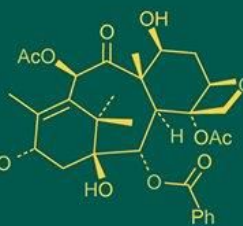
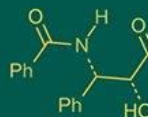


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Syeda Nabeela Thasneem
MSc Scholar, Department of
Vegetable Science, College of
Horticulture, SKLTGHU,
Telangana, India

S Neeraja,
MSc Scholar, Department of
Vegetable Science, College of
Horticulture, Mojerla,
SKLTGHU, Telangana, India

M Poojithaaa
Research Scholar, Department
of Floriculture and Landscape
Architect, Uttara Banga Krishi
Viswavidyalaya, West Bengal,
India

Corresponding Author:
Syeda Nabeela Thasneem
MSc Scholar, Department of
Vegetable Science, College of
Horticulture, SKLTGHU,
Telangana, India

Advances in screening and breeding strategies for stress tolerance and quality enhancement in horticultural plants

Syeda Nabeela Thasneem, S Neeraja and M Poojithaaa

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Abstract

Horticultural crops are vital for global nutrition, food security, and economic development due to their high nutritional value, dietary diversity, and contribution to agricultural income. However, the productivity, stability, and quality of these crops are increasingly constrained by a wide range of abiotic and biotic stresses, which are further intensified by climate change and environmental variability. Enhancing stress tolerance while maintaining or improving quality attributes has therefore emerged as a major objective of contemporary horticultural breeding programs. Recent advances in stress screening methodologies, precision phenotyping, molecular breeding, and genomics-assisted selection have substantially improved the efficiency and accuracy of identifying stress-resilient genotypes. This review presents a comprehensive synthesis of conventional, physiological, biochemical, and molecular screening approaches used to evaluate stress tolerance in horticultural plants. It further examines traditional and modern breeding strategies, including marker-assisted selection, genome-wide association studies, genomic selection, and gene editing technologies, that facilitate the development of resilient and high-quality cultivars. Special emphasis is placed on strategies that enable the simultaneous improvement of stress tolerance and key quality traits such as nutritional composition, flavor, shelf life, and postharvest performance. Finally, the review highlights current challenges, knowledge gaps, and future research directions aimed at integrating stress resilience and quality enhancement to support sustainable horticultural production under changing climatic conditions.

Keywords: Horticultural crops, stress tolerance, quality traits, breeding strategies, phenotyping, molecular breeding

1. Introduction

Horticultural crops, encompassing fruits, vegetables, ornamentals, and plantation crops, play a fundamental role in global food and nutritional security, human health, and economic development. These crops are major sources of essential vitamins, minerals, dietary fiber, antioxidants, and bioactive compounds that contribute to balanced diets and the prevention of chronic diseases. In addition to their nutritional importance, horticultural commodities generate high economic returns, support rural livelihoods, and contribute significantly to employment in both developing and developed countries. As global populations continue to grow and consumer demand shifts toward nutritious, high-quality, and visually appealing produce, the importance of sustainable horticultural production has become increasingly evident. Despite their importance, horticultural crops are highly vulnerable to a wide range of abiotic and biotic stresses. Abiotic stresses such as drought, salinity, heat, cold, flooding, and nutrient imbalances are major constraints on crop growth, yield, and quality. These stresses disrupt physiological processes, reduce photosynthetic efficiency, impair reproductive development, and negatively affect postharvest quality. Biotic stresses, including diseases caused by fungi, bacteria, viruses, nematodes, and insect pests, further exacerbate yield losses and reduce marketable quality. The intensification of agriculture, monocropping, and reduced genetic diversity in modern cultivars have increased the susceptibility of horticultural crops to these stresses.

Climate change has added another layer of complexity to horticultural production systems. Rising temperatures, altered precipitation patterns, increased frequency of extreme weather

events, and the expansion of pest and disease ranges pose serious challenges to crop stability and productivity. Horticultural crops are particularly sensitive to climatic fluctuations due to their shallow root systems, high water requirements, and narrow optimal temperature ranges for flowering, fruit set, and quality development. As a result, traditional production practices and existing cultivars are often insufficient to cope with rapidly changing environmental conditions, highlighting the urgent need for stress-resilient horticultural varieties.

Improving stress tolerance in horticultural crops, however, cannot be pursued in isolation from quality enhancement. Unlike staple crops, horticultural plants are primarily valued for quality traits such as taste, aroma, color, texture, nutritional composition, shelf life, and aesthetic appeal. Stress conditions often negatively influence these attributes, leading to reduced consumer acceptance and economic losses. Moreover, breeding for stress tolerance alone may result in trade-offs with yield or quality if not carefully managed. Therefore, the simultaneous improvement of stress tolerance and quality traits represents a central challenge and opportunity in modern horticultural breeding programs.

Conventional breeding approaches, including selection, hybridization, and the use of landraces and wild relatives, have historically contributed to the development of improved horticultural varieties. However, these methods are often time-consuming and constrained by complex trait inheritance, strong genotype $\times$ environment interactions, and limited selection efficiency for stress-related traits. In many horticultural crops, long juvenile phases, polyploidy, and clonal propagation further slow genetic improvement. Additionally, phenotypic screening for stress tolerance and quality traits under field conditions is often labor-intensive, costly, and influenced by environmental variability, significant advances in screening techniques and breeding strategies have transformed horticultural crop improvement. The integration of physiological and biochemical screening methods has enabled a deeper understanding of plant responses to stress at multiple levels of organization. Traits such as water-use efficiency, osmotic adjustment, antioxidant capacity, and membrane stability are increasingly used as reliable indicators of stress tolerance. Controlled environment facilities and *in vitro* screening systems have further enhanced the precision and reproducibility of stress evaluations, particularly for early-stage selection.

The advent of molecular breeding and genomics-assisted approaches has further accelerated progress in horticultural improvement. Marker-assisted selection, genome-wide association studies, and genomic selection have facilitated the identification and utilization of genetic loci associated with stress tolerance and quality traits. High-throughput phenotyping platforms, combined with remote sensing and imaging technologies, now allow rapid and non-destructive assessment of complex traits across large populations. More recently, gene editing technologies such as CRISPR/Cas have emerged as powerful tools for precise modification of genes controlling stress responses and quality attributes, offering new possibilities for targeted crop improvement. Despite these advances, several challenges remain in effectively integrating stress tolerance and quality enhancement in horticultural breeding. The genetic architecture of stress tolerance is often complex and

polygenic, while quality traits are influenced by multiple metabolic pathways and environmental factors. Understanding trade-offs, identifying stable genetic gains across environments, and ensuring the adoption of improved varieties by growers are critical considerations. Addressing these challenges requires a holistic and interdisciplinary approach that combines advanced screening methods, innovative breeding strategies, and systems-level understanding of plant performance, the present review aims to synthesize recent advances in screening and breeding strategies for improving stress tolerance and quality traits in horticultural plants. By integrating insights from physiology, molecular biology, genomics, and breeding, this review highlights current achievements, emerging technologies, and future research priorities to support the development of resilient, high-quality horticultural crops under changing environmental conditions.

2. Major Stresses Affecting Horticultural Crops

Horticultural crops are exposed to a wide array of environmental and biological stresses that significantly limit their growth, productivity, and quality. Due to their high economic value and sensitivity to environmental fluctuations, these crops often suffer greater losses compared to staple cereals. Understanding the nature of major stresses and their impacts on horticultural plants is essential for designing effective screening and breeding strategies aimed at improving stress tolerance and quality attributes.

2.1 Abiotic Stresses

Abiotic stresses represent some of the most severe constraints to horticultural production worldwide. Among these, drought stress is a predominant factor, particularly in arid and semi-arid regions where water scarcity is becoming increasingly common. Drought stress affects plant water relations, reduces cell turgor, limits photosynthesis, and disrupts nutrient uptake, ultimately leading to reduced yield and inferior quality. In fruit and vegetable crops, drought stress can cause reduced fruit size, poor color development, increased bitterness, and shortened shelf life.

Salinity stress is another major challenge, especially in irrigated horticultural systems where the accumulation of salts in the root zone negatively affects plant growth. High salt concentrations induce osmotic stress and ion toxicity, impairing root function and causing nutrient imbalances. Sensitive horticultural crops such as tomato, strawberry, citrus, and ornamental plants often exhibit reduced growth, leaf chlorosis, and yield losses under saline conditions. Salinity stress also alters metabolic pathways, leading to changes in flavor, texture, and nutritional composition. Temperature extremes, including heat and cold stress, have profound effects on horticultural plants. Heat stress disrupts cellular homeostasis, denatures proteins, and impairs reproductive processes such as pollen viability and fertilization. In crops like tomato, pepper, and cucumber, high temperatures reduce fruit set and quality, resulting in disorders such as blossom-end rot and sunscald. Conversely, cold and chilling stress affect tropical and subtropical horticultural crops by causing membrane damage, reduced enzymatic activity, and delayed growth. Chilling injury during pre- or postharvest stages can severely compromise marketability. Flooding and waterlogging stress are increasingly prevalent due to erratic rainfall patterns and

poor drainage. Excess water reduces oxygen availability in the root zone, leading to hypoxia or anoxia, root decay, and impaired nutrient absorption. Horticultural crops such as onion, lettuce, and many fruit trees are particularly sensitive to waterlogging, which can result in reduced vigor, increased disease susceptibility, and yield losses.

2.2 Biotic Stresses

Biotic stresses caused by pathogens and pests pose persistent and evolving threats to horticultural crops. Diseases caused by fungi, bacteria, viruses, and oomycetes significantly reduce yield and quality, often requiring intensive chemical management. Fungal diseases such as powdery mildew, downy mildew, and anthracnose are widespread in fruits and vegetables, while bacterial and viral diseases can cause systemic infections leading to severe crop losses. Insect pests, including aphids, whiteflies, thrips, and fruit borers, damage horticultural crops directly through feeding and indirectly by transmitting plant viruses. Nematodes further compromise root systems, reducing water and nutrient uptake. The continuous use of pesticides has led to the development of resistant pest populations, environmental contamination, and health concerns, underscoring the need for genetic resistance as a sustainable management strategy.

2.3 Combined and Emerging Stress Factors

In natural field conditions, horticultural crops are often subjected to multiple stresses simultaneously or sequentially. For example, drought stress can increase

susceptibility to pest and disease attacks, while heat stress may exacerbate the effects of salinity or nutrient deficiencies. The combined impact of abiotic and biotic stresses is often more severe than the effect of individual stresses, making breeding for multiple stress tolerance particularly challenging. Emerging stresses associated with climate change, such as elevated atmospheric CO₂, increased ultraviolet radiation, and shifts in pest and disease dynamics, further complicate horticultural production. These factors not only affect plant growth and yield but also influence quality traits, including nutritional content and secondary metabolite production.

2.4 Implications for Horticultural Breeding

The diverse and complex nature of stresses affecting horticultural crops necessitates the development of integrated breeding strategies. Stress tolerance traits are often quantitatively inherited and strongly influenced by environmental interactions, requiring precise and reliable screening methods. Additionally, breeding efforts must consider the impact of stress responses on quality attributes to ensure consumer acceptance and market value. Understanding the physiological, biochemical, and molecular mechanisms underlying stress responses provides a foundation for identifying reliable selection criteria and genetic targets. The integration of stress tolerance and quality enhancement in breeding programs is therefore essential for developing resilient horticultural varieties capable of maintaining productivity and quality under increasingly challenging environmental conditions.

Table 1: Major Abiotic and Biotic Stresses in Horticultural Crops and Their Effects

Stress Type	Example Crops Affected	Physiological/Biochemical Effects	Impact on Yield and Quality
Drought	Tomato, Pepper, Strawberry, Citrus	Reduced photosynthesis, osmotic stress, stomatal closure, oxidative stress	Reduced fruit size, lower yield, poor flavor and texture
Salinity	Tomato, Lettuce, Eggplant, Citrus	Ion toxicity, osmotic imbalance, reduced nutrient uptake	Leaf chlorosis, reduced fruit quality, yield losses
Heat Stress	Tomato, Cucumber, Pepper	Protein denaturation, impaired pollen viability, disrupted enzyme activity	Blossom-end rot, poor fruit set, reduced shelf life
Cold/Chilling	Banana, Mango, Papaya	Membrane damage, reduced metabolic activity	Chilling injury, delayed growth, poor color and texture
Waterlogging/Flooding	Onion, Lettuce, Citrus	Root hypoxia, reduced nutrient absorption	Poor growth, susceptibility to diseases
Fungal Diseases	Tomato, Potato, Citrus	Tissue necrosis, pathogen spread	Yield reduction, cosmetic damage
Bacterial/Viral Diseases	Tomato, Pepper, Papaya	Systemic infection, leaf curling, chlorosis	Severe crop losses, quality degradation
Insect Pests	Aphids, Whiteflies, Thrips	Direct feeding damage, vector-borne virus transmission	Reduced yield, compromised fruit/leaf quality

Table 2: Screening Approaches for Stress Tolerance in Horticultural Crops

Screening Method	Key Parameters Measured	Advantages	Limitations
Phenotypic Screening	Survival rate, growth reduction, yield stability, disease severity	Low cost, real-field relevance	Labor-intensive, environmental variability affects accuracy
Physiological Screening	Relative water content, stomatal conductance, photosynthesis, chlorophyll fluorescence	Early detection of stress response, quantitative	Requires specialized equipment
Biochemical Screening	Proline, antioxidant enzymes, osmolyte levels, ROS scavenging	Reflects stress-induced metabolic changes	Time-consuming, laboratory-dependent
Controlled Environment Screening	Growth under defined drought, salinity, temperature	Precise stress application, reproducible	Limited field applicability, space and cost constraints
<i>In vitro</i> Screening	Tissue culture tolerance to stress agents	Rapid evaluation, early selection	May not fully reflect field performance
High-Throughput Phenotyping (HTP)	Canopy temperature, plant growth dynamics, biomass, leaf senescence	Rapid, non-destructive, scalable	Expensive, requires technical expertise

Table 3: Breeding Strategies for Stress Tolerance and Quality Improvement

Breeding Strategy	Description	Advantages	Limitations/Challenges
Conventional Breeding	Selection, hybridization, backcrossing using landraces and wild relatives	Well-established, utilizes natural diversity	Time-consuming, linkage drag, polygenic traits slow progress
Marker-Assisted Selection (MAS)	Use of DNA markers linked to stress or quality traits	Improves selection accuracy, reduces breeding cycles	Limited for polygenic traits, requires known markers
Genome-Wide Association Studies (GWAS)	Identification of loci associated with traits across diverse germplasm	Dissects complex traits, identifies new loci	Requires large populations and high-density markers
Genomic Selection (GS)	Predicts breeding values using genome-wide marker data	Accelerates selection, especially for long-cycle crops	High cost, computationally intensive, needs accurate training sets
Genetic Engineering	Introduction of transgenes for stress tolerance or quality improvement	Targeted trait improvement, rapid gains	Regulatory barriers, public acceptance issues
Gene Editing (CRISPR/Cas)	Precise modification of specific genes	Accurate, can modify stress and quality traits simultaneously	Regulatory uncertainty, requires molecular expertise

3. Screening Approaches for Stress Tolerance in Horticultural Plants

Effective screening is the foundation of breeding programs aimed at improving stress tolerance in horticultural crops. Given the complexity of stress responses and strong genotype $\times$ environment interactions, the use of robust, reliable, and scalable screening methods is essential. Recent advances have enabled the integration of conventional phenotyping with physiological, biochemical, molecular, and high-throughput approaches to enhance selection efficiency.

3.1 Conventional Phenotypic Screening

Conventional phenotypic screening remains a widely used approach for evaluating stress tolerance in horticultural crops. This method involves assessing plant performance under natural or managed stress conditions using traits such as survival rate, plant vigor, yield stability, disease severity, and visual stress symptoms. Field-based screening allows evaluation under realistic agronomic conditions and captures complex interactions between plants and the environment (Ceccarelli *et al.*, 2010) ^[33]. However, phenotypic screening is often time-consuming, labor-intensive, and influenced by environmental variability. In perennial horticultural crops such as fruit trees, long juvenile phases further delay selection. Despite these limitations, phenotypic screening remains indispensable for validating stress tolerance and quality traits, particularly at advanced breeding stages.

3.2 Physiological and Biochemical Screening

Physiological screening provides insight into plant functional responses to stress and is increasingly used to complement phenotypic evaluation. Traits such as relative water content, stomatal conductance, chlorophyll fluorescence, canopy temperature, photosynthetic efficiency, and root hydraulic conductivity are reliable indicators of abiotic stress tolerance (Blum, 2011) ^[7]. These traits are particularly useful for screening drought, heat, and salinity tolerance in vegetables and fruit crops. Biochemical markers further enhance screening precision by reflecting stress-induced metabolic changes. Accumulation of osmolytes such as proline and glycine betaine, enhanced antioxidant enzyme activity, and changes in reactive oxygen species scavenging capacity are commonly associated with stress tolerance (Hasanuzzaman *et al.*, 2020) ^[41]. In horticultural crops, biochemical screening has been successfully applied to identify tolerant genotypes under salinity, drought, and temperature stress.

3.3 Controlled Environment and *in vitro* Screening

Controlled environment screening using growth chambers and greenhouses allows precise manipulation of stress intensity and duration, improving reproducibility and early-stage selection. These systems are particularly useful for screening seedlings and large populations under uniform stress conditions. *In vitro* screening techniques using tissue culture have gained importance in horticultural crops such as banana, potato, ornamentals, and fruit rootstocks. *In vitro* systems allow rapid screening for salinity, drought, and disease resistance by exposing explants to stress-inducing agents under controlled conditions (Ashraf & Foolad, 2013) ^[31]. Although *in vitro* responses may not always fully reflect field performance, they provide a valuable preliminary selection tool.

3.4 High-Throughput Phenotyping and Digital Tools

High-throughput phenotyping (HTP) represents a major advancement in stress screening. Imaging technologies, including RGB, thermal, hyperspectral, and fluorescence imaging, enable non-destructive, rapid, and repeated measurement of plant traits over time (Fahlgren *et al.*, 2015) ^[40]. These technologies are increasingly integrated with unmanned aerial vehicles and sensor-based platforms for field-scale evaluation. HTP allows precise quantification of complex traits such as growth dynamics, canopy temperature, water status, and stress-induced senescence. When combined with artificial intelligence and machine learning, HTP significantly enhances the ability to screen large populations and identify superior genotypes for stress tolerance.

4. Breeding Strategies for Stress Tolerance in Horticultural Crops

Breeding for stress tolerance in horticultural plants requires strategies that address complex trait inheritance, environmental variability, and quality considerations. Advances in molecular genetics and genomics have expanded the range of tools available to breeders, enabling more targeted and efficient improvement.

4.1 Conventional Breeding and Use of Genetic Resources

Conventional breeding approaches such as selection, hybridization, and backcrossing continue to play a central role in horticultural crop improvement. The use of landraces and wild relatives has been particularly important for introducing stress tolerance traits, as these genetic resources often harbor alleles for resilience to drought, salinity, heat, and diseases (Dempewolf *et al.*, 2017) ^[39]. However,

challenges such as linkage drag, reproductive barriers, and long breeding cycles limit the efficiency of conventional approaches, especially in perennial and clonally propagated crops.

4.2 Marker-Assisted Selection

Marker-assisted selection (MAS) enables indirect selection of stress tolerance traits using DNA markers linked to quantitative trait loci (QTLs). MAS has been successfully applied for disease resistance and some abiotic stress traits in horticultural crops, improving selection accuracy and reducing breeding time (Collard & Mackill, 2008) ^[37]. In crops such as tomato, pepper, and fruit trees, MAS has facilitated pyramiding of resistance genes and selection at early developmental stages. However, its effectiveness for complex traits controlled by many small-effect loci remains limited.

4.3 Genome-Wide Association Studies and Genomic Selection

Genome-wide association studies (GWAS) have emerged as powerful tools for dissecting the genetic basis of complex stress tolerance traits. By exploiting natural genetic diversity, GWAS enables identification of loci associated with stress responses and quality attributes across diverse germplasm collections (Huang & Han, 2014) ^[42]. Genomic selection (GS) further extends this approach by using genome-wide marker data to predict breeding values. GS is particularly promising for horticultural crops with long generation times, as it allows selection without extensive phenotyping in each breeding cycle (Crossa *et al.*, 2017) ^[38].

4.4 Genetic Engineering and Gene Editing

Transgenic approaches have been used to introduce stress-responsive genes, transcription factors, and metabolic regulators into horticultural crops. Genes involved in osmotic adjustment, antioxidant defense, and hormone signaling have shown potential for improving stress tolerance (Bhatnagar-Mathur *et al.*, 2008) ^[32]. More recently, CRISPR/Cas-based gene editing has revolutionized plant breeding by enabling precise and targeted modification of genes associated with stress tolerance and quality traits. Gene editing offers advantages in speed, specificity, and regulatory acceptance, making it a promising tool for future horticultural improvement (Chen *et al.*, 2019) ^[34].

5. Integration of Stress Tolerance and Quality Traits in Breeding Programs

One of the major challenges in horticultural crop improvement is the simultaneous enhancement of stress tolerance and quality traits. Unlike staple crops, horticultural plants are primarily valued for attributes such as taste, aroma, color, texture, nutritional composition, shelf life, and aesthetic appeal. Stress conditions often negatively influence these quality parameters, making it essential to integrate resilience and quality improvement within breeding strategies. Stress tolerance and quality traits are frequently governed by complex genetic architectures involving multiple genes and strong genotype × environment interactions. In some cases, stress tolerance mechanisms may divert resources away from quality-related pathways, resulting in trade-offs. For example, drought or salinity stress can increase the accumulation of certain secondary metabolites, improving antioxidant content, but

may also reduce yield or fruit size. Modern breeding approaches aim to identify genotypes that maintain desirable quality traits under stress rather than those that simply survive adverse conditions. Physiological and biochemical markers play a key role in linking stress tolerance with quality. Traits such as osmolyte accumulation, antioxidant enzyme activity, and membrane stability are associated with stress adaptation and can influence flavor, nutritional quality, and postharvest performance. For instance, enhanced antioxidant systems not only improve stress tolerance but also increase levels of health-promoting compounds such as phenolics, carotenoids, and vitamins in fruits and vegetables.

Molecular breeding tools have greatly facilitated the integration of these traits. Marker-assisted selection and genomic selection enable breeders to simultaneously target stress-responsive loci and quality-related quantitative trait loci. In fruit crops such as tomato, grape, and apple, genomic tools have been successfully used to combine disease resistance with improved fruit quality and shelf life. Additionally, gene editing technologies offer precise opportunities to modify specific genes involved in stress signaling or quality metabolism without altering the overall genetic background.

6. Challenges and Limitations in Screening and Breeding for Stress Tolerance and Quality

Despite significant progress, several challenges continue to limit the effectiveness of screening and breeding strategies in horticultural crops. One major constraint is the complexity of stress tolerance traits, which are often polygenic and highly influenced by environmental variability. Reliable phenotyping under field conditions remains difficult, particularly for traits related to root architecture, water-use efficiency, and stress resilience over multiple growth stages. Another challenge lies in the lack of standardized screening protocols across different crops and stress conditions. Variations in experimental design, stress intensity, and developmental stages make it difficult to compare results across studies and environments. High-throughput phenotyping platforms, while promising, are often expensive and require technical expertise, limiting their adoption in resource-constrained breeding programs.

Quality traits present additional complications due to their subjective nature and dependence on consumer preferences and market demands. Traits such as flavor, aroma, and texture are difficult to quantify and may vary with environmental conditions and postharvest handling. Furthermore, breeding for quality often requires long evaluation periods, particularly in perennial horticultural crops, which slows genetic gain. Socio-economic and institutional constraints also play a role. Limited funding, inadequate infrastructure, and insufficient collaboration between breeders, physiologists, and molecular biologists can hinder the successful implementation of advanced breeding technologies. Regulatory frameworks governing genetically modified and gene-edited crops further influence the adoption of innovative approaches in different regions.

7. Future Perspectives and Opportunities

The future of horticultural crop improvement lies in the integration of multidisciplinary approaches that combine conventional breeding, advanced phenotyping, genomics, and digital technologies. The development of climate-

resilient, high-quality horticultural varieties will require a shift toward systems-based breeding that considers multiple stresses, environmental variability, and consumer preferences simultaneously. Emerging tools such as artificial intelligence, machine learning, and big data analytics offer new opportunities for analyzing complex datasets generated from genomics, phenomics, and environmental monitoring. These technologies can improve trait prediction accuracy, optimize selection decisions, and accelerate breeding cycles. Remote sensing and precision agriculture tools can further support real-time stress monitoring and adaptive management. Participatory breeding and stakeholder engagement will also be critical for ensuring that newly developed varieties meet the needs of farmers, consumers, and supply chains. Incorporating farmer knowledge and market demands into breeding objectives can enhance adoption and impact. Additionally, greater emphasis on underutilized and indigenous horticultural crops may contribute to dietary diversity, resilience, and sustainability. Finally, strengthening international collaboration, capacity building, and policy support will be essential for scaling up successful breeding strategies. Aligning horticultural breeding efforts with global sustainability goals, including climate adaptation, nutrition security, and environmental conservation, will ensure that advances in screening and breeding strategies contribute meaningfully to resilient food systems.

8. Conclusion

Advances in screening and breeding strategies have significantly enhanced the capacity to develop horticultural crops that are both stress tolerant and high in quality. The integration of conventional breeding approaches with modern physiological, biochemical, and molecular tools has enabled more precise identification and selection of resilient genotypes under diverse environmental conditions. Emerging technologies such as high-throughput phenotyping, genomics-assisted selection, genome-wide association studies, and gene editing are accelerating genetic gains while improving the understanding of complex stress-response mechanisms. Importantly, the simultaneous improvement of stress tolerance and quality traits is increasingly feasible through systems-based breeding approaches that consider genotype $\times$ environment interactions and multiple trait integration. While challenges remain, including trait complexity, phenotyping limitations, and regulatory constraints, continued innovation and interdisciplinary collaboration offer promising pathways forward. Future breeding efforts must emphasize sustainability, climate resilience, and consumer-driven quality attributes to ensure the long-term viability of horticultural production systems. By aligning scientific advances with practical breeding goals and policy support, horticultural crops can be effectively improved to meet global food, nutrition, and environmental challenges in a changing climate.

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