



REVIEW ARTICLE

Drought stress in vegetable crops: Physiological mechanisms, adaptation strategies and management approaches: A review

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Abstract

Drought stress is one of the most limiting factors in vegetable cultivation across the world, with its impact becoming increasingly serious owing to climate change and greater climatic variations. The lack of water in the environment is detrimental to vital physiological and biochemical functions in the plants, such as photosynthesis, respiration and nutrient absorption that reduce plant growth and yield potential as well as quality of vegetables. Vegetable plants are highly vulnerable to the negative effects of moisture stress particularly at crucial stages of growth such as flowering and fruit production. The process causes interference with normal plant metabolism, which affects vegetative growth and production of yield. Despite the adaptive responses displayed by plants such as morphological, physiological and biochemical adaptation, which may fail in some instances, there is a need for proper drought stress management in vegetable cultivation. This can be achieved through strategies like selecting and developing drought-tolerant plant varieties, grafting on stress-resistant rootstocks and adopting better techniques in vegetable breeding and biotechnology. Other important methods include implementing efficient irrigation practices like drip irrigation, mulching, crop rotation and intercropping. Future research needs to consider the identification of drought-tolerant genotypes as well as the adaptation mechanisms to stress and incorporate modern breeding and biotechnological approaches into the cultivation process. The implementation of these approaches and technologies is crucial for securing future vegetable yields in the face of increasing water scarcity.

Keywords: agricultural methods; breeding; drought stress; germplasm selection; molecular methods; rootstocks; vegetable crops

Introduction

The environmental stress factors play a very critical role in influencing the productivity of crops and are the major yield losses encountered in agriculture. The negative impact on plants due to

both abiotic and biotic stress is experienced through disturbances in plant physiology and metabolism. In crops such as wheat and maize, yields could be greatly reduced through stresses exceeding 50 %. Of all the abiotic stresses in agriculture, the drought is one of the most significant and widespread limitations that influence yields

negatively. Drought is widespread in agro ecological regions and affects virtually all crops throughout the life cycle stages of the crops (1–4). Climate change and its effects on agriculture pose great challenges to food production because of the increasing frequency and severity of drought episodes. Food insecurity is likely in the near future if proper measures are not put in place to ensure agricultural productivity. Vegetables play an important role in nutrition since they contain many nutrients that help sustain human health. Vegetables are a good source of vitamins, minerals, antioxidants and other nutrients that promote human health and longevity. Vegetable crops are the source of these vital vitamins, minerals, dietary fibre, antioxidants and health-promoting phytochemicals that people need to eat to stay healthy (5). The thing about vegetables is that they are sensitive to not having water. This is because they have a lot of water in them and their roots do not go deep into the ground. So, when there are not water most vegetable crops will have a hard time dealing with it. Owing to this, vegetable crops are highly susceptible to drought stress.. Vegetable crops are just not able to handle drought well. Significant decreases in growth, yield and quality occur when there is a water deficit during crucial developmental phases such as blooming, fruit set and seed formation (6–9). Despite a general rise in vegetable output worldwide, the present supply is still insufficient to satisfy rising nutritional needs, especially considering expanding environmental stressors (5).

Drought is described from an agricultural standpoint as the insufficiency of water availability, including precipitation and soil moisture storage, in terms of quantity and distribution during the crop life cycle, which limits the expression of plants' entire genetic potential (10). Drought tolerance is defined as the capacity of plants to sustain commercial production with minimum loss in water-limited situations as opposed to ideal moisture settings (11). Elevated temperatures, which increase evapotranspiration and negatively impact photosynthetic efficiency, are frequently associated with drought stress and exacerbate production losses (12). At the physiological level, drought stress in vegetable crops causes considerable changes in photosynthetic rate, stomatal conductance, relative water content and leaf water potential (3, 13). Long-term exposure to water deficit conditions disrupts protein structure and enzyme activity, compromises membrane integrity and permeability and ultimately leads to cellular damage and cell death. Oxidative and osmotic stress are also brought on by drought stress, which leads to an excessive buildup of reactive oxygen species (ROS) that harm metabolic activities and cellular organelles (14, 15).

To deal with damage from drought vegetable crops use ways to protect themselves. These ways work at different levels like at a small molecular level a biochemical level, a physiological level and even at the whole plant level. Vegetable crops respond to drought stress by accumulating osmolytes to maintain cellular osmotic balance, activating protective compounds to mitigate oxidative damage, modulating stress-responsive signalling pathways and regulating protein synthesis and degradation to sustain cellular function. Vegetable crops use these methods to handle drought (16–18). Previous research has extensively examined drought tolerance mechanisms and ways for improving agricultural drought resistance (19–21). Recent research has focused combining traditional breeding methods with innovative plant breeding technology to increase drought tolerance in vegetable crops. The introduction of genetically modified and gene-edited cultivars has

created new prospects for improving stress resistance and yield stability under water-limited situations, consequently contributing to long-term agricultural growth (22, 23). The use of climate-smart agriculture technologies such as irrigation scheduling, drip irrigation, soil moisture retention and application of biostimulants has proven beneficial in reducing drought stress (24, 25). Irrigation techniques promote efficient use of water by plants and help in making the plants tolerant to drought stress. They aid in maintaining oxidative stress metabolism, osmotic regulation and physiological mechanisms for improving yield and quality in the case of reduced nutrient availability (26–28). This study aims to investigate the ways by which plants react to drought conditions. Biochemical processes in plants that occur during water shortage will be examined. The effects on vegetables during drought conditions will also be investigated. It sees what management practices can help reduce the effects of drought on these crops. The people doing this study are using what they know about how plants work, how to breed plants and how to manage crops to find ways to make vegetable crops stronger, against drought. They want to help keep vegetable production steady when the weather is changing.

Drought stress

Drought stress is caused by moisture deficiency in the soil owing to either lack of rains or long spells of dry weather. The situation is compounded by rising temperatures that cause more evaporation from the soil, making water unavailable for plants to absorb. Hence, plant development becomes negatively affected, there is decreased photosynthesis activity and signs of water scarcity become evident (Fig. 1). Besides, drought causes physiological and biochemical stress in plants, thus limiting cellular activities leading to lower productivity.

Effect on vegetable crops

The climate plays a crucial role in determining the productivity of vegetable crops. Due to the current climate change phenomena, there has been observed increased variability and frequency of extreme weather occurrences that negatively affect agricultural production. Climate change in this case is caused by higher levels of greenhouse gases, mostly carbon dioxide (CO₂), leading to changes

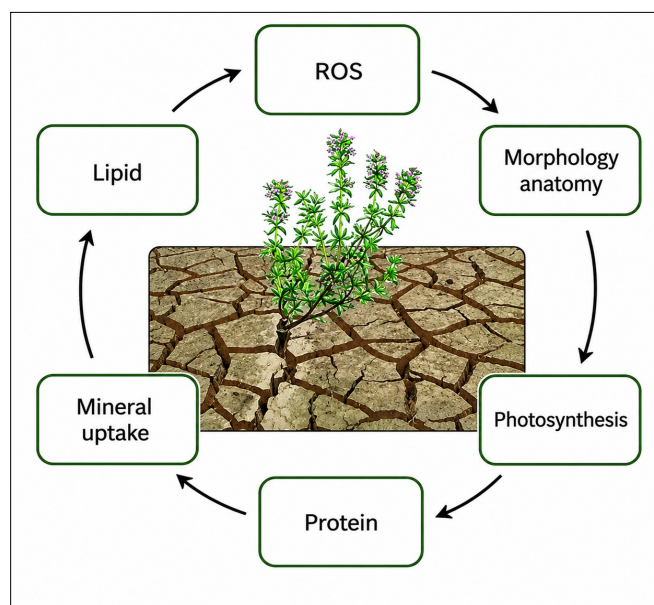


Fig. 1. Impact of drought stress on physiological and biochemical processes in plants.

ROS: reactive oxygen species.

in temperature and precipitation, thus, affecting vegetable crop production. This is going to affect when and how much we will rain and have water for agriculture. Climate is a vital component in vegetable production. Climate change is creating problems for farmers due to weather conditions. It is caused by the hotter planet and elevated carbon dioxide levels in the atmosphere that affect the climate. This affects vegetable crops (29). In addition, insufficient rainfall, together with prolonged temperature, sun exposure, moisture deficit in the soil and dry winds can worsen the water shortage for the vegetable crops (30). The effects of climate change have a negative impact on agriculture. This is a serious issue faced by developing nations. Lack of rainfall results in lower productivity for farmers in terms of their produce every year. Climate change creates problems for agriculture and affects crop yields. It makes it even tougher for developing nations. The fact is, climate change is bad, for farming and it hurts developing nations a lot (31–33). Similar tendencies are also being seen in temperate places, such as the United Kingdom, where it is anticipated that changed rainfall patterns may make drought situations more frequent and severe (4). Cropping techniques and cultivation practices are also being forced to alter because of frequent drought and water scarcity, which is increasingly moving conventional agricultural zones (34). Climate modelling studies in Korea indicate significant shifts in rainfall patterns from September to November between 2030 and 2050,

Table 1. Effect of drought stress in vegetable crops

Crop	Effect of drought stress	References
Tomato	Induces flower abscission	(1, 2)
Onion and bhendi	Reduces germination of seeds	(3, 7)
Potato	Reduces germination of tubers	(4, 6)
Bell pepper (late flowering–early fruit set stage)	44 % reduction in yield	(9, 35)
Onion (3 and 7 leaf stage)	26 % reduction in yield	(8, 36)

which are anticipated to have a negative impact on Chinese cabbage output (3). The major effects of drought stress on vegetable crops are presented in Table 1.

Plants under drought stress undergo a variety of physiological and biochemical reactions that are brought on by water shortages. The growth, development, production and marketable quality of crops are all significantly impacted by decreased rainfall and insufficient soil moisture. In Chinese cabbage (*Brassica rapa* subsp. *pekinensis*), insufficient irrigation in the early heading stage following seeding causes leaves to develop more slowly, growth rates to decrease and biomass accumulation to significantly decrease plants that do not get water often have smaller leaves and fewer leaves may exhibit chlorosis (yellowing) due to impaired chlorophyll synthesis, as well as wilting under severe water deficit conditions. In advanced stages of stress, necrosis characterised by localised tissue death may occur (9). Moreover, the tomato crop is highly susceptible to water deficit especially when the plant is developing its vegetative organs and setting its fruits. Tomato plants which experience water deficit at this period fail to bear fruits and consequently have a poor fruit yield (8). Likewise, pepper (*Capsicum annuum* L.) needs adequate supply of water during the flowering and fruiting period since water deficit at this period affects the quality of fruits produced (35).

Vegetable crops growth and productivity are largely

impacted by the severity, frequency and duration of water deficit. The prolonged period of water deficit negatively impacts physiological activities like photosynthesis resulting in poor expansion of leaves and poor accumulation of biomass eventually leading to poor yield. For example, water deficit in cabbage negatively impacts photosynthetic rate, leaf development and consequently, results in reduced yield (36). Moreover, water deficit negatively impacts plant growth through restriction of leaf, stem and root growth. Considering the growing unpredictability in terms of water availability as a result of climate change, it is highly important to make plants resistant to droughts in vegetable crops. This would imply having an extensive knowledge of how these plants cope with water stress and what physiological and biochemical mechanisms come into play. Also, it is highly important to develop drought-tolerant varieties using conventional methods and biotechnology techniques along with implementing advanced agricultural practices.

Mechanisms

Drought avoidance

Drought stress is overcome by plants through certain adaptive strategies that ensure water absorption and prevent water loss when soil moisture becomes scarce. For instance, one of the adaptive strategies for drought is drought escape whereby plants mature before drought stress sets in. Moreover, plants develop extensive roots that allow them to absorb water from deep soil. Stomata partially close because of drought stress, hence ensuring reduced transpiration and water conservation during drought. Adaptive strategies increase survival chances in moisture-deficit conditions (10, 11, 19, 20).

Drought tolerance

Drought resistance involves the capacity of plants to tolerate water shortage without compromising cellular function and metabolism. Various physiological and biochemical approaches are utilised by plants to adapt to drought stress through osmotic regulation, antioxidant defence system and plant hormones. Osmotic regulation is achieved through the synthesis of compatible solutes such as proline, glycine betaine, mannitol, sorbitol and trehalose to maintain cell turgidity and proper water balance under stress conditions. Compatible solutes also assist in protein stabilisation, membrane integrity and enzymatic activities during dehydration stress (14, 16, 19, 22).

Another strategy used by plants to tolerate drought stress involves the control of stomatal openings to reduce transpiration losses. Moreover, increased antioxidant activity contributes towards neutralising ROS generated because of drought stress to prevent oxidation damage to cellular structures (14, 15, 17). Additionally, morphological modifications such as deep rooting, decreased leaf surface area and altered leaf orientation also play vital roles in developing drought resistance. Overall, these mechanisms allow plants to perform properly even under water-limiting conditions (2, 3, 13, 20).

Drought recovery

Some plants can recover from the effects of the termination of drought conditions. Recovery from drought is characterised by restoring the status of water within the plants, repairing damaged tissues and restarting their physiological activities. After rehydration, plants restore turgor pressure, restart photosynthesis and produce new leaves and stems. Cellular repair takes place along with the

restoration of metabolic activities during recovery periods (1, 19, 30). Plant response to drought conditions is very complex and includes various responses ranging from morphological changes to biochemical changes. The responses include changes in morphology, stomata behavior, photosynthesis, osmoregulation and antioxidants production. These types of adaptation mechanisms are essential for survival of plants during drought conditions. Fig. 2 provides details about the important responses of plants to drought conditions (19, 20, 22).

In breeding vegetable varieties, plant breeders should incorporate drought tolerance by using conventional breeding methods together with modern techniques. Drought tolerance is one feature that is determined by genes. The other aspect of drought tolerance is the physiology of plants as well as their biochemical composition. There have been various scientific research that prove that the physiological activities like root development and salt tolerance of plants are controlled genetically. Breeding vegetable crops for drought tolerance is one interest of plant breeders. Drought tolerance is a deal for plant breeders. Recessive alleles control features like thick root tips, whereas dominant alleles oversee longer and more numerous roots. Root traits are primarily transmitted in a polygenic fashion (37, 38). One dominant gene has been found to regulate drought tolerance in cowpea, suggesting that simple inheritance patterns may also exist for other stress tolerance features (39).

In addition to physical characteristics, drought adaptation is greatly aided by metabolic reactions such the production of suitable solutes. Both stress resistance and cellular homeostasis are enhanced by these metabolic alterations. When it comes to horticultural qualities, yield-related characteristics, such the number of pods per plant, have demonstrated moderate to high narrow-sense heritability and genetic advancement under drought. However physiological features such as leaf water potential are

more inheritable when plants face drought stress. This is especially true for crops like okra. These features have been found to be accurate markers, for selection (40, 41). In any case, we will need to examine traits possessed by plants that can be successfully transferred through generations and are able to demonstrate considerable progress due to their genetic nature. The mentioned drought-tolerant genotypes are essential because they can be helpful for selecting plants that will be able to adapt to harsh conditions of water deprivation. Indeed, it is necessary to select drought-resistant crops that will remain efficient and viable despite being exposed to severe droughts. Nevertheless, the selection of drought-resistant crops is quite challenging for breeders. First, it is necessary to identify reliable traits that indicate drought resistance and allow breeders to efficiently test large samples of plants, especially when their growth processes are extremely slow. To produce drought-tolerant vegetables, breeders will need to study both their morphology and physiology and their chemical and genetic characteristics.

Physiological changes

Drought stress occurs due to insufficient water availability. This affects the soil and the way plants grow. It also affects crop productivity. Drought stress affects plant growth and crop productivity (42, 43). When water is scarce it has an impact on plants. The number of solutes in plant cells goes up. This means that the water inside the plants tissues decreases. It also messes with the balance of the cell membranes. All these things together affect how well the plants can do photosynthesis. The photosynthesis process is important, for plants and limited water availability can disrupt it (44).

Vegetable crops are highly sensitive to water deficit, particularly during critical growth stages such as flowering and fruit development. Even mild water stress can reduce plant growth and photosynthate production. For example, in potato, water deficit during tuber initiation and development impairs carbohydrate

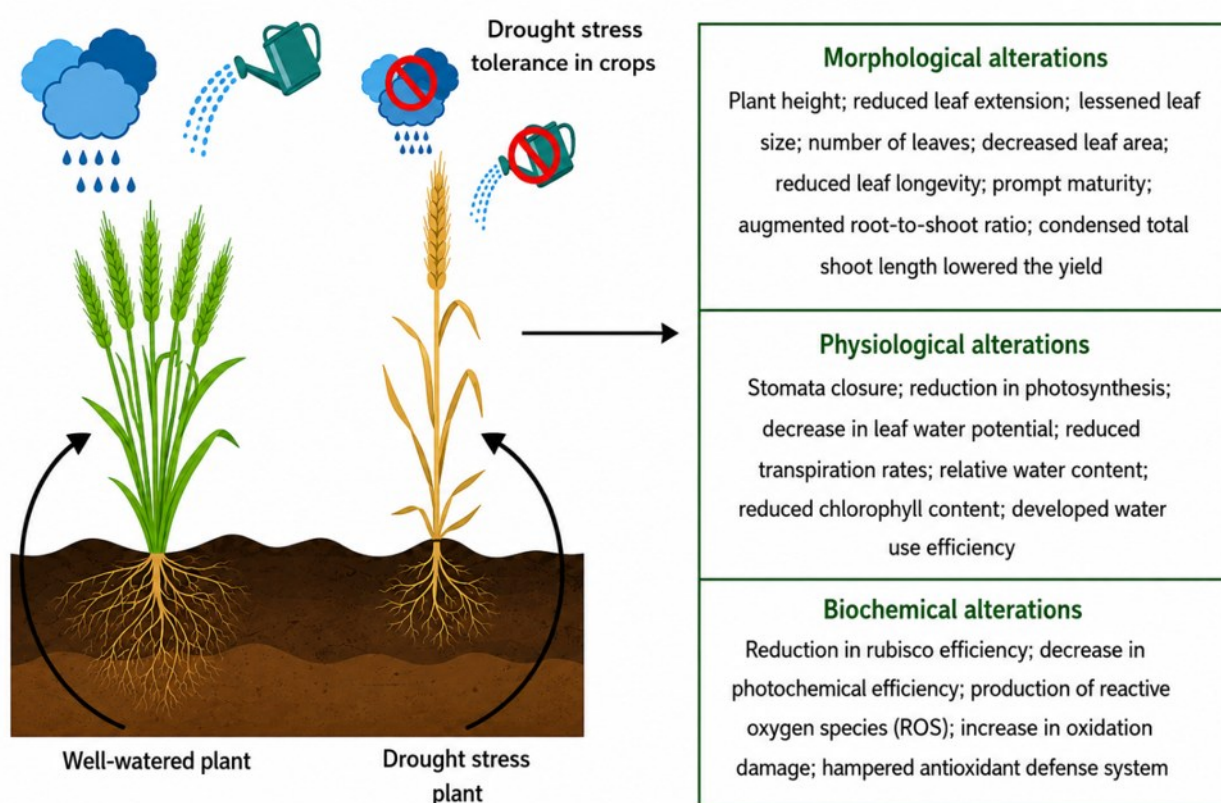


Fig. 2. Drought stress-induced morphological, physiological and biochemical alterations in crops.

translocation from leaves to tubers, resulting in reduced tuber size and quality (45). Under such conditions, plants experience significant physiological stress, which ultimately affects overall productivity.

Molecular changes

Plants undergo serious stress in the state of water deficiency. This is what occurs when plants undergo drought. In water-deficit stress, plants face disruption of normal biological activities, resulting in overproduction of ROS. Reactive oxygen species are produced mainly by chloroplasts, mitochondria and peroxisomes, where photosynthetic reactions, energy generation and metabolism occur respectively. Reactive oxygen species benefit plants in some respects because they work as stress indicators. However, the overproduction of these ROS poses serious health challenges for plants. Overproduced ROS cause damage to plant proteins, lipids and nucleic acids, all vital elements necessary for the survival of the plants (42). To counteract this harm, plants activate their defence systems. The defence system involves components responsible for the generation and scavenging of reactive molecules such as antioxidants and non-antioxidants. Plants use their defence systems to regulate homeostasis and promote growth in stressful conditions. They employ these systems to enable them to perform their biological activities as expected. Plants must maintain the balance of substances called ROS to survive and perform normal biological functions (44).

The plant hormones play an essential role in coping with water stress in plants. Once there is no moisture and the plants suffer water stress; the roots start signaling to other parts of the plant via the xylem. As a result, the plant starts producing hormones such as acid or plant hormones. The effect of the plant hormones such as acid involves closure of stomata thus reducing water loss by the plants. These hormones activate the expression of genes that enable plants to cope with water deficiency conditions (43). In the case of leaves, we see that there is wax on them. This is useful because it enables plants to conserve water. Examples of such plants include cucumber and tomatoes whose leaves are waxed. The wax really helps reduce the amount of water that is lost from the leaf surface, which is not related to the way that plants breathe and this is a big help when water is scarce. Plants, like cucumber and tomatoes, can survive with water because they have more of this wax on their leaves (45, 46).

Implications for vegetable productivity

Drought stress limits the productivity of vegetables by affecting yield and quality. It negatively influences quality-related traits like size, texture and nutritional value mainly due to effects on growth, development and reproduction processes in plants. During water-deficient conditions, plant leaves become small; moreover, the process of photosynthesis becomes less efficient. Thus, the transportation of photosynthates to different plant organs is disturbed, limiting its productivity. In addition, drought stress has negative effects on many physiological processes in plants. For example, it disturbs the balance between ROS and the plants' tolerance to stress. In addition, it interferes with the ability of plants to produce the layer that prevents water loss. Drought stress influences physiological processes such as abscisic acid (ABA) signalling and the production of cuticular waxes that contribute greatly to adaptation of plants to water deficit conditions. However, under drought stress, the plants experience difficulties in carrying out these physiological activities that help them adapt to water-

deficient environments. Vegetables experience significant problems during droughts (47–49).

We have found some resources that can handle drought in important vegetable crops, which you can see in Table 2. These vegetable crops with drought tolerance can be used to help breed vegetable crops that can deal with drought and do well in climates that do not have a lot of water. The genetic resources with drought tolerance are very useful for breeding programmes that want to develop vegetable crops with drought tolerance that can grow well

Table 2. Genetic resources for drought-tolerant vegetable crops

Sl. No.	Crops	Genotypes	References
1.	Chilli	<i>Capsicum chinense</i> Jacq., <i>Capsicum baccatum</i> var. <i>pendulum</i> (Willd.) Eshbaugh,	(50)
2.	Okra	<i>Abelmoschus caillei</i> (A. Chev.) Stevels, <i>Abelmoschus rugosus</i> (Roxb. ex Hornem.) Merr., <i>Abelmoschus tuberosus</i> (L.) Moench	(51)
3.	Onion	<i>Allium fistulosum</i> , <i>Allium munzii</i> Ownbey, <i>Arka Kalyan</i>	(50)
4.	Watermelon	<i>Citrullus colocynthis</i> (L.) Schrad.	(52)
5.	Sweet potato	VLS6, IGSP 10, IGSP 14, Sree Bhadra	(50)

in places where water is limited. Vegetable crops with drought tolerance are important, for people who want to grow vegetable crops in areas that do not get a lot of rain.

Management strategies

Germplasm selection

The selection of germplasm is a very important thing to do when we want to manage drought stress in vegetable crops. We need to find varieties that have well developed root systems. These root systems help the vegetable crops absorb water from layers of soil. This is very helpful when there is no water around. There exist vegetables which are best grown in dry conditions and areas where water is a limiting factor. Beans, cowpeas, lima beans, chillies, cluster beans, drumsticks, brinjals and okras are some examples of crops that have relatively better adaptation and tolerance to drought. Such crops can grow and yield profitable harvests under dry conditions. Bean and cowpeas are examples of legume vegetables which have been found to be well adapted to areas of drought due to effective use of limited water. They can produce good yields under drought situations (20, 39, 50). Some vegetable crops can complete their life cycles prior to extreme drought thus avoiding drought effects (46, 52). Some crops like chillies and okras also have adaptations which help ensure sustainable growth and yield production under drought conditions (4, 35, 40, 53, 54). The role of germplasm selection as a drought management strategy and examples of drought-resilient vegetable crops are presented in Table 3.

Use of drought-tolerant rootstocks

Grafting vegetable varieties such as tomato and chilli onto drought-tolerant rootstocks is an effective approach to sustain plant growth and productivity under limited water availability. These rootstocks enhance water and nutrient uptake, improve osmotic adjustment and help plants withstand moisture stress. This technique has been successfully employed in vegetable crops such as tomato, brinjal and chilli, where the use of drought-resilient rootstocks significantly

Table 3. Management strategies for drought stress in vegetable crops

Management strategy	Mechanism / Purpose	Example of vegetable crops	References
Germplasm selection	Use short-duration, deep-rooted and drought-resilient varieties with rapid recovery to maintain yield stability	French bean, cowpea, lima bean, chilli, brinjal, okra, drumstick	(53)
Drought-tolerant rootstocks	Grafting onto drought-resilient rootstocks improves water uptake, osmotic adjustment and nutrient absorption	Tomato, eggplant, chilli	(44, 55)
Conventional breeding	Select and combine multiple traits like root depth, early vigour, stomatal conductance, leaf posture and water-use efficiency; methods include pedigree, bulk, backcross and biparental mating	General vegetable crops	(53)
Molecular and biotechnological approaches	Introduce drought-responsive genes; enhance osmolyte production (mannitol, trehalose, proline, glycine betaine); use functional genomics to identify stress-resistance genes	Tomato, cucumber, pepper, solanaceous and cucurbit crops	(43, 54)
Agronomic practices	Mulching, cover cropping, minimum tillage for moisture retention; optimised irrigation (drip, deficit); biostimulant application; crop rotation and intercropping for drought mitigation	All vegetable crops	(45, 46, 49)

improves plant performance under water-deficit conditions. The mechanism and examples of drought-tolerant rootstocks used for drought stress management in vegetable crops are presented in Table 3 (44, 55).

Conventional breeding approaches

The development of drought-tolerant vegetable cultivars mainly depends on conventional breeding methods. Selection is commonly used in many crops, while bulk and pedigree selection are useful in others. Backcross breeding helps introduce drought-tolerant traits into high-yielding varieties. Methods such as half-sib, full-sib and biparental mating are also used to develop drought-tolerant genotypes. Breeders evaluate several traits including early vigour, root depth, root density, stomatal conductance, leaf orientation and water-use efficiency to identify drought-tolerant lines. Vegetable cultivars possessing these traits are better able to withstand drought stress. Details of conventional breeding methods used for drought tolerance improvement in vegetable crops are given in Table 3 (53, 54).

Molecular and biotechnological approaches

However, drought can be a difficult phenomenon for crops. But at the same time, a lot has been done regarding biotechnology and biology. It has become possible for people to create new traits in crops in order to protect them against drought. Through genetic engineering, it becomes possible for people to insert genes into the plants so that their resistance capacity can increase. Through the insertion of genes, people manage to create compounds such as mannitol, trehalose, fructans, proline and glycine betaine in plants. These compounds have an important role to play. Their presence in plants helps them retain their structure and minimise their stress when no water is available. Thus, these plants are protected from dehydration in drought conditions. In addition, we use genomic methods including microarray analysis, proteomic studies, metabolomic methods and mutations. Such genomic techniques allow us to investigate gene function during drought conditions. Gene regulatory elements such as drought-responsive element (DRE) and abscisic acid responsive element (ABRE) regulate drought-tolerant genes. Drought-tolerant genes are essential for plants. These genes make plants survive when there is not enough water. Another key role here belongs to transcription factors. Drought-tolerant genes and genetic engineering are very significant, because they ensure the creation of crop plants (42, 43, 55) (Table 3).

Agronomic practices for drought stress management in vegetable crops

Application of agricultural practices is very significant when it comes to the management of drought in vegetable crops. Water conservation practices, such as the use of mulch, crop planting without turning the soil are very significant in helping to conserve water. This is because they help prevent water evaporation hence keeping the soil moist. In situations where there is inadequate water, irrigation techniques such as drip irrigation and giving plants sufficient water can be of great assistance. Application of plant growth promoting rhizobacteria (PGPR) and biostimulants improves the stress tolerance of crops. This is because these factors assist the plants to maintain physiological processes through improvement of their physiological and biochemical processes. Diversification of crops and intercropping are other ways through which plants' resilience to drought is improved. The important agronomic practices used for drought stress management in vegetable crops are listed in Table 3.

Conclusion

Drought stress can lead to problems in the development, productivity and quality of vegetables. The reason is that drought affects the processes taking place within the plant. Vegetables are highly susceptible to lack of water, especially when the plants are at the flowering and fruiting stages. It happens due to the high-water needs and the shallow roots that most vegetables have. To cope with drought, the plants undergo certain adaptations such as root growth, production of substances for protection of cells, activation of protective mechanisms and expression of stress-related genes. The above-mentioned measures allow the plants to overcome difficult conditions and continue to grow. Utilising drought-tolerant and fast-growing varieties using improved rootstocks as well as breeding for increased efficiency in the utilisation of water through conventional and high-tech means can enhance the ability of the crops to withstand drought. Activities such as the mulching of soils with drip irrigation, partial irrigation, planting of cover crops with plant growth enhancers and the intercropping of drought-resistant crops with others will also conserve water while promoting crop development. Future research efforts should concentrate on combining improved genetics with optimum agronomic management practices for developing drought resistance vegetable production systems. This will facilitate the creation of efficient vegetable production systems that are drought resistant.

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Authors' contributions

Conceptualisation was carried out by JM, KY, KRV, VJ, KD, RR, CJ, GG, SK and TUM. Formal analysis was performed by JM, KC, VWR, AM, GG, SN and NM. Supervision and validation were undertaken by CJ, SK, TUM and VJ. Language editing was carried out by JM, KRV and VJ. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

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