

ENHANCING VEGETABLE CROP BREEDING AND ADAPTATION TO CHANGING CLIMATES

Abstract

The ability of the world to feed itself is under danger due to the global loss in agricultural output caused by climate change. Given that it is anticipated that by 2020, there will be more than 10 billion people on the planet, stakeholders and governments are concerned about food security. Crop improvement combining modern breeding techniques, efficient agronomic methods, advancements in microbiome applications, and using the natural variety in underutilised crops is a great step in the correct path for meeting future food needs. The breeding objectives concerning fruit quality, yield, and resilience to environment stress will be discussed, with a particular emphasis on how climate change could influence these goals. Next, we will discuss the utilization of traditional and molecular breeding strategies.

Keywords: Breeding, Climate change, Biotic stress, Abiotic stress tolerance, Molecular breeding, Genomics.

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I. INTRODUCTION

Due to their potential contribution to a healthy diet for humans, especially for vegetarians who rely on them as a rich supply of vitamins, minerals, and dietary fibres, vegetable crops are referred to as protective foods. These crops' growth, productivity, and quality are threatened by a variety of biotic and abiotic stressors. In terms of reproduction, these crops might be classified as annual, biennial, or perennial. It is difficult to improve economic agricultural qualities using traditional breeding techniques [1]. According to [2], producing crops with a high yield and superior quality while using little inputs will eventually be extremely difficult for modern agriculture. Vegetable crops provide abundant nutrients like, minerals, vitamins, dietary fiber, and phytochemicals, making them protective foods essential for fulfilling people's vital nutritional requirements [3].

To lower the risk of cardiovascular diseases, a person should consume over 400 g of vegetables and fruits each day [4]. Vegetable crops, like all other food crops, are susceptible to a variety of biotic and abiotic challenges [5,6]. As a result, it is necessary to design crops of the next generation that can withstand severe environmental conditions [7]. To address the demands of a new era, turf vegetable breeding is continually evolving and developing new tactics. In recent years, the world has been primarily concerned with food quality to meet the demands of health-conscious consumers and food quantity to cater to the rapidly expanding global population. Additionally, challenges related to abiotic and biotic stresses have resulted in significant financial losses for farmers [8].

Due to climate change, we can expect a rise in global temperatures and CO₂ levels, along with rise in the frequency of unpredictable droughts, floods, and storms worldwide [9,10,11]. At the same time, the global population is rapidly expanding [12]. Crop yields are expected to be significantly impacted by rising temperatures [13], hence the speedy creation of new resistant varieties is necessary to mitigate this [14, 15].

Increasing crop yields is crucial, but if there is need to increase the areas where crops may be grown, we must create crop types that can withstand inferior soils, added variable precipitation, and/or salt [16]. In the future, crops may face the challenge of combating new sets of pests and pathogens, while also adapting to the direct abiotic burden of climate change and unfavourable growth conditions. These biotic pressures are thought to affect crop yields by 20–40% [17], and it is anticipated that many diseases' native geographic ranges may change as a result of climate change [18]. Although climate-tolerant varieties are created, this added (and currently somewhat unpredictable; [19] stress, new pests, and illnesses could cause a large decrease in production.

Climate prediction models forecast dramatic shifts in weather patterns that would lead to more frequent floods and droughts, a rise in global temperatures, and a reduction in the amount of fresh water available for agriculture. Therefore, preparing for future climates presents a significant difficulty. This chapter delves into the techniques used for breeding climate-resilient superior genotypes of vegetable crops, aiming to enhance agricultural productivity and address the challenges of future global food security.

II. CROPS RESPONSE TO CLIMATE CHANGE

The most probable scenario requiring the establishment of plant breeding targets includes:

1. Certain higher temperatures leading to reduced crop yield.
2. Certain rise in CO₂ concentration with both straight and unintended effects.
3. Highly probable growing occurrence of drought.
4. Likely upsurge in the areas affected by salinity.
5. Very probable rising incidence of biotic stress.

Given this situation and the fact that crop breeding has been successful in enhancing the yield [20], it is possible that crop breeding has the ability to facilitate the development of innovative cultivars with improved traits, better suitable to adapt to climate change circumstances, by leveraging both traditional and genetic technologies [21]. These characteristics include resistance to salinity and water logging [22], pests and diseases that continue to result in crop losses [23], drought and heat stress resistance, and pest and disease resistance. Amongst most significant and typical goals of many breeding initiatives for each of the major food crops in almost all countries has historically been breeding for drought resistance [24,25]. The variations in phenology or improved responses to increasing CO₂ are potential opportunities for novel varieties with increased drought resistance. In terms of water, some studies have shown that key crop species (such as maize and soybeans) have undergone genetic alterations that have boosted their water-deficit tolerance [26, 27, 28], while it's possible that not all crops have undergone these adaptations. In general, there is currently insufficient knowledge regarding how genetically modified characteristics work in actual farming and forestry applications [29].

III. CHALLENGES, PRIORITIES, AND BREEDING OBJECTIVES

Vegetable crops have a range of challenges that influence their breeding objectives. In line with the diverse range of growth conditions, breeders will concentrate on their key breeding objectives and use them either as-is or after processing. These objectives can be broken down into two groups: (1) adjustment to growth situations in terms of reaction to abiotic and biotic challenges; and (2) vegetable quality on both a sensory and dietary level. (3) Cold tolerance.

IV. APPROACHES TO DEVELOP CLIMATE-RESILIENT VEGETABLE CROP

1. The Abiotic Stress: Vegetables face numerous abiotic stresses, such as drought, temperature, salinity, and heat, which adversely affect their crop yield. Conventional breeding methods can mitigate pressures to some extent, but new cutting-edge technologies, like as CRISPR-Cas 9, have the potential to produce more resilient genotypes that can handle these stresses [30]. A significant stressor that slows the development and produce of vegetable crops is high temperatures.

- **Drought Tolerance:** The majority of potato types have thin, shallow roots that are susceptible to a diversity of abiotic challenges, like excessive salt and dryness, which lowers tuber output and quality. Even brief bouts of drought stress have the potential to inflict significant harm and a sharp decline in tuber yield. Since drought was not

seen as a significant yield-limiting factor for potatoes for a very long time, research on drought tolerance in potatoes did not begin until the 1960s to 1980s. Over the past few years, the situation regarding drought in potato production has undergone a radical change, with a growing recognition of its significance and a notable interest in developing potato cultivars that can thrive in drought-prone areas [31].

Many scientists have tested the drought tolerance of different potato landraces. In Andean landraces, mainly in the species *S. curtilobum* (Juz. and Bukasov) in the cultivar families *Stenotomum*, *Andigenum*, and *Chaucha*, a many number of accessions merging drought tolerance through high irrigated production were discovered. *S. chillonanum*, *S. okadae* and *S. jamesii* were discovered by [32] through the screening of 44 accessions of wild species chosen based on their drought territories derived from geographic information system (GIS).

Because of the fundamental and plastic nature of roots, they are typically implicated in both drought avoidance and tolerance during water shortages. Because of its tremendous plasticity, RSA can adapt quickly to environmental changes like a water shortage. According to [33], potato plants have significantly higher ABA concentrations in their xylem when water content in the substrate decreases.

[34] Described the 83 tomato WRKY genes and showed how each one behaved differently to pathogen infection, salt, drought, heat, and cold stimuli. Some genes (SIWRKY3, SIWRKY3, and SIWRKY33) were shown to be impacted by a diversity of conditions, including salinity and drought stress, and they were recognised as possible study candidates. For a group of genes belonging to the ERFs family [35] and the Hsp20 gene family [36], the expression profiles of additional tomato stress-response genes were also studied. Single genes that are crucial for tomato tolerance to abiotic stress include SIJUB1, which enhances tolerance to drought, and ShDHN, MYB49, and SIWRKY39, which promote tolerance to a variety of stress conditions [37, 38, 39].

Numerous investigations have concentrated on locating the genes in pepper that can withstand heat stress and testing them in transgenic model systems. For instance, CaHSL1, a protein kinase involved in shielding plants from high-temperature stress under high humidity, was described by [40]. [41] discovered a gene called BAX inhibitor-1 that confers transgenic plants through increased tolerance to a variety of stress stimuli and is linked to the regulation of programmed cell death. Despite the acknowledgment of genetic diversity for heat stress tolerance [4,43] and particular molecular investigations on the activity of heat shock proteins [44,45], research on the quantitative inheritance of heat tolerance in pepper is still lacking. Upcoming plant breeding initiatives are required to create cultivars that are better able to withstand the stress of high temperatures.

Advanced cultivars with outstanding root characteristics, capable of absorbing water from deeper sections of the soil and under lower soil water strength, are being bred to enhance the utilization of soil water and contribute to the efficient use of water in vegetable production, whether from precipitation or irrigation.

- **Salinity Tolerance:** Salinity-sensitive potato leaves are brutally harmed by overhead watering with salinity-rich water. Toxic effects from chlorine and salt uptake by leaves can manifest as leaf burn around the edges. According to [46], salt stress had a deleterious impact on the cultivar Desiree's comparative water content, leaf stomata or conductance, and transpiration rate.

The pH is raised by sodium carbonate, which is formed when the quantity of exchangeable sodium ions in the soil solution increases due to saline water. These alkaline circumstances make it harder for plants to get nutrients like phosphate, iron, zinc, and manganese. This destructive process is stopped in soils high in calcium carbonate, a fact that has been demonstrated in-vitro where extra calcium prevented salinity induced nuclear deterioration in root meristematic cells [47]. In a study cited as [48], it was found that adding 2% gypsum to salty soil enhanced the potato production in pots, improved their protein, potassium, and calcium content, and reduced their glycoalkaloid levels.

The in vitro system was utilised to show that exogenously given proline offered some level of defense against salt stress and was deemed appropriate for testing salt tolerance [49]. [50] showed that salt-tolerant and sensitive potato cultivars had different antioxidant enzyme activities, indicating that the salt-tolerant varieties may be well protected compared to reactive oxygen species due to their capacity to increase antioxidant enzyme activity under salt stress. Using an in vitro microtuberization system, [51] discovered variations in salt sensitivity between two potato cultivars. According to [52], the effects of 5-aminolevulinic acid (ALA), a crucial precursor in the manufacture of porphyrins like chlorophyll and heine, encouraged potato microtuber formation and growth as well as improved protective activities against oxidative stressors.

MYB49, ShDHN, and SIWRKY39 are single genes for multi-stress tolerance factors, and DREB1A and VP1.1 are single genes for salinity tolerance [43,38].

The characterization of a few chosen tomato cultivars served as the basis for setting the threshold for saline tolerance described above. [53] observed a considerable genotypic heterogeneity in fresh-market tomato cultivars' responses to salinity. This demonstrates the potential for the crop to produce salt-tolerant cultivars.

In Capsicum, there is a significant genotypic heterogeneity for tolerance to salt [53]. The sensitive types in the study accumulated noticeably more sodium ions in the shoot than in resistant varieties. According to [54], salt-tolerant cultivars had higher levels of enzymatic antioxidants and less relative water content loss.

It has been discovered that a few mitigating strategies for dealing with high salinity are relatively helpful in the production of peppers. These cultural techniques include better nutrient management, the usage of protectants like catechin or glycine betaine, and better watering techniques. For example, calcium nutrition can be improved to lessen harm from sodium or chloride. Saline-tolerant grafted plants can be produced using rootstocks that have been found [55].

2. **Biotic Stresses:** Environmental circumstances are constantly changing, and by 2050, maintaining the production of food to feed the growing population will be difficult due to a lack of arable land [56]. A key strategy for addressing this problem is the creation of robust crops with high-stress tolerance.

New pests and pathogens should enter production areas as a consequence of global climate change. Climate prediction models forecast abrupt changes in weather patterns that would lead to more frequent floods and droughts, a rise in global temperatures, and a reduction in the amount of fresh water available for agriculture. Therefore, strengthening plant resistance and tolerance to pests is a major task [57].

- **Disease Resistance:** At different stages of crop growth, crop plants are affected by many and distinct forms of diseases, which severely reduce production. There are several ways to avoid crop losses brought on by these dangerous diseases. Many diseases harm the pepper crop. Therefore, it's crucial to apply fungicides, miticides, and insecticides responsibly in order to effectively manage infections and pests, as well as to achieve the best possible production and fruit value. However, incorporating the usage of resistant types is a pest management strategy that is good for the environment. Every crop breeding programme now places a high priority on finding and using key genes for disease resistance in the crop. Breeders trying to create resistant types have a significant challenge as the disease races continuously evolve at various speeds to overcome host resistance. Pyramiding various resistance genes with various mechanisms of action collectively in one line is one solution to this issue. In pepper, polygenic resistance to Potato virus Y outperformed monogenic resistance, according to research by [58]. There is information available on pepper germplasm's high or moderate susceptibility to several of the major diseases, as well as the way the resistance trait is inherited.

Contrary to disease resistance features, little is known about the genetics of various pest resistance. Leaf position and ontogeny have an impact on thrips resistance, according to studies on the subject [59], and QTLs for this characteristic have been found in particular mapping populations [60]. Diterpenes and flavonoids may aid in thrips resistance, according to more recent metabolomic studies [61].

Table 1: Resistance to Diseases in Various Vegetable Crops

Crop	Wild Species	Resistance Character transferred against
Okra	<i>Abelmoschus caillei</i>	YVMV (Bhendi yellow vein mosaic virus)
Tomato	<i>Solanum hirsutum</i>	Fusarium wilt (<i>Fusarium oxysporum</i> f. sp. <i>lycopersici</i>)
Potato	<i>Solanum demissum</i>	Late blight (<i>Phytophthora infestans</i>)
Potato	<i>Solanum demissum</i>	Leaf roll (Potato leafroll virus)
Brinjal	<i>S. stenototum</i>	Bacterial wilt (<i>Pseudomonas solanacearum</i>)
Chilli	<i>Capsicum chinense</i>	Fruit rot (<i>Colletotrichum capsici</i>)
Onion	<i>Allium fistulosum</i>	Purple blotch (<i>Alternaria porri</i>)
French bean	<i>P. flavescens</i>	Rust (<i>Uromyces appendiculatus</i>)
Cucumber	<i>Cucumis Hardwiiki</i>	Green-mottle mosaic (Cucumber green mottle mosaic virus)

- **Pest Resistance:** The global temperature is expected to rise, there will be more frequent droughts and floods, there will be less fresh water available for agriculture, and there will be dramatic changes in weather patterns. Therefore, strengthening plant resistance to pests and tolerance to them is a significant challenge.

In wild species, a variety of pest resistances have been found. According to several research [62], insect resistance is attributed to glandular trichomes, glycoalkaloids, and other unidentified mechanisms. [63] tested 100 species of wild potatoes for insect resistance and found that the glycoalkaloid tomatine, thick hairs, and glandular trichomes were all associated with resistance. According to Jansky et al. [64], species with abundant glandular trichomes (*S. polyadenium* and *S. tarijense*) or high amounts of glycoalkaloids (*S. chacoense*) have proven resistance to the Colorado potato beetle. *S. hougasii* exhibited high levels of resistance to the Columbia root-knot nematode. Additionally, the Argentinian wild species *S. vernei* and *S. acaule* were found to possess resistance to cyst nematodes [65].

Hypersensitive resistance and extreme resistance are two popular subtypes of single gene viral resistance in potato. It's common for viral strains to have unique hypersensitive resistance genes. When plants with these genes are exposed to viruses, they typically exhibit systemic necrosis or local necrotic lesions in the diseased tissue. In potatoes, a number of genes have been identified that code for hypersensitive resistance to potato viruses A, S, X, and Y [31]. The Solanaceae family exhibits a conserved location of genes imparting resistance to various diseases in addition to resistance to *Phytophthora*. The resistance gene hot spot on the long arm of chromosome 11 is home to three potato genes that code for resistance to PVY (Ryadg and Rysto) and PVA Naadg [66].

Attacking plants, the onion thrips (*Thrips tabaci* L.) decreases photosynthetic activity, acts as a disease entry point, and spreads the IYSV [67]. To manage thrips, some onion cultivators employ biological and cultural controls, while the majority resort to insecticides. However, this practice may lead to the development of insecticide-resistant thrips and result in significant environmental problems. To address these concerns, efforts are underway to advance onion cultivars with inherent resistance to thrips. After analysing the germplasm from various countries, limited tolerant sources that can be exploited in breeding programs have been identified [68]. It has been shown that onion plants with glossy or semi glossy foliage are not more susceptible to thrips feeding damage [69]. It would be preferable to apply family-based assortment to increase genetic improvement because genetic studies reveal that thrips resistance is not extremely heritable [70].

- **Root-Knot Nematodes Resistance:** Temperatures over 30 °C impair plant defense mechanisms, frequently rendering important resistance genes useless. For instance, high temperatures inactivate the tomato Mi-1.2 resistance gene to the root-knot nematode and the Cf-4/Cf-9 genes to *Cladosporium fulvum*.

Another intriguing strategy that requires little effort throughout the growing season and is good for the environment is the use of root-knot nematode-resistant

cultivars [71]. The study of pepper genetic resources against diseases, nematodes, and arthropods [72] lists excess than 40 accessions as tolerant or very resistant to several root-knot nematode species. In the Solanaceae family, resistance to root-knot nematodes is primarily dominant and regulated by a small number of crucial genes. Nine diverse dominant genes have been found to confer resistance to root-knot nematodes in several populations of peppers. Out of these, the resistance of *M. incognita*, *M. javanica*, *M. arenaria*, and *M. haplanaria* to N, Me1, and Me3 (= Me7) was assessed [73].

Table 2: Resistance in Various Vegetable Crops against Insects

Crop	Wild Species	The resistant Character transferred against
Potato	<i>Solanum verni</i>	Nematode (<i>Meloidogyne</i> spp.)
Cucurbits	<i>Cucumis trigonus</i>	Fruit fly (<i>Bactrocera cucurbitae</i>)
Brinjal	<i>S. incanum</i>	Shoot & fruit borer (<i>Leucinodes orbonalis</i>)
Tomato	<i>Solanum hirsutum</i>	White fly (<i>Bemisia tabaci</i>)
Okra	<i>Abelmoschus manihot</i>	Shoot & fruit borer (<i>Earias vitella</i> , <i>E. insulana</i>)

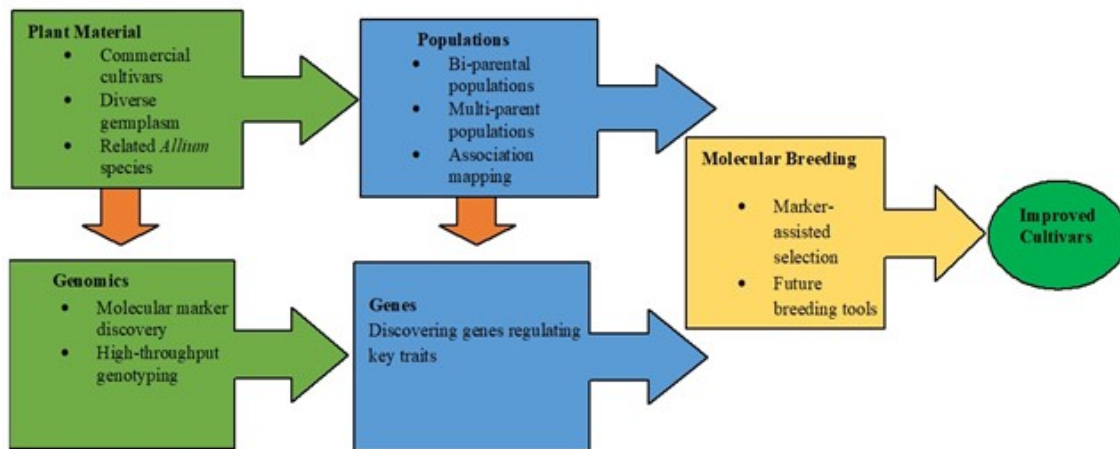


Figure 1: A genomics-based breeding strategy for Allium [74]

Table 3: Onion Morphological Marker Loci for Biotic and Abiotic Factors [75]

Loci	Genotypes	Phenotypes	Clarifications
Foc1	foc1foc1	Susceptible	Fusarium basal plates rot tolerance locus 1 is partially dominating with Foc2 and exhibits additive resistance.
	Foc1foc1	Partial resistant	
	Foc1Foc1	Resistant	
Foc2	foc2foc2	Susceptible	Resistance locus 2 for Fusarium basal plate rot. Foc1 is somewhat dominant and exhibits additive resistance.
	Foc2foc2	Partial resistant	
	Foc2Foc2	Resistant	
Pr1	pr1pr1	Resistant	Pink root tolerance locus. It has been shown that other modifier genes may be implicated in resistance.
	Pr1pr1	Susceptible	
	Pr1Pr1		
Pd1	pd1pd1	Susceptible	Dominant gene introduced from <i>A. roylei</i> for downy mildew tolerance locus 1.
	Pd1pd1	Resistant	
	Pd1Pd1		
Oz	ozoz	Susceptible	Ozone resistance gene. Individuals that have a recessive allele at the Oz gene are more vulnerable to ozone stress.
	Ozoz	Tolerant	
	OzOz		

- 3. Vegetable Quality Improvement:** Advanced post-harvest technologies are required for fruit and vegetable (F&V) storage constancy and prolonged shelf life because they are highly perishable food products [76]. T1 homozygous plants with long shelf lives were produced in tomato by replacing the allele of ALC with the alc gene via the homology-directed repair (HDR) mechanism. In many food applications, potato starch purity is crucial. In potatoes, full knockouts of the genes for the starch-branching enzymes (SBEs) SBE1 and SBE2 as well as the starch synthase gene (SS6) have been reported to improve starch quality [77, 78]. Similar to this, enzymatic browning in brinjal was associated with the three-polyphenol oxidase (PPO) genes SmelPPO4, SmelPPO5, and SmelPPO6. These three target PPO genes have been disabled utilising CRISPR-Cas9-based mutagenesis to prevent the browning of fruit flesh. [79].

In particular, beta-carotene, the precursor to retinol (vitamin A), and lutein and zeaxanthin, which are significant antioxidants for eye health, are nutritionally valuable pepper carotenoids. Numerous research has examined entire carotenoid levels and composition in various pepper cultivars due to the nutritional importance of carotenoids. According to Brewster [80] and [81], the first-class of onion cultivars is attributed by the bulb colour (anthocyanin and flavonoid content), firmness, number of scales, number of developing points, neck thickness, Total soluble solids (TSS), pungency, and antioxidants.

Table 4: Improvement of quality in various vegetable crops

Crop	Wild Species	Character transferred
Tomato	<i>Solanum hirsutum</i>	Carotenoid content
Potato	<i>Solanum acule</i>	Starch content
Chilli	<i>Capsicum frutescence</i>	High capsaicin
Melons	<i>Cucumis melo</i> var. <i>cantaloupensis</i>	Thick rind and good keeping quality
Onion	<i>Allium kurrat</i>	Leaf flavour

- 4. Cold Tolerance:** Cold is a main abiotic stress affecting agricultural productivity globally, impacting the growth and development of agronomic species. Given that approximately 64% of the earth's land area experiences a usual minimum temperature below 0 °C and about 48% below 10 °C, comprehending the mechanism of frost damage and developing cold-tolerant varieties becomes highly essential. To boost output and stability in cold conditions that are getting worse with climate change, potato crops must adapt. In order to defend themselves from harm caused by below-freezing temperatures, plants have evolved two strategies. First, acclimated xylem parenchyma cells of moderately resistant woody plants are typically linked to supercooling, a low-temperature tolerance mechanism. Acclimatization is the second and most typical low-temperature response mechanism. According to [82], acclimatization is a slow progression that causes changes in almost every quantifiable physiological, morphological, and biochemical characteristic of the plant. The complicated interactions between genetics and environment are what cause these alterations.

Peppers grown in tropical climates are vulnerable to frost. Numerous studies have examined how chilling stress negatively affects the various metabolic systems in peppers

[83]. The plants cultivated at the lesser night temperature exhibited superior chilling tolerance after being exposed for 4 nights at 6 °C [84]. Low nighttime temperatures (14 °C or lower) have a detrimental effect on the flower's female reproductive system, pollen viability, and pollen production [85]. The work by [86] demonstrated the function of reactive oxygen species in the harm caused by cold stress. Low-temperature tolerance has a known genetic component [87], although no selections for this feature have been documented. Peppers are vulnerable to cold damage when the harvested fruit is left in the cold (7 °C) for an extended period of time. A sign of cooling harm is surface pitting. It is likely to improve the cold storability of food by combining low-temperature conditioning with the use of methyl jasmonate and UV-C treatments [88, 89]. A proteomic investigation found that the stress of freezing caused bell peppers to create more ethylene, modify the composition of their sugars and organic acids, and drastically alter the proteins involved in the regulation of redox homeostasis and the breakdown of carbohydrates.

5. **Herbicide Resistance:** Selective herbicides are commonly employed during cultivation to control weed growth and development, as weeds are a substantial stress factor impacting vegetable produce and its quality. To confer herbicide resistance in plants, the herbicide target gene acetolactate synthase (ALS) has been modified using CRISPR-Cas9 technology in crops such as watermelon, tomato, and potato [90,91].
6. **Nutrient Use Efficiency:** When it comes to boosting crop harvests in the face of escalating climate change and global warming, nutrient-efficient plants are crucial. At least 60% of the arable land on the planet has mineral or elemental toxicity issues. "The plant development, physiological action, yield, or harvested yield per unit of nutrient" is how the term "nutrient use efficiency" (NUE) is defined. The balance of nutrients and biological activity are the two main factors that affect a plant's productivity [31].

V. FUTURE PROSPECTS

To ensure global food security amid the continuing and projected climate change, which includes increasing temperatures and random climate events across large regions of the world, it is crucial to breed crop plants with enhanced yield potential and enhanced tolerance to such conditions. The goal of climate-resilient agriculture can only be accomplished with upgraded plant types that can withstand diseases and pests while effectively using less resources and demonstrating stable yields in stressful conditions in the near future. Research focus is essential for currently underutilised crop species if they are to contribute to climatic resilience. To address crop plants' sensitivity to climate change, smart breeding relies heavily on creating huge breeding populations, effective high throughput phenotyping, large data management technologies, and ensuing molecular approaches.

To prepare for the challenges of a warmer climate, characterized by increased vulnerability to droughts, floods, and potential threats from novel pests and viruses, it is crucial for current research to identify crop varieties and Crop Wild Relatives exhibiting adaptive tolerance to these stresses. Despite these efforts being carried out for vegetable crops, it seems that progress has been slow and, until recently, lagged behind developments in other crops.

VI. CONCLUSION

The continuing development of innovative crops and new kinds of plant-based foods will be essential for future food production. To help with climate adaptation, research will need to be focused on crop species that are now underutilised. One of the major and difficult areas of agriculture is vegetable breeding. Breeding in agricultural crops benefits from both traditional and molecular approaches. In order to prepare for a warmer world that will be more vulnerable to droughts and floods as well as the prospect of novel pests and viruses becoming a threat, it is imperative that current research find cultivars of crops with adaptive resilience to these stresses. Even if this is being done for the vegetable crop, it seems like progress is being made slowly and has lagged behind other crops up until very recently. Despite not being among the most essential vegetables internationally, many nations and cultures rely heavily on vegetables in their diets, therefore any reduction in production could have a negative impact on these populations. In this chapter, I've emphasised what is already known about vegetable crop tolerances that might be useful in a future climate, as well as several crucial research directions that ought to be given top priority.

Plant breeders can potentially design and produce the appropriate genotype by selecting the finest allele for each gene, enabling enhanced performance in the marked environment. The path to this approach is swiftly being defined by functional genomics.

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