the Mehler reaction in chloroplasts, and electron transport in mitochondria are some of the main metabolic processes in cells that make ROS. Tight regulation and/or effective metabolism are required to maintain the proper ratio between intracellular ROS generation and removal. This equilibrium is required to sustain growth, metabolism, development, and total plant production, as well as to reduce the possibility of ROS damaging cellular components [57].

In situations of water deficiency, the first element of a plant to detect water loss is its roots, which then transmit the stress signal via the xylem. Abscisic acid is the primary chemical signal that integrates into roots and travels to shoots and leaves to control stomata in water scarcity [58]. As ABA closes stomata, it sets off a complex chain of signalling pathways and turns on genes that are sensitive to drought stress.

Plants respond to water deficiency by producing several defensive mechanisms, one of which is the formation of cuticular wax. Cuticular wax from plants functions as a barrier to prevent water deficiency [59]. The epidermal cells are responsible for producing the cuticle. Researchers have shown that tomatoes) and cucumbers produce more cuticular wax, leading to a reduction in non-stomatal transpirations and an improvement in tolerance to water deficiency situations [60,61]. Al-Abdallat et al. [60] observed a decrease in tomato cuticular permeability, an increase in cuticular wax production, and an enhancement in drought tolerance [62-66].

5. CONCLUSION

The biggest abiotic elements affecting vegetable production worldwide are drought, cold, and salt. Stress from droughts, colds, and salinity reduces vegetable plant health and productivity. When subjected to abiotic stress, vegetables activate genes and systems (e.g., antioxidant defence mechanisms) that allow tolerance. Several methods may improve their tolerance. By improving agricultural yields with fewer resources, the rising population can get more food sustainably. Abiotic and biotic stressors significantly impede most crops.

Salt is one of the most significant abiotic constraints on crop productivity. Plant scientists and breeders struggle to understand salt damage and tolerance, as well as develop methods to boost crop development and output in salt-affected regions. Vegetables, a typical food crop, provide nutrients. Root medium salinity is detrimental to most vegetable crop development and output. Unlike major staple food crops, vegetable salt tolerance mechanisms have received minimal study. Researchers have done little to improve these crops' salt tolerance. It's time to apply model plant knowledge to vegetables.

Researchers have used a variety of methods to enhance stress tolerance. Exogenous inorganic fertilizers with extra Boron and Calcium, as well as plant growth regulators like methyl jasmonate and polyamines, helped vegetable crops grow in salty conditions. Exogenous GB, bacterial injection, and grafting have improved auberge salt tolerance. One study documented the use of saline nitrogen fertilizer in cauliflower. There is a dearth of literature on the remaining vegetables. However, the exogenous application of suitable solutions like glycine and betaine, as well as plant growth. Therefore, more research is required to determine whether shotgun methods could enhance crop salt tolerance.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I hereby declare that no generative AI technologies such as large language models (ChatGPT, copilot, etc) and text-to-image generators have been used during writing or editing of manuscripts. I will be responsible for any consequences.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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