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A review of breeding for abiotic stress tolerance in ornamental crop

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Abstract
Abiotic stress poses a significant challenge in various regions of India, particularly impacting agricultural areas. This issue arises from extreme temperatures, both low and high, prolonged drought conditions, and heightened soil salinity levels. These factors collectively hinder the progress and productivity of crops, creating a substantial hurdle for their growth. However, only limited initiatives have been directed towards addressing this concern, especially within the realm of ornamental crops. Among the various stress factors, soil salinity emerges as a prominent contributor, detrimentally influencing the overall development and expansion of plants. Now, compared to other crops, decorative crops have the potential to generate higher income and play a significant role in the national economy. The modern challenge is to breed ornamentals that can also thrive in challenging environments. There are several strategies for coping with abiotic stress, but relatively few have been shown effective for attractive crops. A fundamental technique that has shown promise in enhancing the drought tolerance of different crops involves the transfer of abiotic stress-resistant traits from cultivated varieties to their wild counterparts through wide crossbreeding methods, encompassing both interspecific and intergeneric hybridization. Another significant strategy involves *In vitro* mutagenesis, a pivotal approach that combines tissue culture methodologies with induced mutation techniques. This innovative approach holds the potential to not only augment the yield and overall quality of crop plants but also to bolster their resilience towards various stressors. In the context of ornamental crops, incorporating novel attributes such as unique colors and enhanced abiotic stress resilience through conventional breeding methods often presents considerable difficulties. However, the process of genetic transformation offers a more expedient avenue for achieving these goals. The focus of this paper lies in the comprehensive investigation of research pertaining to holistic plant breeding techniques geared towards conferring abiotic stress resistance in ornamental crops. Specifically, the study delves into the intricacies of breeding strategies that address the challenges posed by temperature variations (both low and high), drought, and salinity stress. It is important to note that the comprehensive exploration of breeding methodologies in response to these specific stressors exceeds the scope of this review.

Keywords: Abiotic stress, Ornamental flowers, Genetic engineering, hybridization

Introduction

The genotype, environment, and genotype-environment interaction all affect a plant's Phenotypic performance. Stress occurs when an environmental condition prevents a person's genotype from fully expressing itself.

Stressors affecting organisms can be categorized as either biotic, arising from living agents like pathogens, pests, and weeds, or abiotic, originating from non-living factors. Abiotic stressors encompass diverse factors such as moisture levels, extreme temperatures (high or low), imbalances in mineral content (deficiencies or toxicities), salinity, variations in soil pH, air pollution, and more. The ramifications of abiotic stress are substantial, leading to significant declines in global agricultural output [1]. Extensive research efforts have been directed towards investigating stressors such as heat, salinity, and drought [2]. Notably, intensive research attention has been dedicated to stress conditions like drought, salinity, and heat [2]. It's important to acknowledge that crops and other plants commonly encounter an array of abiotic stressors within real-world field condition. In regions susceptible to drought, several crops often encounter a dual challenge, contending with not only dry conditions but also additional stressors such as elevated temperatures or soil salinity.

This is particularly evident in arid and semi-arid locales where groundwater tends to possess a naturally high salt content. The demands for water resources across agriculture, industry, and households intensify, leading to fierce competition for available freshwater reserves. Compounding this issue, certain areas experience a decline in their freshwater supplies. In nations grappling with water scarcity, the utilization of alternative water sources becomes an unavoidable necessity for irrigating urban landscapes, as well as nurturing nursery and greenhouse crops. This often involves the application of reclaimed or recycled water, as indicated by studies conducted by Fox *et al*. (2005) and Tanji *et al*. (2008)

Attributes of abiotic stresses

1. The manifestations of abiotic stresses can exhibit significant variation based on the specific geographic region.
2. The prominence of different abiotic stressors is predominantly determined by the geographical location
3. The intensity of some pressures may vary during the crop season.
4. The effects of distinct abiotic stresses can often intersect. For example, enhancing a plant's capacity to withstand salinity may inadvertently enhance its resilience to drought, as the traits triggered by salinity stress can coincide with those induced by drought stress.
5. A particular abiotic component may have an impact on the severity of another abiotic stress, for example, moisture stress in a salty soil might exacerbate salinity stress.
6. The capacity of various plant/crop species to endure a particular stress varies.
7. A crop's ability to withstand abiotic stressors might also vary across different kinds.

Drought

In a region where there is little precipitation, drought is characterised by unusually dry weather. It is influenced by a number of things, including temperature extremes, photon irradiance, and a lack of water. Due to the large concentration of solutes, the water potential is low.

Mechanism for Tolerance to Drought

Drought Escape

Drought escape refers to the capability of a plant to successfully finish its life cycle before the available soil water depletes, allowing the plant to transition into a state of dormant seeds before the onset of a dry season. Plants exhibiting rapid growth and development are often categorized as drought escapers, owing to their capacity to complete their life cycle within a limited water availability window

Drought Avoidance

Drought avoidance pertains to the ability of plants to uphold relatively elevated tissue water potential even in the face of inadequate soil moisture. This is achieved through strategies such as cultivating deeper roots that tap into deeper soil layers, regulating transpiration by means of stomatal control, and reducing water loss through adaptations like smaller and thicker leaves, which leads to a reduced surface area for water evaporation from the epidermis. These mechanisms collectively enable plants to resist the impacts of drought by conserving water and maintaining their turgor pressure.

Drought tolerance

It is the capacity to resist low tissue water potential and water deprivation. Through osmotic adjustment (a mechanism that causes solute buildup in cells), an increase in cell flexibility, and a decrease in cell size, drought tolerance involves the maintenance of turgor.

Impact of drought stress

- **Impact on the Metabolism of Nitrogen:** Nitrite reductase activity is unaffected by a decrease in nitrate reductase activity.
- **Impact on the metabolism of carbohydrates:** Starch is lost, simple sugars are gained, and carbohydrate translocation is reduced
- **Impact on Growth:** Reduced cell diameters lead to a decrease in turgor pressure, affecting the overall growth of the plant.
- **Impact on Photosynthesis:** Drought stress results in the disruption of Photo System II (PS II), closure of stomata, and a decline in electron transport, collectively contributing to a reduction in photosynthetic activity.
- **Alteration in Nucleic Acids and Proteins:** Drought stress triggers a decrease in the levels of nucleic acids and proteins within the plant. This decrease subsequently leads to an increase in protease activity, elevated levels of free amino acids, higher RNAase activity, increased RNA hydrolysis, and alterations in DNA content.

Salt stress

"Salt stress happens when the soil has too much salt, which prevents crop growth and ultimately results in crop mortality. Water consumption efficiency is decreased, ions are increased, heat stress is induced, and stem extension in plants under salt stress is reduced.

The degradation of biological macromolecules is triggered by the accumulation of free ions. In the context of salinity stress, a reduction in hydrogen peroxide production, altered electrolyte levels, and diminished cellular water content were noted in plants [3]. Notably, the accumulation of salts in soil poses a significant risk, leading to reduced plant productivity and quality. This phenomenon adversely affects processes such as germination, plant growth, and overall development. Salt stress impacts more than 45 million hectares of irrigated agricultural land globally [4]. This stressor exerts a range of adverse effects on plants, encompassing ion toxicity, physiological drought, nutritional imbalances, disruptions in metabolic processes, oxidative stress, compromised membrane integrity, and reduced cellular division.

Ornamental plants exhibit multifaceted reactions in response to salt stress

Involving intricate interactions between physiological, biochemical, and morphological processes. Amid the spectrum of consequences arising from salt stress, an early and discernible plant response is the diminished rate of leaf growth, as highlighted in research [5].

The influence of salt stress on ornamental plants is primarily attributed to the osmotic impact of salts surrounding the roots, which subsequently curtails the flow of water to leaf cells. Elevated concentrations of salts in the soil can also impede the growth of roots [6], leading to a decline in both root length and total mass, as well as their functional capacity [7].

This root growth inhibition is associated with decreased cell elongation and division rates in leaves, resulting in a reduction of their ultimate size and consequently a decrease in overall leaf area [8, 9]. This reduction in leaf area can be attributed to diminished turgor in leaves, notable alterations in cell wall characteristics, or a decline in the rate of photosynthesis

Ornamental plants are indeed susceptible to these challenges. As suggested by Cassaniti *et al*. [10], the initial observable consequences of salinity stress, regardless of whether the species is sensitive or tolerant, include a decrease in shoot dry weight and leaf area. This phenomenon was noted in species like Cotoneaster lacteus (sensitive) and Eugenia myrtifolia (tolerant). Additionally, an often-observed outcome of elevated salt concentrations is the thickening of leaves, a response observed in ornamental plants such as Coleus blumei and Salvia splendens [11].

Table 1: Salt stress tolerance rootstock of flower crops

Rootstock	Salinity range	Main results	References
The following rose rootstocks were studied: R. 'Manetti', R. odorata, 'Natal Briar', R. multiflora, and R. 'Dr. Huey'	The plants were subjected to sodium chloride (NaCl) treatments at concentrations of 0 mM, 15 mM, and 30 mM	Among the studied rootstocks, R. 'Manetti' and R. 'Natal Briar' demonstrated relatively higher salt tolerance in comparison to R. odorata, R. multiflora, and R. 'Dr. Huey'**.**	[38]
The studied rose rootstocks included R. × fortuniana, R. multiflora, and R. odorata.	The plants were exposed to different electrical conductivity (EC) levels: a control EC of 1.6 dS m-1, along with treatments at EC levels of 3.0, 6.0, and 9.0 dS m-1 for a duration of 15 weeks. Salinization was achieved using various salts, with NaCl being the dominant contributor at 87%, along with MgSO4 and CaCl2	Irrespective of the rootstock used, a majority of the plants did not survive when subjected to an electrical conductivity (EC) of 9.0 dS m-1. However, at an EC of 6.0 dS m-1, there was a notable reduction in growth compared to the control conditions and an EC of 3.0 dS m-1. In this context, R. × fortuniana exhibited slightly greater tolerance compared to the other two rootstocks	[39]
The examined rose varieties were Rosa 'Manetti', R. odorata, R. 'Natal Briar', and R. 'Dr. Huey'.	In Experiment 1, the plants were treated with sodium chloride (NaCl) solutions at concentrations of 0 mM, 5 mM, and 30 mM. In Experiment 2, a combination of NaCl and calcium chloride (CaCl2) was used, with concentrations of NaCl + CaCl2 set at 0 mM, 1.5 mM, 3 mM, 6 mM, 12 mM, and 24 mM	In terms of performance, R. 'Manetti' demonstrated the most favorable results, followed by R. 'Natal Briar'. Greenhouse roses, as a collective, were capable of enduring an overall electrical conductivity (EC) level of 3.0±0.5 dS m-1 or tolerating sodium (Na) and chloride (Cl) concentrations up to 10±2 mM.	[37]

Heat stress

Heat stress occurs when temperatures surpass a critical threshold and endure for a duration that leads to enduring negative impacts on plant growth and development. Elevated temperatures beyond the optimal range can induce heat stress in plants.

Heat significantly influences a plant's survival, growth, developmental trajectory, and physiological functions. The nature and severity of these effects are primarily determined by the temperature level, the plant species, and the specific physiological processes involved. Heat stress is characterized by a sustained elevation in temperature that leads to irreversible damage to plant growth and development [12]. Throughout its life cycle, heat stress affects a plant's growth, although the specific heat threshold's significance can vary notably across different experimental stages. Elevated temperatures resulting from high ambient conditions pose a significant challenge to crop production worldwide. Predictions from various global circulation models indicate that the gradual increase in average global temperature is a consequence of greenhouse gas emissions. Rapid and severe heat stress can cause substantial cellular harm, even leading to cell death within a short timeframe. Among the direct impacts at moderately high temperatures are protein degradation and aggregation, as well as heightened fluidity of membrane lipids. Heat stress induces a range of detrimental effects, including enzyme inactivation, inhibition of protein folding, protein degradation, and compromised membrane integrity.

Table 2: Heat stress tolerance of flower crops

S. No.	Crop	Variety	Breeding Method	Parents (if any)	Trait
1.	Lisanthus	UF7-53	Selection	Blue poppy	Heat tolerance
2.	Lisanthus	UF94- 404	F3 Selection	UF92-17 X Blue Lisa	Heat tolerance
3.	Lisanthus	UF94-34	F4 Selection	UF8-21 X Mermaid blue	Heat tolerance
4.	Lisanthus	UF96-393	F2 Selection	UF94-226 X UF94-230	Heat tolerance
5.	Lisanthus	UF99-49	F6 Selection	UF94-404 X UF94-46	Heat tolerance
6.	Marigold (Afro-French)	Zenith	Polyploidy (triploid)		Heat tolerance

Cold stress

Cold stress is an abiotic factor that detrimentally affects plant growth and agricultural output. It encompasses both chilling (0–15 °C) and freezing (0 °C) conditions. Chilling stress is a common constraint on plant growth and development, and it elicits a range of noteworthy effects on plant cells. The sustainability of crop production is significantly jeopardized by cold stress, leading to substantial potential crop losses. Phenotypic indications of cold stress in plants encompass various manifestations such as poor germination, stunted seedling growth, leaf yellowing, restricted leaf expansion, wilting, and, in severe cases, tissue death or necrosis. Cold stress profoundly affects the development of plant reproductive systems. A major adverse consequence of cold stress is the extensive damage inflicted on plant cell membranes. Cold or chilling stress typically occurs within the temperature range of 0 to 15 °C. In response to these conditions, plants strive to maintain internal balance, aiming to foster freezing tolerance. This endeavour requires substantial adjustments in both metabolic processes and gene expression, leading to a process of reprogramming [13, 14].

Table 3: Cold stress tolerance of flower crops

S. No.	Crop	Variety	Breeding Method	Parents (if any)	Trait
1.	Lilium	East red	Hybridization	Co Amore x Acapulco	Cold tolerance
2.	Lilium	Joyous Event	Hybridization	Acpulco x Miami	Cold tolerance
3.	Lilium	Water lily Dew	Hybridization	Golden Horn x Brunello	Cold tolerance
4.	Lilium	Mid-day	Hybridization	Golden Horn x Brunello	Cold tolerance

Rose species resistant to different abiotic stress

***Rosa indica var odorata*:** Resistant to alkaline soil

***Rosa rugosa*:** Winter hardiness

***Rosa multiflora*:** Resistant to acid soil.

Rosa spinosissima, *Rosa macrantha* and *Rosa laxa*: Winter hardiness

Approaches to enhance abiotic stress tolerance through breeding

Wide distant hybridization

Wide distant hybridization, encompassing both interspecific (between species) and intergeneric (between genera) crosses, holds immense promise for enhancing a crop's capacity to withstand abiotic stress. This method involves the introduction of stress-tolerant traits from closely related wild species into cultivated varieties, capitalizing on the superior abiotic stress tolerance often found in wild relatives that cultivated varieties lack [15, 16]. For instance, the intergeneric hybridization of perennial ryegrass (*Lolium perenne*) with Atlas fescue (*Festuca mairei*) led to the development of a drought-tolerant variety, inheriting drought resistance from the wild species [17]. Similarly, the use of interspecific hybridization has resulted in the creation of multiple drought-tolerant *Chrysanthemum* cultivars [18]. By employing ovary rescue techniques, interspecific hybrids between *Dendranthema morifolium* and *Dendranthema nankingense* were generated, leading to enhanced cold tolerance in cultivated species [19]. This method of hybridization offers a valuable avenue for transferring beneficial stress-tolerance traits from wild relatives to cultivated crops, fortifying their ability to endure challenging environmental conditions.

***In vitro* mutagenesis**

In vitro mutagenesis is a crucial technique to increase crop plants' capacity to withstand stress as well as their production and quality. *In vitro* mutagenesis is a hybrid technique that merges induced mutation methods with tissue culture procedures. In a notable application of this approach, a NaCl-tolerant variety of *Chrysanthemum* (*Chrysanthemum morifolium Ramat*.) was established using ethyl methane sulfonate (EMS) as a chemical mutagen. This technique induced stable mutations that rendered the plant more tolerant to salt stress. The developed *Chrysanthemum* variety exhibited resilience in maintaining blossom quality and yield even under stress conditions. The enhanced tolerance of the E2 variety was attributed to multiple factors. Notably, the increased activity of enzymes like superoxide dismutase (SOD), ascorbate peroxidase (APX), and dehydroascorbate reductase (DHAR) played a role. These enzymes are linked to the management of oxidative stress. Additionally, the E2 variety showed reduced levels of membrane damage compared to the NaCl-treated control plants, which further contributed to its improved salt tolerance.

Isoform analysis revealed a significant activation of the Cu/Zn isoform, which was the predominant factor contributing to the overall increase in superoxide dismutase (SOD) activity in the E2 variant. Elevated levels of carotenoids and ascorbate observed in E2 leaves corresponded to a heightened free radical scavenging capacity (RSC), assessed through DPPH (diphenyl-1 picrylhydrazyl) scavenging ability. The data underline the importance of maintaining a proper balance between enzymatic and non-enzymatic defence systems for effective salt stress mitigation in *Chrysanthemum*. Notably, the E2 variant exhibited superior performance under the same salt stress conditions, further confirming its inherent tolerance. This stability of salt tolerance traits across different time frames supports the notion that E2 is characterized by inherited salt-tolerant attributes.

In summary, the E2 variation, which was derived from 0.025 EMS treatment, can be recognized as a NaCl-tolerant strain with advantageous traits for withstanding salt stress [20].

Genetic modification to enhance abiotic stress tolerance

To achieve optimal yield and ensure production stability, it is imperative to develop plant varieties that exhibit robust resistance to abiotic stressors. However, traditional breeding methods aimed at enhancing abiotic stress tolerance have encountered significant challenges due to the complexity of abiotic stress factors and their intricate genetic regulation. The limitations of conventional approaches stem from the multifaceted nature of abiotic stress and the inherent difficulties in identifying and selecting relevant traits.

In contrast, genetic engineering offers a more efficient solution by introducing specific, desirable genes into crops, resulting in shorter development times compared to traditional breeding methods. Unlike traditional breeding, genetic engineering allows the precise transfer of only the desired genes, minimizing the risk of unwanted gene transfers. Crucially, understanding the genetic mechanisms underlying stress tolerance is pivotal for successful genetic engineering efforts. Identification of these key genes and regulatory pathways provides the foundation for introducing stress-tolerance genes into crops, yielding varieties that can withstand challenging environmental conditions. Recent advancements in cellular and molecular biology have facilitated the cloning and transfer of essential genes across species barriers, enabling stable expression and transmission of these genes in various organisms. This breakthrough allows scientists to transcend the limitations of sexual hybridization, providing a powerful tool to develop stress-tolerant crops.

In summary, the development of plant varieties with heightened abiotic stress resistance is paramount for maximizing yield potential and stabilizing production. Genetic engineering, driven by advancements in genetic understanding and molecular techniques, holds the promise of efficiently introducing stress-tolerance genes into crops to yield robust and resilient varieties. Across the spectrum of life, organisms have evolved mechanisms to counteract or endure abiotic stresses. In particular, plants synthesizing essential enzymes or proteins sourced from diverse organisms, central to abiotic stress tolerance systems, have demonstrated a marked advantage over their wild type counterparts in challenging conditions. This advantage stems from the improved presence of transgenic products, including radical scavengers and supplementary osmolytes. Efforts are being directed towards optimizing the deployment of these resilient transgenic traits. This encompasses the strategic distribution of beneficial products like radical scavengers and osmolytes, which can fortify plants against abiotic stresses. To achieve enhanced tolerance to multiple stressors, a comprehensive understanding of the molecular intricacies of stress perception, signal transduction, and response mechanisms in both plants and other organisms is crucial.

Innovative strategies and ideas are actively being explored to bolster the efficacy of inheritable engineering for abiotic stress tolerance. This pursuit is driven by the need to develop plants endowed with robust resistance to diverse stresses. As researchers delve deeper into the molecular basis of stress responses, it is anticipated that novel approaches will emerge, leading to the creation of crops that are exceptionally well-equipped to thrive under challenging environmental conditions [22].

Table 4: Genetic Modification to Enhance Abiotic Stress Tolerance

S. No.	Crop Species	Gene used	Trait Improvement	Reference
1.	Rose	*RhEXPA* (A rose expansingene)	Salt and drought tolerance	[22]
2.	Rose	*SOD* (Superoxide dismutase2)	Drought tolerance	[31]
3.	*Chrysanthemum*	*CmWRKY1 (*WRKY transcription factor (TF) gene*)*	Drought tolerance	[32]
4.	*Chrysanthemum*	*DgWRKY5*	Salt tolerance	[33]
5.	*Chrysanthemum*	*CmHSFAS*	Salinity tolerance	[34]
6.	Petunia	*ATNHX1* (Na+/N+ exchanger1)	Salt and drought tolerance	[23]
7.	Petunia	*CBF* (C-repeat binding factor)	Cold tolerance	[10]
8.	China rose	*AtDREB2A-CA* (dehydration responsive element binding)	Enhanced salinity tolerance	[35]
9.	China rose	*RcXET* and *MtDRRBIC (Medicago truncatula* dehydration responsive element binding)	Freezing and drought tolerance	[36]

Conclusion

Abiotic stress, stemming from factors such as temperature fluctuations, drought, or salinity, poses a significant hurdle to optimal crop growth and productivity. To enhance the ability of ornamental crops to withstand these challenges, several breeding techniques have demonstrated effectiveness. These include interspecific and intergeneric hybridization, *in vitro* mutagenesis, and genetic engineering. Through interspecific and intergeneric hybridization, genetic material from related species or genera is combined to introduce desirable traits like abiotic stress tolerance. *In vitro* mutagenesis involves inducing controlled genetic mutations to generate new variants with improved stress resilience. Genetic engineering takes this a step further by introducing novel features not naturally present in the organism, thereby enhancing its capacity to tolerate abiotic stressors. In the context of genetic engineering, the introduction of foreign genes or modification of existing genes can confer new abilities to combat abiotic stress. These introduced genes might encode for specific enzymes, proteins, or other molecules that enhance stress tolerance mechanisms in ornamental crops.

In summary, abiotic stress significantly impedes the growth and yield of crops, including ornamental varieties. Breeding techniques such as hybridization, mutagenesis, and genetic engineering offer promising avenues for enhancing abiotic stress tolerance. Genetic engineering, in particular, enables the introduction of novel attributes that can empower ornamental crops to better withstand the challenges posed by abiotic stressors.

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