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Abiotic Stress and Nanoparticle Responses in Ornamental Crops

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The action of abiotic stress on ornamental plants has been a subject of numerous studies. Plants can survive and grow even under unfavorable abiotic stress, however, many abiotic stresses, encountered at critical growth stages, adversely affect their aesthetics, quality and productivity in terms of yield. Further, climate change is likely to increase frequency, intensity, and duration of abiotic stresses. Wide and distant hybridization has contributed positively to improving drought, salt and heat tolerance in ornamentals through introducing abiotic stress-tolerant trait from their wild relatives. *In vitro* mutagenesis is another important technique used for inducing stress tolerance. Using marker assisted selection, functional genomics, QTL mapping and genetic engineering in ornamental crops, potential gene(s) have been identified, and several traits have been improved. Genes viz. *AP2/ERF*, *bZIP TFs*, *MYC*, and *MYB* have been implicated in drought stress response and Na^+/H^+ antiporter genes (*AtNHX1*, and *AtSOS1*), *DREB1A*, *SOS1*, *WRKY4*, *NAC1*, and *SOS3*, etc. have been identified for imparting salt tolerance in ornamental crops. VAM fungi maintain the homeostasis of plants under soil salinity, drought, high soil temperature, adverse pH, toxic and heavy metal stresses. In recent days nanoparticles playing major role in improve the biotic and abiotic stress tolerance.

Introduction

Flowering is the corner stone of floricultural crops, regardless of class viz. bedding plants, herbaceous perennials, cut flowers and flowering potted plants. Flower quality is affected not only after harvest but also throughout the growth stages of a plant right from pre-planting operations to senescence. There are many external environmental cues that affect flowering in plants: photoperiod (day length), water (drought or flood), temperature (heat and cold), solar radiation, soil compactness, soil salinity, mineral nutrition, stress (fire, water levels), heavy metals and atmospheric pollutants. In addition, lack of stress or supra-optimal levels of nutrients or saturating water levels can also impact progression towards flowering. During the growing cycle, plants are affected by a number of abiotic and biotic factors that can greatly influence their growth and development and can further affect their production and quality. The biotic factors, viz. bacteria, viruses, fungi, insects and nematodes are considered major damage-causing factors, and their exclusion is an important requirement for the international trade of flowers. Further, their occurrence in plants is also integrated with the exposure to abiotic factors which is regulated by an intricate network of complex signaling pathways.

Abiotic stress events occurring separately cause less damage in comparison to these events occurring simultaneously like drought stress coupled with heat stress (Mittler, 2006; Prasad *et al.,* 2011). In addition, abiotic stresses such as shade, UV exposure, photo-inhibition, air pollution, wind, hail and gaseous deficiency which are often sporadic and highly localized in occurrence. Abiotic stress factors have been reported to cause the occurrence and spread of fungal and bacterial pathogens, insects, and weeds (Coakley *et al.,* 1999).

In some cases, such as the supply of water, too little (drought) or too much (flooding) can both impose stress on plants. Natural plant defenses to abiotic stresses include synthesis & accumulation of plant compatible solutes including glycine, betaine, sugars, proline and compatible proteins (late-embryogenesis abundant (LEA) protein, dehydrins & heat shock proteins). Proline is an amino acid synthesized into nitrogen metabolism with functions related to osmoprotection and cellular homeostasis, which can contribute to improving the plant tolerance under situations of abiotic stress. *LEA* genes are expressed during late stages of seed development and in vegetative tissue when plant undergoes abiotic stress. The *LEA* protein genes also confer tolerance to drought, salinity & freezing stresses. Glycine betaine is naturally produced in many plant spp. and high accumulation levels are associated with drought and salt tolerance.

Effect of light stress

Sunlight is the energy source for photosynthesis; its deficit inevitably limits photosynthesis. However, too much sunlight can induce photo inhibition of photosynthesis and even photodamage of the photosynthetic apparatus in plants, and thus it may become a stress factor (i.e., light stress). Photoinhibition is a phenomenon of a light-induced decrease in photosynthetic activity when light energy received by the photosynthetic apparatus is in excess of what can be used by photosynthesis. Light stress often causes photoinhibition of photosynthesis in the upper layer leaves of plant canopies. Low solar irradiance can decrease flowering of the day-neutral *Rosa* x *hybrida* L. by increasing the occurrence of 'blind' shoots, i.e. aborted flowers (Nell *et al.,* 1978). In contrast, high solar irradiance can substitute for a photoperiod requirement in *Hibiscus moscheutos* (Warner *et al.,* 2002). Photoperiodic flowering responses can be divided into several different response groups, short-day plants, long-day plants, day-neutral plants, intermediate-day plants and ambiphotoperiodic plants (Thomas *et al.,* 1996) have been summarized and mentioned in table.1.

Effect of drought stress

Among the environmental stress factors, one of the most widely limiting for crop production globally is water. Drought stress occurs when soil moisture status is low, relative humidity is low, and temperature is high. Water deficit conditions under drought lead to the accumulation of reactive oxygen species in chloroplasts (Munne-Bosch, 2003), damage the phospholipids of the cell membrane, and increase lipid peroxidation (Mittler, 2002).

Chrysanthemum plants survive under drought stress by enhancing proline and SOD activity (Hong *et al.,* 2006) and tolerate heat stress via regulating photosynthesis (Hong *et al.,* 2009). Plants under moisture stress conditions synthesize abscisic acid which stimulates closure of stomata and reduces transpiration water loss. The results were: reduced leaf size, stem extension, and root proliferation which in turn disturb plant water relations and ultimately reduce the water-use efficiency. Further, the activity of various enzymes gets hampered, particularly CO_2 fixation, adenosine triphosphate synthesis, and other physiological factors such as stomatal closure, membrane damage, and CO_2 assimilation by leaves are reduced (Farooq *et al.,* 2009).

Short-term water stress caused a shortening of the juvenile phase and induction of early flowering in Celosia (Erwin, unpublished data). Similarly, short-term heat stress caused earlier flowering on newer cultivars of garden mums. High or low temperature affects a plant's photoperiodic response. For example, at temperatures < 17^0C, cineraria is a day-neutral plant while at temperatures > 17^0C, it is a short-day plant. In contrast, when temperatures exceed 23^0C, the flowering of many species can be delayed. Reports say that some species are sensitive to high night temperatures (*Euphorbia pulcherrima*, *Gomphrena globosa*, *Tagetes erecta*), some species are sensitive to high day temperatures (*Fuchsia* x *hybrida*, *Antirrhinum majus*), and some species are sensitive to high day or night temperatures (*Impatiens hawkeri*, *Dendranthema x grandiflora*, *Schlumbergera truncata*, many *Pelargonium* spp.) (Erwin, 1999). A different pattern in the distribution and relative enrichment in the xanthophylls (appearance of antheraxanthin and zeaxanthin) was observed in drought-stressed *Nerium oleander* (Demming *et al.,* 1988). In general, drought stress on ornamental crops resulted in reduced seed germination and seedling development (aster, chrysanthemum); poor vegetative and reproductive growth; reduced plant height and leaf area; significant reduction in leaf weight; reduced photosynthesis (gerbera, rose); reduced stomatal conductance (rose, aster) and ultimately significant reduction in the total dry matter.

Effect of soil compactness stress

With increasing soil compactness, a decrease in shoot and root growth was observed. Growth of the shoot was inhibited more than that of the root. Furthermore, increasing soil compactness resulted in increased leaf resistance to gas diffusion and decreased transpiration (Smith, 1988). Table.2 summarizes the data in the literature on changes in phytohormone concentrations occurring in response to modifications of parameters of the soil environment. The information available is certainly not complete, but it is clear that there is a correlation between the soil environment, plant growth, and changes in the concentration of phytohormones.

Effect of salinity stress

Saline conditions occur naturally or through other human activities in the part of agriculture practices (Nawaz *et al.,* 2010). When the total concentration of salt becomes excessive, plant growth is suppressed. When a plant experiences saline conditions, ions present in the rhizosphere cause osmotic stress which restricts the water absorption by roots and leads to deprived plant growth. Salt stress in plants exhibits an osmotic and ionic component that is responsible for the inhibition of plant growth and restricts water uptake resulting that loss of turgor leading to a higher concentration of ions in the cells, it leads to the accumulation of toxicity in cells finally death occurs. Further, ionic disequilibrium created by salt stress causes enzyme inactivation, deficiency of nutrients, ionic toxicity in tissues, and oxidative stress which leads to DNA damage, photosynthesis inhibition and complete plant death (Greenway *et al.,* 1980; Blumwald *et al.,* 2000). It is an alarming concern in the floriculture sector as delicate ornamental plants are easily affected by salinity stress. Leaf chlorosis due to salt stress deteriorates foliage and flower quality along with overall plant health decline and is considered a contributing factor in decreasing the appeal of flower crops (Jaleel *et al.,* 2008; Yang *et al.,* 2019). Visual quality and growth parameters along with chlorophyll contents, gas exchange, and ion concentration in shoots are used to determine the salinity stress tolerance in ornamental plants. Ornamental plants grown in alkaline soil often display a characteristic yellow color on the new growth. The effects of salinity on *Rosa* species are very high depending on the type of salts used and their concentrations used during agricultural practices (Lorenzo *et al.,* 2000). Increased salt concentrations gives negative effects on growth and flowering, which leads to visual damage and quality losses in several rose species (Cabrera *et al.,* 2009). Due to the presence of high salt concentration, *Rosa chinensis* does not bloom and directly it enters into dormancy (Jiang *et al.,* 2009).

Rosa chinensis does not bloom under salt-stress conditions and enters directly into dormancy (Jiang *et al.,* 2009). When Miniature roses (*Rosa* x *hybrida* L. 'Red Imp') were grown under salt stress conditions, it showed delayed flowering with a smaller number of flowers per plant (Cha-um *et al.,* 2010).

Similarly, *Rosa* x *hybrida* L. cultivars (Caldwell Pin', 'Carefree Delight', 'Marie Pavie', and 'The Fairy') showed less number of flowers per plant (Cai *et al.,* 2014). Stem elongation rate gradually decreased in Rosa x *hybrida* cv. 'Kardinal' by the increased salt concentration in the soil.

Hura *et al.,* 2017 stated that *Rosa rubiginosa* grown under saline conditions, lose its ability of water uptake due to salt accumulation in leaf water and showed drying of leaves. The increase in salinity level leads to significant reduction in height of cv. Kardinal (Rehman *et al.,* 2014). Sedibe *et al.,* 2013 studies the effects of different salinity conditions on Rosa geranium leaf (*Pelargonium graveolens* L.) and reported that as salinity started, plants immediately developed capitate trichome density however, rose geranium have some degree of resistance against salinity stress. Ali *et al.,* (2014) investigated the resistance response of Taif Roses against salinity along with gibberellic acid and results showed that relative water, plant height, leaf area, stem dry weight, number of branches and leaf area decreased due to saline conditions and an application of gibberellic acid reduced the bad effect of saline conditions. Aydinsakir *et al.,* (2010) examined the effects of various salinity levels on freesia and observed a reduction in flower stem length, flower number, flower yield, cormel yield, flower diameter and spike length under varying salinity conditions. Shillo *et al.,* (2002) experimented to estimate the response of bulb species and cut roses against the saline environment and reported that the root and leaf weight of bulbous species was significantly improved due to the saline conditions whereas herbaceous plants were badly affected. Sonneveld *et al.,* (1983) reported that chrysanthemum and carnation Roses had low resistance against salinity. However, *Hippeastrums* and gerbera showed medium and anthuriums showed high sensitivity against salinity stress. Rahman *et al.,* (2019) tried different salinity levels on tuberose cv. Single and double, and reported that spike diameter and spike length, number of florets per spike, number of spikes per plant, bulb weight, and number of underground bulbs were significantly reduced but the single cultivar proved to be more highly sensitive than double cultivar to soil salinity. Perez, 2009 conducted a research trial to evaluate the impact of salinity on greenhouse roses and concluded that leaf K remained same under salinity stress of $CaCl_2$ and NaCl while the plants treated with KCL leaf K proportion increased due to an increase in KCL in salt concentration.

`Küçükahmetler (2000) conducted a research trial to determine the impact of salinity on the performance, quality, and yield of cut flowers and stated that osmotic upset, various physiological variations viz. transpiration, stomatal conductance, chlorophyll content, photosynthesis, leaf and root expression changed significantly. Therefore, there is a reduction in the quality of the flower (size, color, length and stem thickness) and yield. Marosz, 2004 carried out research to check the growth and nutrient uptake of ground cover shrubs: Cotoneaster "Ursyno'*w***,**" *Cotoneaster horizontalis*, *Potentilla fruticosa*, Spiraea "Grefsheim" and "Longacre", at various soil salt stress and concluded that resistance such as *Cotoneaster horizontalis* and *Potentilla fruticosa* shown significant tolerance against with salinity stress.

Deviation in mineral nutrient concentration is either an increase or a decrease, from the optimum mineral concentration resulting in a decrease in the concentration of cytokinins and gibberellins. Itai *et al.,* 1968 and Vaadia, 1976 reported that exposure of sunflower plants to NaCl salt resulted in decrease in cytokinin in the xylem exudates. Woody shrubs and trees tend to accumulate toxic levels of Cl^- or Na^+ that cause leaf burn, necrosis, and defoliation. Besides causing specific toxic effects, salinity can induce nutritional disorders in plants. Deficiency symptoms caused by lack of mineral nutrients are mentioned in table 3.

The salt tolerance limits presented in table.4 for some ornamental shrubs, annuals, bulbous crops, trees, and ground covers indicate the maximum permissible EC for an acceptable appearance. The type of injury seen on woody ornamentals and trees is similar that were observed for fruit trees and vines. Roses are generally sensitive to moderately sensitive to salt stress; however, some rose cultivars are moderately salt tolerant and can be irrigated with a solution at an electrical conductivity between 3 to 4 dSm^{-1} without significant growth reduction or foliar damage. In case of garden roses, salt stress means a more compact plant with less branching, fewer flowers, and thus less attractive. For cutting roses, the flower stems become shorter with fewer flowering shoots, thus lower yield. Salt injury symptoms appear more quickly under hot, dry, and windy conditions than in a cool, humid environment (Fox *et al.,* 2005; Niu *et al.,* 2007; Wu *et al.,* 2001). In addition to this, plants also respond internally to salinity, expressed in changes in physiological and metabolic processes such as photosynthesis, leaf conductance, chlorophyll fluorescence, chlorophyll content, ion uptake and accumulation in tissues (Cai *et al.,* 2014; Niu *et al.,* 2008; Niu *et al.,* 2013).

Effect of heat stress

When the temperature rises above the threshold level for a period more than the critical limit, plants suffer from irreversible damage and this phenomenon is called "heat stress". The normal physiology of the plant gets affected and plant maturity is accelerated. In some cases, plants shed leaf/flower/fruit and even become sterile to overcome the unprecedented stress.

In general, an increase of usually 10-15^{0}C above ambient temperature results in heat shock or heat stress but along with elevated temperature, intensity, duration and rate of increase also play an important role in deciding the extent of heat stress in plants (Govindaraj *et al.,* 2018). The short-term stress adaptation induces a change in the concentration of certain metabolites, phosphorylation-dephosphorylation of proteins, alteration in membrane-bound complexes, membrane fluidity, and membrane topology in general.

Heat stress results in a progressive decline of photosynthetic activity in terms of electron transport and CO_2 fixation. In general, the photosynthetic activity remains stable up to 30^{0}C but sharply decreases above this temperature to reach a complete inhibition at about 40°C. Most of the environmental stresses when experienced by green plants bring about oxidative damage of cell structures and consequently a loss in cellular activities.

Heat tolerance is largely dependent upon genetic factors as cool season crops often have lower threshold temperature values compared to tropical crops (Lau *et al.,* 2019). Heritability of heat stress has been studied in case of diploid roses where it was observed that 9 interrelated rose families responded differently to higher temperatures (Liang *et al.,* 2017) and a similar response was shown in population generated through crossing heat tolerant lines with heat sensitive diploid roses (Wang *et al.,* 2008). In chrysanthemum, (Adachi *et al.,* 2000) observed the reduction or delay in flowering under high temperatures in many cultivars. Heat stress also inhibits chrysanthemum growth, flower bud differentiation and pollen development and causes delayed inflorescence and abnormal flowers (Warner and Erwin, 2002).

Movement and changes in size of the chloroplasts, quenching excess energy by interconversion of the xanthophyll cycle components, and redistribution of excitons between the Photosystem-I and Photosystem-II are a few examples of short-term adaptations. While during long-term adaptation of chloroplasts, the stress signals lead to the synthesis of proteins, lipids, and pigments. Excess or limited production of light-harvesting Chl a/b protein (LHCII), D1 proteins of the PSII core leading to stoichiometric changes of photosystems of the thylakoids, and alterations in the quantity of Rubisco transcripts and its proteins are the stress-induced responses are considered long-term adaptation. The synthesis of stress-tolerant proteins like high light-induced, early light-inducible proteins (ELIPs), heat stress-induced heat-shock proteins (HSPs), and drought-induced dehydrin also is a typical example of the long-term adaptation of chloroplasts to environmental stress.

High temperatures can change many factors in flowers by photo period or vernalization. Due to Continuous exposure of high temperature to ornamental plants, flower production will become very less. In *Antirrhinum majus*, *Calendula officinalis*, *Impatiens wallerana*, *Mimulus* x *hybridus*, and *Torenia fournieri* flower production is very less due to this high temperature compared to cool temperature (Warner and Erwin, 2002). High temperature can reduce flowering as well as photosynthesis for instance *Impatiens hawkeri* and *Viola* x *wittrockiana* exhibits less photosynthesis at 35^{0}C it was compared with normal plants (Warner and Erwin, 2002). The observed reduction of flowers in *I. hawkeri* cultivars under high-temperature conditions (Strope, 1999). Due to this high temperature, flower numbers get reduced and increase the floral sterility resulting in reduced seed set, fruit size, and yield. Under high-temperature flowers will become very sensitive by the reduction of carbon assimilation (Ranney *et al.,* 1994), increased respiration (Berry and Bjorkman, 1980), reduced chloroplast number, and reduced photosynthetic assimilation compared to vegetative tissues. Temperature is increasing day by day resulting in flower numbers decreasing per inflorescence of *Pelargonium* spp and *P. peltatum* (Erwin, 1999). Similarly, *P.* x *domesticum* flower number per inflorescence decreased with the average daily temperature (Erwin and Engelen, 1992a). Similarly, in *Pelargonium* x *hortorum* 'Veronica' 52- 15 flower numbers were decreased per inflorescence (Erwin and Heins, 1992b). *Fuchsia* x *hybrida* 'Dollar Princess' flower number per node increased from 2.3 to 6 flowers as the average daily temperature increased from 12 to 15^{0}C then decreased to 2.3 flowers per node as the average daily temperature further increased to 25^{0}C (Erwin and Kovanda, 1990). Some plant flowers are very sensitive to today and night temperatures. *Antirrhinum majus* flowers are very sensitive to even day temperature and *Impatiens hawkeri*, *Dendranthema* x *grandiflora*, and *Fuchsia* x *hybrida* flowers are sensitive to day and night temperature. Prolonged exposure of *V.* x *wittrockiana* to high temperatures (30^0C) compared to a 'non-stress' environment (20^0C) reduced flowering of all cultivars studied (Warner *et al.,* 2003).

Lisianthus seedlings are sensitive to high temperatures from the time seeds absorb water during germination till the development of 3-4 leaf pairs and thereafter they will bolt. An earlier and longer seedling is exposed to heat stress, and the higher the temperature to which seedlings are exposed, the greater the percentage of plants that will rosette.

High temperature or heat stress in *R.* x *hybrida*, causes leaf damage, flower abscission, decreased flower size and quality that greatly reduce market value. Excessive heat stress may cause a negative effect on the longevity and quality of a cut rose (Moe, 1975; Marissen, 2001; Greyvenstein *et al.,* 2014).

It also had negative effect on flower size, petal number, flower color (intensity, anthocyanin concentration), flower number (by increasing flower abscission), flower productivity (flower intensity, leaf area), the flowering stem length, the time to flowering, and leaf appearance (Dela *et al.,* 2003; Gitonga *et al.,* 2014; Shin *et al.,* 2001). Roses generally experience a decrease in flower productivity and size in response to summer temperatures greater than 30^0C (Greyvenstein *et al.,* 2019).

General effects of heat stress on plant observed are decrease of flowering; seedling establishment is hampered (e.g. China aster, marigold, chrysanthemum, etc.); drying of leaf margins and scorching effect on leaves (*Nyctanthus arbortristis*, chrysanthemum, crossandra, gerbera, petunia, etc.); defective pollen development (lilium, gerbera, aster, etc.) and reduction in total biomass.

Effect of low temperature/ Cold injury/ frost stress

Low temperatures prevailing for a longer duration can induce several physiological responses in plants that include freezing of water inside plant cells causing severe dehydration which does membrane damage and tissue death. Cold stress is becoming a challenge to the survival and adaptability of ornamental plants in the landscape and in the other crop plants, it can lead to major crop losses in terms of growth and yield. Plants under cold stress show poor seed germination, stunted growth, chlorosis, leaf size reduction, wilting, and decline in the reproductive development of plants (Anderson *et al.,* 2004). In some species, hardening and dehardening to low temperatures works upon an annual cycle (Larcher and Bauer, 1981), for example, *Metrosideros carmine* succumbs to low temperatures at -2^0C in summer and -5^0C in winter (Warrington and Stanley, 1987).

Low temperatures damage the plants both by a chilling effect, leading to physiological and developmental abnormalities, and by freezing, causing cellular damage directly. Chilling and freezing injury can directly affect crop growth by causing physical damage or by interfering with normal biochemical and physiological functions, thus reducing yield.

Acclimatization to cold stress has been largely studied in conifers of the boreal zone which encounter a considerable combined stress of low temperature and high light during winter when photosynthetic dissipation of energy is blocked. The winter-stressed Scots pine (*Pinus silvestris*) has been shown to accumulate substantial amounts of xanthophylls, essentially zeaxanthin (Ottander *et al.,* 1995).

Effect of atmospheric pollutant stress

Atmospheric pollutants, including several photo oxidants such as O_3, SO_2, NO_2, have caused severe destruction of forests, with degradation of photosynthetic pigments. Mineral deficiency of iron has been observed in ornamental plants (Terry and Abadia, 1986). In such cases, plants show chlorosis of leaves in acropetal manner along with reduction in pigment content.

Many ornamental crops are sensitive to the effects of air pollution as a result of hydrocarbon combustion (Rogers, 1985). Peppers are sensitive to sulfur dioxide injury, resulting in necrotic interveinal tissue. Silvering, bronzing, and sometimes death of lower leaf surfaces may result from exposure to peroxycetyl nitrate (PAN) in susceptible varieties.

In contrast, peppers are resistant to ozone layers, another common air pollutant. Physiological disorders induced by various abiotic stresses and their remedies to overcome them are mentioned in table 5.

Table.1 Classification of ornamental plants based on photoperiod response.

Short day (long night of 10-14 h)	Long day (short night of 8-10 h)	Day-neutral (flowering not influenced by day length)	Long short day	Short long day
Amaranths, Azalea, Bougainvillea, *Cattleya trianae*, Chrysanthemum, China aster, Cosmos, Dahlia, *Euphorbia pulcherimma*, gardenia, Kalanchoe, Morning glory (*Ipomoea hederacea*), Poinsettia, Rieger begonia (called as winter begonia & facultative), Salvia, Tuberous begonia (tuber formation is long night response),Zinnia (facultative)	Antirrhinum, Aster, Bryophyllum (plantlets form along the margins), Calceolaria, Carnation (facultative), Cineraria, *Chlorophyttum comosum*, Dahlia, Easter lily (height increases), *Fuchsia hybrida*, Gypsophilla, Hollyhock, *Oenothera* spp, Petunia, Rex begonia, Rudbeckia, Sweet William, Tuberous begonia	Balsam, Calceolaria, Cineraria, Coleus, Gomphrena, Jasmine, Marigold, Orchids, Rose	Aloe	Campanula, Pelargonium (facultative), White clover

Table.2 Response of plants to environmental parameters in the soil

Parameter	Whole plant response	Changes in phytohormone concentration
Water ↓	Growth ↓	ABA ↑
Oxygen ↓	Growth ↓	ABA ↑, Ethylene (ACC) ↑
Mineral nutrients ↓	Growth ↓	CK ↓, GA ↓
Mineral nutrients ↑	Growth ↓	CK↓, ABA ↑ temperature
Salinity ↑	Growth ↓	CK↓, ABA ↑ temperature
Temperature ↓	Growth ↓	CK ↓, GA ↓, ABA ↑
Soil compactness ↑	Growth ↓	No data

ABA: Abscisic acid; ACC: 1-aminocyclopropane-1-carbohylic acid; CK: Cytokinins; GA: Gibberellin.
[a]Decreased or increased concentration indicated by direction of arrows.

Table.3 Role and deficiency symptoms observed in plants due to mineral nutrients.

Nutrient	Role	Deficiency symptoms
N	* Structural constituent of cells * Vegetative growth * Delay maturity * Synthesis of amino acids, proteins & component of chlorophyll, enzymes	Chlorosis observed in older leaves; stunted growth; late flower production
P	* Growth &development of roots, flowers, seeds * Structural component of membrane system * Essential constituent of DNA, RNA, NADP, ATP & ADP;	Anthocyanin production in older leaves; reduction in yields; available in soil pH 5.5-7.0; readily fixed in soil
K	* Opening & closing of stomata i.e. Osmotic regulation, * Maintains cytoplasm pH * Reduction of lodging of plants * Catalyst for enzyme reaction, protein synthesis, translocation & storage of starch	* Older leaves to new leaves * Necrotic spots in leaves * Weakness of roots & stems leading to lodging; mottled leaves; interveinal chlorosis & leaf curling

	* Sugar translocation * Carotenoid biosynthesis	
Ca	* Maintain membrane integrity as calcium pectate * Maintain chromosome structure * Regulation of enzyme activity	1st appear on shoot tip; tissue formation is incomplete; terminal buds cease to grow & leave blunt end;; margins of young leaves is no formed & results in strap leaves; chlorosis followed by brown scorching of new leaf tips
Mg	* Constituent of chlorophyll, protoplasm & chromosome * Activate enzyme systems * Antagonistic with K ions	1st appear on older leaves, (yellowing of leaf margin); antagonism is prevented when K to Mg ratio is 3: 1 to 4:1 in growing medium
S	* Constituent of cysteine, methionine * Stabilization of protein structure	Chlorosis 1st observed on young leaves; stems of deficient plant become weak, thin, hard & woody
Fe	* Key element of respiration, electron transfer system * Synthesis of chlorophyll & nucleic acid * Reduction of nitrate & sulphates	Interveinal chlorosis 1st observed on younger leaves & become whitish
Mn	* Key element in respiration * Electron transfer in photolysis of water * Activation of enzymes, -CHO metabolism, phosphorylation	Chlorosis on older leaves;
Cu	* Oxidation-reduction reaction * Utilization of protein * Influences water permeability of xylem vessels * Soils high in organic matter are prone to deficiency	Chlorosis on terminal leaves; leaf blade become necrotic; terminal leaves & bud die & whole plant become stunted
Zn	* Synthesis of tryptophan, RNA * Essential for CO_2 evolution and utilization * Important for anaerobic respiration * Sugar regulation & transformation of –CHO. * Essential component of enzymes & enzyme activator * Promotes seed maturation * Formation of auxins and growth promoting substances	Short internodes, little leaf symptoms noticed on old & new leaves; drastic reduction in size of leaves e.g. Kalanchoe is susceptible to Zn deficiency
B	* Salt absorption & translocation of sugars, starch, nitrogen & phosphates * Pollen grain germination & growth * Regulation of stomata opening * Lignifications, xylem differentiation & carbohydrate metabolism * Movements of hormones & sugars * Seed set and fruit development * Cell division & development	* Corky area in cortex * Browning in core region * Suppressed development of terminal /apical bud * Plant produces growth described as witches broom; young leaves thicken & become leathery & chlorotic; stems become hollow & crack
Mo	* Role in N_2 metabolism, protein synthesis; constituent of enzyme- nitrogenous and nitrate reductase. * Availability increases as soil pH increases	Yellow spots in leaves; leaves become pale green & roll up
Cl	* Involved in O_2 evolution in photosynthesis * Maintain turgor pressure in guard cells	* Blotchy leaf chlorosis & necrosis; * Bronzing and wilting of leaves * Stunted growth

Table.4 Salt tolerance of few ornamental plants

Common name	Botanical name	Maximum permissible soil salinity[a] EC (dSm^{-1})	Reference
Very sensitive			
Star jasmine	*Trachelospermum jasminoides*	1-2	Dirr *et al.,*1976; Francois *et al.,*1978; Sonneveld and Voogt, 1983; Wu *et al.,* 2016
Pyrenees cotoneaster	*Cotoneaster congestus*	1-2	”
Photinia	*Photinia x Fraseri*	1-2	”
Red columbine	*Aquilegia canadensis*	1-2	”
Rose, cv. Grenoble	*Rosa* spp.	2-3	”
Southern yew	*Podocarpus macrophyllus*	2-3	”
Tulip tree	*Liriodendron tulipifera*	2-3	”
Algerian ivy	*Hedera canariensis*	3-4	”
Japanese pittosporum	*Pittosporum tobira*	3-4	”
Chinese hibiscus	*Hibiscus rosa-sinensis*	3-4	”
Laurustinus, cv. Robustum	*Viburnum tinus*	3-4	”
Crape myrtle	*Lagerstroemia indica*	3-4	”
Aster	*Aster spp.*	3-4	”
Poinsettia	*Poinsettia pulcherrima*	3-4	”
Gladiolus	*Gladiolus x hybridus*	3-4	”
Azalea	*Rhododendron spp.*	3-4	”
Gardenia	*Gardenia jasminoides*	3-4	”
Gerbera	*Gerbera jamesonii*	3-4	”
Amaryllis	*Amaryllis belladonna*	3-4	”
African violet	*Saintpaulia ionantha*	3-4	”
Yellow sage	*Lantana camara*	4-6	”
Orchid tree	*Bauhinia purpurea*	4-6	”
Southern magnolia	*Magnolia grandiflora*	4-6	”
Japanese boxwood	*Buxus microphylla*	4-6	”
Japanese black pine	*Pinus thunbergiana*	4-6	”
Indian hawthorn	*Raphiolepis indica*	4-6	”
Spreading juniper	*Juniperus chinensis*	4-6	”
Cardinal flower	*Lobelia cardinalis*	4-6	”
Hawaiian heather	*Cuphea hyssopifolia*	4-6	”
Small scabious	*Scabiosa columbaria*	4-6	”
Weeping bottlebrush	*Callistemon viminalis*	6-8	”
Oleander	*Nerium oleander*	6-8	”
Blue dracaena	*Cordyline indivisa*	6-8	”

Rosemary	*Rosmarinus officinalis*	6-8	”
Texas firecracker	*Anisacanthus quadrifidus* var. wrightii	6-8	”
Rock rose	*Pavonia lasiopetala*	6-8	”
Blue mist	*Caryopteris* x *clandonensis* ‘Dark knight’	6-8	”
Chrysanthemum	*Chrysanthemum morifolium*	6-8	”
Carnation	*Dianthus caryophyllus*	6-8	”
Stock	*Matthiola incana*	6-8	”
Brush cherry	*Syzygium paniculatum*	> 8[b]	”
Natal plum	*Carissa grandiflora*	> 8[b]	”
Bougainvillea	*Bougainvillea spectabilis*	> 8[b]	”
Italian stone pine	*Pinus pinea*	> 8[b]	”
Rosea iceplant	*Drosanthemum hispidum*	> 10[b]	”
Purple iceplant	*Lampranthus productus*	> 10[b]	”
Croceum iceplant	*Mesembryanthemum croceus*	> 10[b]	”
Orange cestrum	*Cestrum auruantiacum* ‘Orange Peel’	> 10[b]	”
Hummingbird plant	*Dicliptera suberecta*	> 10[b]	”

EC_e, electrical conductivity of the saturated-soil extract.
[a] Salinities exceeding the maximum permissible EC_e may cause leaf burn, loss of leaves, and/or excessive stunting.
[b] Maximum permissible EC_e is unknown. No injury symptoms or growth reduction was apparent at 7 dSm^{-1}. The growth of all ice plant species was increased by soil salinity of 7 dSm^{-1}.

Table.5 Physiological disorders and their remedies in ornamental plants.

Name of disorder	Cause(s)	Remedies
Alstroemeria		
Flower abortion	Excessive salt or over watering	**Maintain salt concentration & irrigation**
Carnation		
Sleepiness (temporary or permanent wilting of flowers)	Ethylene injury; Ca deficiency or high-water stress	**Do not transport with ethylene releasing plants; maintain proper moisture**
Calyx splitting	Night temperature < 10^0C; low B nutrient	**Maintain proper night temperature & micronutrient supply**
Curly tip (poor flower quality)	Low light, low temperature, water stress & B deficiency	**Maintain adequate light, temperature & moisture condition & sprays boron**
Chrysanthemum		
Crooked stem	Day night temperature variation	**Maintain day/ night temperature**
Crown buds	Insufficient light	**Maintain proper light**
Heat delay	High temperature (>28^0C) during production	**Maintain temperature**
Tip scorch	Calcium deficiency	**Spray $CaNO_3$ @ 1%**

Lilium-		
Leaf tip burn or leaf scorch	Excess Mn and Al salts in soil, high fluoride level, high relative humidity	**Spray 70 mM Calcium nitrate**
Bud blast or bud abortion	Low light and ethylene	**Apply silver thiosulphate (STS) in standing crop**
Leaf yellowing	Easter lilies & Oriental hybrids are highly susceptible. Root rot, over watering, moisture stress, etc.	**Spray 100 ppm Promalin or Accel**
Bulb split	Aphids & high greenhouse temperature	**Maintain humidity**
Puffy foliage	Frost injury	**Maintain proper temperature in green house**
Gladiolus-		
Crooked stem	Water stress	**Maintain proper moisture**
Topple & bud rot	Calcium deficiency	
Blindness	Unfavorable temperature	**Maintain proper temperature**
Flower blasting	Low light intensity	**Maintain proper light intensity**
Orchids		
Bud loss	Occurs from flower sticks during flowering phase due to excess high temperature about light intensity	**-**
Dripping spikes and leaves	Moisture drops from stem	**-**
Loss of glossiness in flowers	Lack of potassium; high humidity with dark conditions.	**Maintain humidity**
Sunken spots on foliage	Stress/ excess of light intensity	**Maintain proper light intensity**
Dry sepal injury	High humidity & smog	**Maintain proper humidity**
Deformed flowers (flowers with an abnormal number of petals/ lip are called 'peloric'	Low temperature & chilling injury (a genetic trait but expression is environmentally influenced & appears random.	**-**
Rose		
Blind shoot	Low light intensity & prolonged exposure to low temperature	**Maintain proper temperature**
Tuberose		
Stem cracking	Calcium deficiency	**Maintain calcium level in nutrition**
Gerbera		
Stem bending	Calcium deficiency	**Maintain calcium level in nutrition**
Uneven stem length	High chlorides, water stress & reduced soil temperature	**Maintain proper Ca & water condition**
Browning of leaf veins & necrosis	Phosphorous deficiency	**Maintain proper nutrition**
Leaf burning from edge to inside	**Potassium deficiency**	**Maintain proper nutrition**

Table.6 Resistant species and cultivars with improved traits.

S. No.	Crop	**Species & Cultivar(s)**	**Improved Trait**	**Reference**
1.	Carnation	*Dianthus japonicus*	Heat tolerance	Niu *et al.,* 2013
2.	Chrysanthemum	Pudijin, Beilinhuang, Guoqingzi, Liujinsuiyue, Chongbanwanhuang	Drought tolerance	Lu *et al.,* 2012
3.	Chrysanthemum	6 putative hybrid lines by crossing *C. gradiflorum* x *C. indicum*	Drought tolerance	Sun *et al.,* 2010
4.	Chrysanthemum	*C.* x *hybridum*, *C. rubellum*, Twilight Pink Daisy, Red Daisy, White Daisy, Coral Daisy	Frost tolerance	Anderson *et al.,* 2012
5.	Chrysanthemum	*Chrysanthemum* cv. Zhongshanjingui (Anemone type) x *Ajania przewalskii* (non-anemone type)	Cold tolerance	Deng *et al.,* 2012
6.	Chrysanthemum	*Dendranthema morifolium* x wild diploid relative *D nankingense* & adopting ovary rescue technique	Cold tolerance	Cheng *et al.,* 2010
7.	Chrysanthemum	*C.* x *morifolium* cv. Maoyan x *Artemisia japonica*; *C. chanetii*	Salt tolerance	Zhu *et al.,* 2013
8.	Chrysanthemum	Delano, Yellow Mandalay, Sunny Mandalay	Heat tolerance	Kaicker *et al.,* 1986
9.	Chrysanthemum	Apricot Miros, Bronze Miros, Dark Miros, Golden Horim, White Horim, Red Chief, Duluth, Minngopher, Maxi-Mum, My Favorite (γ-rays)	Frost tolerance	Ascher *et al.,* 1997
10.	Clematis	'Blue Boy', a cross of *C. integrifolia* x *C. viticella*	Cold tolerance	Beskaravainaya *et al.,* 1978
11.	Impatiens	*Impatiens usambarensis*, Accent Pink, Dazzler Pink & Dazzler White	Heat tolerance	Beskaravainaya *et al.,* 1978
12.	Lilium	*L.* x *formolongi, L. candidum*	Cold tolerance	Rhee *et al.,* 2018
13.	Rose	*Rosa damascena*, Edouard, *R. rubiginosa*; *R.* x *fortuniana*, *R.* 'Manetti', *R. arkansana, R. laxa*, *R. clinophylla*, *R. bracteata*, Belinda's Dream, Little Buckaroo, Rise N Shine, Sea Foam, Basye's Blueberry, New Dawn	Heat tolerance	De Vries,1976; Cabrera, 2003; Wahome *et al.,* 2001; Niu *et al.,* 2008
14.	Rose	*R. chinensis* 'Major' & *R. hybrida* 'Natal Briar' rootstock; *R. rubiginosa*; *R. multiflora* 'Thumb'; *R. odorata*	NaCl tolerance	Cabrera, 2003; Wahome *et al.,* 2001 Niu *et al.,* 2008
15.	Rose	*R. chinensis*	Freezing & drought tolerance	Cabrera, 2003; Wahome *et al.,* 2001; Niu *et al.,* 2008
16.	Rose	*R. rugosa*	Heat & salinity tolerance	Cabrera, 2003; Wahome *et al.,* 2001; Niu *et al.,* 2008
17.	Rose	*R. hydrida* cv. Front N Center™	Drought tolerance	Cabrera, 2003; Wahome *et al.,* 2001; Niu *et al.,* 2008

Table.7 Investigated genes in ornamental crops for imparting abiotic stress tolerance.

Sl. no.	Crop/ cultivar	Gene(s)	Trait improved	Reference
1.	*Arabidopsis thaliana*	*R_2R_3-MYB* transcription factor	Increased drought & salinity tolerance	Chen *et al.,* 2011
2.	*Anthurium andreaum*	***AabHLH35* Transcription factor**	Improved freezing & drought tolerance	Jiang *et al.,* 2019
3.	*Chrysanthemum grandiflorum*	Heterologous expression of *CgDREBa*	Enhanced drought & salinity tolerance; retain more fresh weight in stress	Chen *et al.,* 2011
4.	*Chrysanthemum morifolium*	*CmPLDa*	Drought tolerance	Zhai *et al.,* 2021
5.	*Chrysanthemum morifolium*	*CmDREB6*	Tolerance to heat stress	Du *et al.,* 2018
6.	*Chrysanthemum morifolium* cv. Jinba	*CmWRKY1* transcription factor	Increased drought tolerance	Fan *et al.,* 2016
7.	*Chrysanthemum morifolium* cv. Jinba	*DgTIL1*	Cold tolerance	Huang *et al.,* 2021
8.	*Chrysanthemum morifolium* cv. Zhongshanzigui	*CgHSP70*	Drought tolerance	Song *et al.,* 2014
9.	*Dendranthema grandiflora*	*DgC3H1, CCH* zinc finger protein gene	Increased cold tolerance	Boi *et al.,* 2021
10.	*Chrysanthemum morifolium*	Phosphomannose-isomerase (*Pmi*) &*Vgb* (from bacterium *Vitreoscilla stercoraria*)	Water logging tolerance & antibiotic resistance	He *et al.,* 2004
11.	*Chrysanthemum morifolium*	*CmBBX19*	Drought tolerance	Xu *et al.,* 2020
12.	*Chrysanthemum morifolium*	*CmBBX24* (a zinc finger transcription factor gene)	Modulation of abiotic stress tolerance & initiation of flowering	Yang *et al.,* 2014
13.	*Chrysanthemum morifolium*	*CmRH56*	Drought stress tolerance	Zhang *et al.,* 2022a
14.	*Chrysanthemum morifolium*	*CmSCL4*	Drought tolerance	Zhang *et al.,* 2022b
15.	*Chrysanthemum morifolium*	*DgMYB2*	Cold tolerance	Yang *et al.,* 2022
16.	*Chrysanthemum morifolium*	*DgC3H1*	Cold tolerance	Bai *et al.,* 2021
17.	*Chrysanthemum grandiflorum*	*CdlCE1*	Cold, drought & salinity tolerance	Chen *et al.,* 2012
18.	*Chrysanthemum lavendulifolium*	*ClNAC9*	Saline, alkaline & drought stress tolerance	Liu *et al.,* 2019
19.	*Dendranthema grandiflora* cv. Fall Colour	*AtDREB1A*	Cold, salt, drought & heat stress tolerance	Hong *et al.,* 2006a; Hong *et al.,* 2006b; Hong *et*

				al.,2009
20.	*Dendranthema grandiflora*	*DgWRKY1*, *DgWRKY2*, *DgWRKY4* & *DgWRKY5* transcription factor	Enhanced salinity tolerance	Li *et al.,* 2015; He *et al.,* 2018; Wang *et al.*,2017
21.	*Dianthus caryophyllus*	*DcaHsf A2a, A2b*	Involved in heat & drought stress response	Li *et al.,* 2018
22.	*Gerbera jamesonnii*	Arabidopsis Ca^{2+}/H^{+} antiporter gene (*CAX1*)	Improved cold tolerance	Chung *et al.,* 2016
23.	*Nelumbo nucifera*	*NnCIPK* (calcineurin B-like protein kinase) gene	Enhanced salinity tolerance in cv. Welcoming Guests	Liu *et al.,* 2014
24.	*Petunia* x *hybrida*	*AtCBF-3* gene from *Arabidopsis*	Enhanced freezing tolerance	Pennycooke *et al.,* 2003; Warner *et al.,* 2010
25.	*Petunia* x *hybrida*	*AtNHX1*	Drought & salinity tolerance	Xu *et al.,* 2009
26.	*Phalaenopsis amabilis*	*LTP* (liquid transfer protein) gene from rice	Enhanced cold tolerance	Qin *et al.,* 2014
27.	*Rosa chinensis*	*RcXET* & *MtDREBIC*	Better drought & freezing tolerance	Chen *et al.,* 2016
28.	*Rosa chinensis*	*AtDREB2A-CA*	Increased salinity tolerance	Josine *et al.,* 2015
29.	*Rosa chinensis*	*RcHSP*17.8	More salinity tolerance	Jiang *et al.,* 2009
30.	*Rosa rugosa*	*RrNHX1*	Increased salinity tolerance	Feng *et al.,* 2015
31.	*Rosa rugosa* cv. Dagmar Hastrup	*RhDHN5*	Cold stress tolerance	Ouyang *et al.,* 2020
32.	*Rosa hybrida* cv. Chandos Beauty	*RhBAM3*, *RhR56*, *RhGK*	Cold stress tolerance	Ouyang *et al.,* 2020
33.	*Rosa multiflora*	*RmMYB108*	Cold, freeze, salt & drought tolerance	Dong *et al.,* 2011
34.	*Rosa hybrida*	*RhNAC2* & *RhEXPA4*	Drought tolerance during petal expansion	Dai *et al.,* 2012

Figure.1 Flow chart of nanoparticles entering in ornamental plant cells.

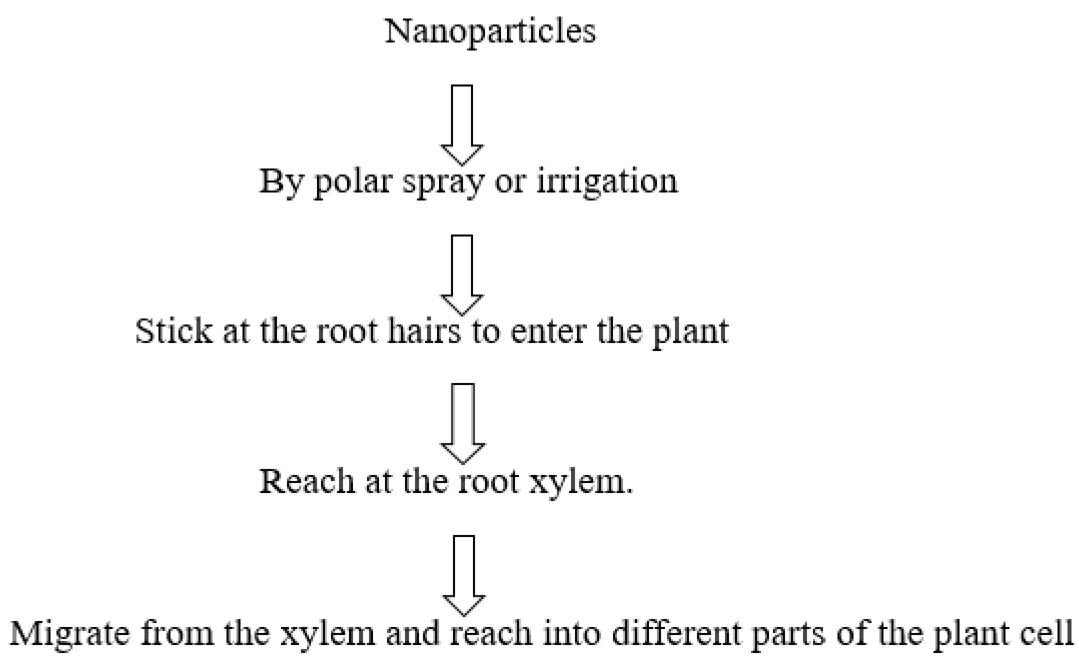


Figure.2 Positive transcriptomic modifications induced by NPs to increase the abiotic stress tolerance in plants. Red arrows indicate an increase in tolerance to abiotic stress.

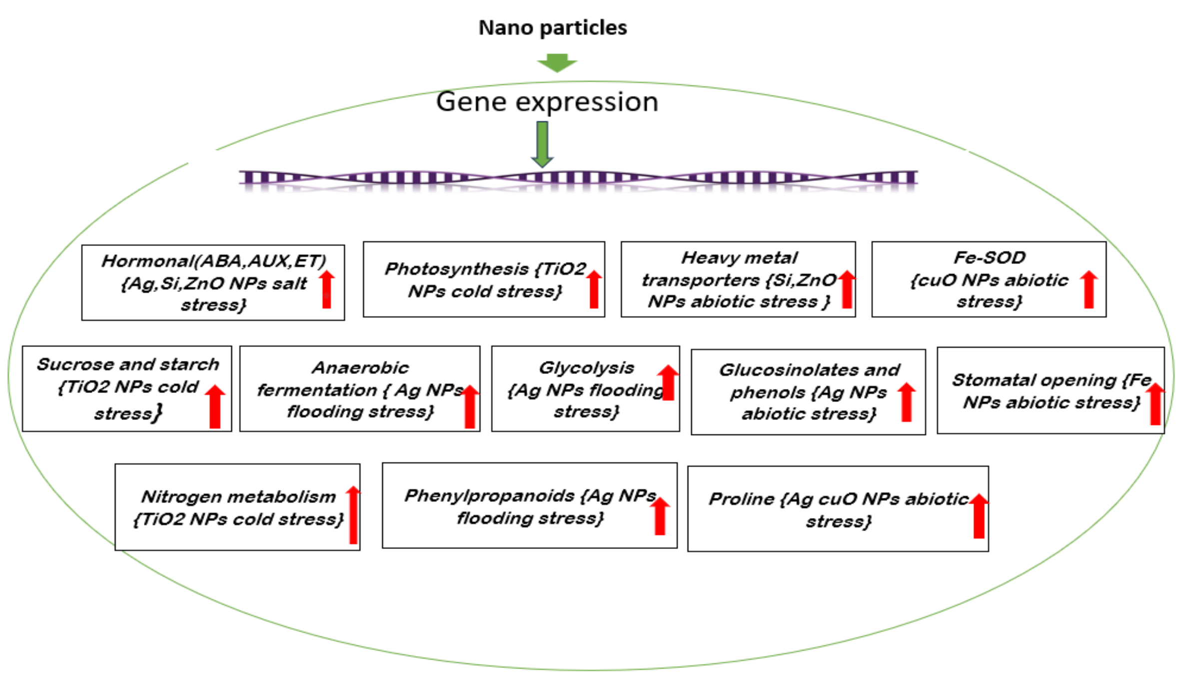
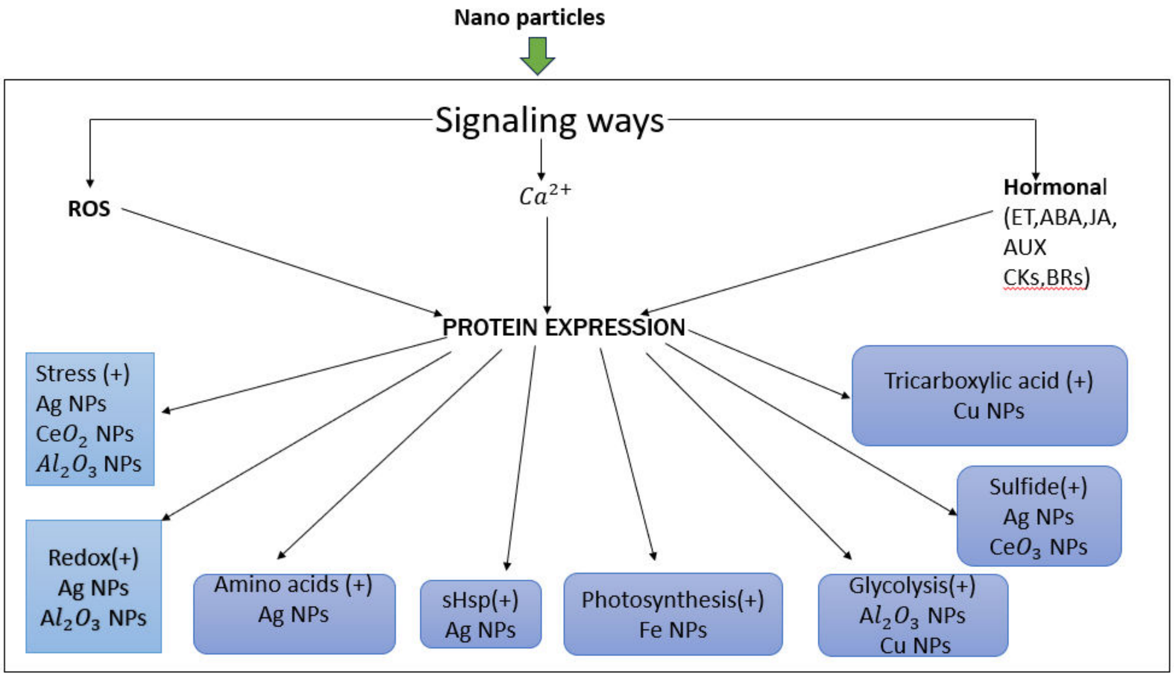


Figure.3 Positive proteomic modifications induced by NPs in plants under the abiotic stress condition.



Mitigating strategies for abiotic stress

Since abiotic stresses are major environmental constraints for crop production and productivity, finding approaches to enhance stress tolerance/ resistance is crucial to increasing crop production and food security. In this regard, several strategies have been developed and adopted timely. Many rose plants are produced at the commercial level by grafting rootstocks with resistance. The salt resistance rootstocks play a significant role in preventing damage in rose quality and yield under salinity stress. To cope with heat stress, the plants implement various mechanisms like maintenance of membrane stability, scavenging of reactive oxygen species (ROS), production of antioxidants, accumulation and adjustment of compatible solutes, induction of mitogen-activated protein kinase (MAPK), and calcium-dependent protein kinase (CDPK) cascades and most importantly chaperone signaling and transcriptional activation.

Drought escape using adjusting the flowering time, where a short life cycle can lead to drought escape (Araus *et al.,* 2002). The characteristics such as root biomass (extensive & prolific root system), length, density, and depth are the main drought avoidance traits to avoid drought by the plants (Subbarao *et al.,* 1995). In addition, waxiness on leaves is considered as a desirable trait for drought tolerance as it helps in the maintenance of high tissue water potential (Richards *et al.,* 1986; Ludlow and Muchow, 1990).

Plant defense systems play a significant role in providing primary protection against many stress conditions. Mitigation of drought includes exploring the plant's adaptations against the stress conditions such as C_4 or CAM metabolism morphological adaptations; thick cuticular layer and wax layer, depressed stomata or regulation of the size of stomatal opening and high density of trichomes; physiological response such as dormancy, exploration of native species adaptive well to the frequently occurring drought stress conditions and many more.

Classical breeding approaches

With the efforts of breeders, using classical breeding approaches, resistance or tolerance to abiotic stress has been imparted in commercial flower crops. Development of abiotic stress tolerant varieties via introgression breeding. The natural and artificial selection in heterogeneous populations of crop plants should increase the frequency of genes for temperature extremes. Natural as well as artificial selection would not only be useful for temperature stress but for other stresses also. For selection to be effective there must be genetic variation which can be identified and distinguished from environmental variations.

Wide and distant hybridization (inter-specific and/or inter-generic hybridization) has contributed positively to improving drought, salt and heat tolerance in numerous ornamental crops through introducing abiotic stress-tolerant traits from their wild relatives. It has potential to combine useful traits, i.e. favorable morphology and some environmental tolerance, of both parents, that could not be achieved by crossing within a single species.

If the genes for stress tolerance are not available in cultivated types, they can be transferred from wild relatives/species. Through *vitro* mutagenesis, (Hossain *et al.,* 2006) developed a table form of NaCl tolerant chrysanthemum (*C morifolium*) using ethylmethanesulfonate (EMS) as a chemical mutagen. A tetraploid *Dendranthema nankingense* was induced by the colchicine treatment using nodal segments and found to have enhanced drought and salt tolerance by alleviating oxidative stress, maintaining good water balance, and higher chlorophyll (a + b) content (Liu *et al.,* 2011). Screening of these cultivars under field as well as under artificial conditions will bring out resistant/ tolerant cultivars to various stresses (Table.6). Hybridization and *in-vitro* mutations can be tried in the case of ornamental crop plants for building cold stress tolerance with limited success due to the complexity associated with the traits controlling the cold stress character.

Genetic engineering approaches

Conventional plant breeding has not been proved that much successful in addressing abiotic stress mitigation so far because of their own merits and demerits. The reason might be that the time required in developing a resistant or tolerant variety and traits are controlled by a number of genes present at a quantitative trait locus (QTL). In flower crops, potential genes like *AREB/ABF* TFs, *AP2/ERF*, NAC TFs, bZIP TFs, *MYC*, and *MYB* have been implicated in drought stress response. The *CBF* genes encode *AP2/ERF* (*APETALA2*/Ethylene-Responsive Factor) transcription factors to initiate cold stress responses in plants. Genes such as Na+/H+ antiporter genes (*AtNHX1, AtSOS1*), *DREB1A*, *SOS1*, *ICE1*, *WRKY4*, *NAC1*, *SOS3*, etc. have been identified for imparting salt tolerance in flower crops. Heat shock transcription factors (HSFs) mediate the expression of heat shock protein, where several genes have been shown to impart heat tolerance such as *HSP70*, *FaHsfA2c*, etc.

In the case of ornamental plants due to constraints of limited genetic resources and other well-known constraints of conventional breeding programs, molecular and transgenic approaches offer much potential. Genetic analysis of *Chrysanthemum rhombifolium*, a highly resistant plant to harsh environments, revealed 130, and 891 unigenes, out of which about 2459 unigenes were designated to be involved in stress tolerance. This plant has been identified as a new plant resource of stress-tolerant genes (Zhang *et al.,* 2021).

Systematic genomic analysis to identify genes or transcription factors related to abiotic stress tolerance which might serve as candidate genes for breeding stress-tolerant ornamental plants will be of great significance. Genes isolated for imparting abiotic stress tolerance were summarized in table.7.

Role of soil microbes

Soil microbes, especially Vesicular Arbuscular Mycorrhiza (VAM) fungi viz. *Glomus fasciculatum*, *G. mosseae*, *G. etunicatum*, *G. tenue* improve mineral nutrient and water status of plants under abiotic stresses. Genus *Glomus* of VAM is predominant in neutral to alkaline Mediterranean soils, besides in mineral deficient and drought-stressed habitats. *Glomus fasciculatum* increases the tolerance of plants to a wide variety of stresses such as salinity, drought, high soil temperature, adverse pH, toxic and heavy metals, etc.

Navarro *et al.,* (2012) conducted research to study the response of carnation plants against salinity and reported that when plants were injected with different strains, *Glomus intradices* showed tolerance against saline environment. Further, leaf color, flowers, flower size, flower number and plant growth were also improved by the combination of injected mycorrhiza with adequate saline concentration.

Role of Nanoparticles in alleviating abiotic stress in ornamental plants

Nanoparticles (NPs) technology is a well-developed technology widely used in all sectors. Agriculture is making high profits by using this technology and this can involve overcoming the biotic and abiotic stress problems in food and ornamental crops (Labrada *et al.,* 2020). Nowadays, by using these nanoparticles fertilizers farmers are getting good profits in ornamental crops, because this nanoparticle contain physiochemical properties i.e. high surface, high reactivity, and tunable pore size. However, these nanoparticles' size is very small, and these NPs will travel easily from the root system and accumulate in the plant cells (Taylor *et al.,* 2014). These nanoparticles overcome the problems from environmental factors, and they control the ROS (Reactive Oxygen Species) in the plant cells and ensure that the plant metabolites are done properly. Moreover, nanoparticles enter into the plants and increase the growth, photosynthesis, antioxidative enzymes, and gene expression levels of the plants. It involves biochemical, physiological, and genetic adjustments of plant cells and ensures that plants survive for longer periods to give a good yield (Labrada *et al.,* 2020; Suzuki *et al.,* 2012; Banavath *et al.,* 2022). How the nanoparticles enter into plant cells and influence on the metabolites is shown in Fig. 1 & 2. So far different concentrations of FeNPs, ZnONPs, Al_2O_3 NPs, Cuo NPs, Si NPs, TiO_2NPs, and AuNPs (Gold NPs), etc. have been used on agricultural and ornamental crops to get the benefits (Labrada *et al.,* 2020; Siddiqui *et al.,* 2015). After metabolic reactions different proteomic modifications occur in the plant cells as shown in Figure 3.

The impact of global climate change on crop production has emerged as a major research priority during the past decade. Promising varieties with abiotic stress resistance or tolerance can be utilized for breeding programs and for commercial cultivation. We believe that by comparing different genes and genetic combinations, researchers will be able to advance the field more quickly and develop stress-tolerant germplasm. Employing transgenic technology will help to combat production constraints like abiotic stress and help in quality improvement.

Transcriptomics analysis has been done in a limited number of flower crops, such as chrysanthemums, roses, and carnations. Therefore, such studies in other commercially important ornamental crops are needed to decipher the important genes regulating abiotic stress responses. Also, seeing the enormous diversity in the ornamental crop or floriculture sector, researchers have ample opportunities in this field for deciphering the complex mechanisms of abiotic stress tolerance. Nanotechnology is giving additional support to ornamental and crops to improve their productivity by minimizing the problems that will occur from the biotic and abiotic stress. There is a greater need to develop crops with nanoparticle fertilizers and pesticides in the present growing population scenario.

Author's Contributions

BJN & MSP: Conceptualization, research supervision, writing of the original draft manuscript; SMJ & DMR: Methodology, formal analysis, research investigation; BJN, MSP, and VBN: Visualization, review, and editing of the manuscript. All authors have read and agreed to the published version of the manuscript.

Data Availability

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish Not applicable.

Conflict of Interest The authors declare no competing interests.

References

Adachi, M., Kawabata, S., and Sakiyama, R. Effects of temperature and stem length on changes in carbohydrate content in summer-grown cut chrysanthemums during development and senescence. Postharvest Biology and Technology, 2000, 20(1): 63–70. https://doi.org/10.1016/S0925-5214(00)00106-X

Ali, E., Bazaid, S., and Hassan, F. Salinity tolerance of Taif roses by gibberellic acid (GA3). International Journal of Science and Research, 2014, 3(3): 184–192.

Anderson, N.O., and Gesick, E. Phenotypic markers for selection of winter-hardy garden chrysanthemum (Dendranthema × grandiflora Tzvelev) genotypes. Scientia Horticulturae, 2004, 101(1–2): 153–167. https://doi.org/10.1016/j.scienta.2003.10.006

Anderson, N.O., Gesick, E., Ascher, P.D., Poppe, S., Yao, S., Wildung, D., Johnson, P., Fritz, V., Rohwer, C., Klossner, L., Eash, N., Liedl, B.E., and Reith-Rozelle, J. Mammoth 'Twilight Pink Daisy' garden chrysanthemum. Hort Science, 2012, 47(9): 1182–1186. https://doi.org/10.21273/HORTSCI.49.12.1600

Araus, J.L., Slafer, G.A., Reynolds, M.P., and Royo, C. Plant breeding and drought in C3 cereals: What should we breed for? Annals of Botany, 2002, 89(7): 925–940. https://doi.org/10.1093/aob/mcf049

Ascher, P.D., Anderson, N.O., Fritz, V., Perillo, C., Poppe, S., Wagner, R., and Wildung, D. [Online]. Retrieved from http://www.extension.umn.edu/distribution/horticulture/components/6728-01.html

Aydinsakir, K., Tepe, A., and Buyuktas, D. Effects of saline irrigation water applications on quality characteristics of Freesia grown in greenhouses. Akdeniz Üniversitesi Ziraat Fakültesi Dergisi, 2010, 23(1): 41–46.

Bai, H., Lin, P., Li, X., Liao, X., Wan, L., Yang, X., Luo, Y., Zhang, L., Zhang, F., Liu, S., and Liu, Q. DgC3H1, a CCCH zinc finger protein gene, confers cold tolerance in transgenic chrysanthemum. Scientia Horticulturae, 2021, 281: 109901. https://doi.org/10.1016/j.scienta.2021.109901

Banavath, J.N., Ganesh, S., Kim, S.-C., Mekapogu, M., Chinreddy, S.R., Ramasubba Reddy, P., Manu, K., Kim, S.-Y., and Lee, S.-H. CRISPR/Cas9 and nanotechnology pertinence in agricultural crop refinement. Frontiers in Plant Science, 2022, 13: 1–12. https://doi.org/10.3389/fpls.2022.843575

Berry, J., and Bjorkman, O. Photosynthetic response and adaptation to temperature in higher plants. Annual Review of Plant Physiology, 1980, 31(1): 491–543. https://doi.org/10.1146/annurev.pp.31.060180.002423

Beskaravainaya, M., Donyushkina, E., and Elmanova, T. Frost resistance of various Clematis species. Byulleten Gosudarstvennogo Nikitskogo Botanicheskogo Sada, 1978, 3: 65–69.

Blumwald, E., Gilad, S.A., and Maris, P.A. Sodium transport in plant cells. Biochimica et Biophysica Acta - Biomembranes, 2000, 1465(1–2): 140–151. https://doi.org/10.1016/S0005-2736(00)00135-8

Boi, H., Lin, P., Li, X., Liao, X., Wan, L., Yang, X., Luo, Y., Zhang, L., Zhang, X., Liu, S., and Liu, Q. DgC3H1, a CCCH zinc finger protein gene, confers cold tolerance in transgenic chrysanthemum. Scientia Horticulturae, 2021, 281: 109901–109907. https://doi.org/10.1016/j.scienta.2021.109901

Cabrera, R.I. Demarcating salinity tolerance in greenhouse rose production. Acta Horticulturae, 2003, 609: 51–57. https://doi.org/10.17660/ActaHortic.2003.609.5

Cabrera, R.I., Solis-Perez, R.A., and John, J.S. Greenhouse rose yield and ion accumulation responses to salt stress as modulated by rootstock selection. Hort Science, 2009, 44(6): 2000–2008. https://doi.org/10.21273/HORTSCI.44.7.2000

Cai, X., Niu, G., Starman, T., and Hall, C. Response of six garden roses (Rosa × hybrida L.) to salt stress. Scientia Horticulturae, 2014, 168: 27–32. https://doi.org/10.1016/j.scienta.2013.12.032

Cai, X., Sun, Y., Starman, T., Hall, C., and Niu, G. Response of 18 Earth-Kind® rose cultivars to salt stress. Hort Science, 2014, 49(5): 544–549. https://doi.org/10.21273/HORTSCI.49.5.544

Cha-um, S., and Kirdmanee, C. In vitro flowering of miniature roses (Rosa × hybrida L. "Red Imp") in response to salt stress. European Journal of Horticultural Science, 2010, 75(6): 239–245.

Chen, J.R., Chen, Y.B., Ziemiańska, M., Liu, R., Deng, Z.N., Niedźwiecka-Filipiak, I., Li, Y.L., Jio, J.X., and Xiong, X.Y. Co-expression of MtDREB1C and RcXET enhances stress tolerance of transgenic China rose (Rosa chinensis Jacq.). Plant Growth Regulation, 2016, 35(4): 586–599. https://doi.org/10.1007/s00344-015-9564-z

Chen, L., Chen, Y., Jiang, J., Chen, S., Chen, F., Guan, Z., and Fang, W. The constitutive expression of *Chrysanthemum dichrum* ICE1 in *Chrysanthemum grandiflorum* improves the level of low temperature, salinity, and drought tolerance. Plant Cell Reports, 2012, 31(9): 1747–1758. https://doi.org/10.1007/s00299-012-1288-y

Chen, S., Jiang, J., Gu, C., and Li, P. Heterologous expression of the chrysanthemum R2R3-MYB transcription factor CmMYB2 enhances drought and salinity tolerance, increases hypersensitivity to ABA, and delays flowering in *Arabidopsis thaliana*. Molecular Biotechnology, 2011, 51(1): 150–173. https://doi.org/10.1007/s12033-011-9451-1

Cheng, X., Chen, S., Chen, F., Fang, W., Deng, Y., and She, L. Interspecific hybrids between *Dendranthema morifolium* (Ramat.) Kitamura and *D. nankingense* (Nakai) Tzvel achieved using ovary rescue and their cold tolerance characteristics. Euphytica, 2010, 172: 101–108. https://doi.org/10.1007/s10681-009-0056-8

Chung, M.Y., Kim, M.B., Chung, Y.M., Nou, I.S., and Kim, C.K. In vitro shoot regeneration and genetic transformation of gerbera (*Gerbera hybrida* Hort.) cultivar 'Gold Eye'. Journal of Plant Biotechnology, 2016, 43(3): 255–260. http://dx.doi.org/10.5010/JPB.2016.43.2.255

Coakley, S.M., Scherm, H., and Chakraborty, S. Climate change and plant disease management. Annual Review of Phytopathology, 1999, 37: 399–426. https://doi.org/10.1146/annurev.phyto.37.1.399

Dai, F., Zhang, C., Jiang, X., Kang, M., Yin, X., Lu, P., Zhang, X., and Zheng, Y. *RhNAC2* and *RhEXPA4* are involved in the regulation of dehydration tolerance during the expansion of rose petals. Plant Physiology, 2012, 160(4): 2064–2082. http://dx.doi.org/10.1104/pp.112.207720

De Vries, D.P. Juvenility in hybrid-tea roses. Euphytica, 1976, 25(1): 321–328. https://doi.org/10.1007/BF00041529

Dela, G., Or, E., Ovadia, R., Nissim-Levi, A., Weiss, D., and Oren-Shamir, M. Changes in anthocyanin concentration and composition in 'Jaguar' rose flowers due to transient high-temperature conditions. Plant Science, 2003, 164(3): 333–340. https://doi.org/10.1016/S0168-9452(02)00417-X

Demming, B., Winter, K., Krunger, A., and Czygan, F.G. Zeaxanthin and the heat dissipation of excess light energy in *Nerium oleander* exposed to a combination of high light and water stress. Plant Physiology, 1988, 87(1): 17–24. https://doi.org/10.1104/pp.87.1.17

Deng, Y.M., Chen, S.M., Chen, F.D., Cheng, X., and Zhang, F. The embryo rescue-derived intergeneric hybrid between *Chrysanthemum* and *Ajania przewalskii* shows enhanced salt tolerance. Plant Cell Reports, 2011, 30(12): 2177–2186. https://doi.org/10.1007/s00299-011-1123-x

Dirr, M.A. Selection of trees for tolerance to salt injury. Journal of Arboriculture, 1976, 2(9): 209–216. https://doi.org/10.48044/jauf.1976.053

Dong, J., Cao, L., Zhang, X., Zhang, W., Yang, T., Zhang, J., and Che, D. An R2R3-MYB transcription factor *RmMYB108* responds to chilling stress of *Rosa multiflora* and conferred cold tolerance of *Arabidopsis*. Frontiers in Plant Science, 2021, 12: 1–10. http://dx.doi.org/10.3389/fpls.2021.696919

Du, X., Li, W., Sheng, L., Deng, Y., Wang, Y., Zhang, W., Yu, K., Jiang, J., Fang, W., and Guan, Z., Chen, S. Over-expression of chrysanthemum *CmDREB6* enhanced tolerance of chrysanthemum to heat stress. BMC Plant Biology, 2018, 18(1): 1–10. https://doi.org/10.1186/s12870-018-1400-8

Erwin, J.E. Ivy geranium production. Ohio Floriculture Bulletin, 1999, 831: 15–20.

Erwin, J.E., and Engelen, G. Regal geranium production. Minnesota Commercial Flower Growers Bulletin, 1992, 41: 1–9.

Erwin, J.E., and Heins, R.D. Environmental effects on geranium development. Minnesota Commercial Flower Growers Bulleti*n*, 1992, 41: 1–9.

Erwin, J.E., and Kovanda, B. Fuchsia production. Minnesota Commercial Flower Growers Bulletin, 1990, 1–3.

Fan, Q., Song, A., Jiang, J., Zhang, T., Sun, H., and Wang, Y. CmWRKY1 enhances the dehydration tolerance of chrysanthemum through the regulation of ABA-associated genes. PLoS ONE, 2016, 11(3): e0150572. https://doi.org/10.1371/journal.pone.0150572

Farooq, M., Wahid, A., Kobayashi, N., Fujita, D., and Basra, S.M.A. Plant drought stress: effects, mechanisms and management. Agronomy for Sustainable Development, 2009, 29: 185–212. https://doi.org/10.1051/agro:2008021

Feng, L., Ding, H., Wang, J.I.A., Wang, M., Xia, W., Zang, S., and Sheng, L. Molecular cloning and expression analysis of RrNHX1 and RrVHA-c genes related to salt tolerance in wild *Rosa rugosa*. Saudi Journal of Biological Sciences, 2015, 22(4): 417–423. https://doi.org/10.1016/j.sjbs.2015.01.008

Fox, L.J., Grose, J.N., Appleton, B.L., and Donohue, S.J. Evaluation of treated effluent as an irrigation source for landscape plants. Journal of Environmental Horticulture, 2005, 23(4): 174–178. https://doi.org/10.24266/0738-2898-23.4.174

Francois, L.E., and Clark, R.A. Salt tolerance of ornamental shrubs, trees, and ice plant. Journal of the American Society for Horticultural Science, 1978, 103(2): 280–283. https://doi.org/10.21273/JASHS.103.2.280

Gitonga, V.W., Koning-Boucoiran, C.F., Verlinden, K., Dolstra, O., Visser, R.G., Maliepaard, C., and Krens, F.A. Genetic variation, heritability, and genotype by environment interaction of morphological traits in a tetraploid rose population. BMC Genetics, 2014, 15(1): 146. https://doi.org/10.1186/s12863-014-0146-z

Govindaraj, M., Pattanashetti, S.K., Patne, N., Kanatti, A.A., and Ciftci, Y.O. Breeding cultivars for heat stress tolerance in staple food crops. In: Ciftci, Y.O. (Ed.), Next Generation Plant Breeding, 2018, pp. 45–74. Intech Open. http://oar.icrisat.org/id/eprint/10935

Greenway, H., and Munns, R. Mechanisms of salt tolerance in non-halophytes. Annual Review of Plant Physiology, 1980, 31(1): 149–190. https://doi.org/10.1146/annurev.pp.31.060180.001053

Greyvenstein, O., Pemberton, H.B., Niu, G., Starman, T., and Byrne, D.H. Heat tolerance in garden roses. Acta Horticulturae, 2019, 1232: 165–170. https://doi.org/10.17660/ActaHortic.2019.1232.25

Greyvenstein, O., Pemberton, H.B., Starman, T., Niu, G., and Byrne, D.H. Effect of two-week high-temperature treatment on flower quality and abscission of *Rosa* L. 'Belinda's Dream' and 'RADrazz' (KnockOut®) under controlled growing environments. Hort Science, 2014, 49(5): 701–705. https://doi.org/10.21273/HORTSCI.49.6.701

He, L., Wu, Y.H., Zhao, Q., Wang, B., Liu, Q.L., and Zhang, L. Chrysanthemum *DgWRKY2* gene enhances tolerance to salt stress in transgenic chrysanthemum. International Journal of Molecular Sciences, 2018, 19(7): 2062. https://doi.org/10.3390/ijms19072062

He, Z., Fu, Y., and Si, H. Phosphomannose-isomerase (*pmi*) gene as a selectable marker for rice transformation via *Agrobacterium*. Plant Science, 2004, 166(1): 17–22. https://doi.org/10.1016/S0168-9452(03)00338-8

Hong, B., Ma, C., Yang, Y., Wang, T., Yamaguchi-Shinozaki, K., and Gao, J. Over-expression of *AtDREB1A* in chrysanthemum enhances tolerance to heat stress. Plant Molecular Biology, 2009, 70(3): 231–240. https://doi.org/10.1007/s11103-009-9468-z

Hong, B., Tong, Z., Ma, N., Kasuga, M., Yamaguchi-Shinozaki, K., and Gao, J.P. Expression of the *Arabidopsis DREB1A* gene in transgenic chrysanthemum enhances tolerance to low temperature. Journal of Horticultural Science and Biotechnology, 2006, 81(6): 1002–1008. https://doi.org/10.1080/14620316.2006.11512146

Hong, B., Tong, Z., Ma, N., Li, J., Kasuga, M., Yamaguchi-Shinozaki, K., and Gao, J. Heterologous expression of the *AtDREB1A* gene in chrysanthemum increases drought and salt stress tolerance. Science China Life Sciences, 2006, 49(5): 436–445. https://doi.org/10.1007/s11427-006-2014-1

Hossain, Z., Mandal, A.K., Datta, S.K., and Biswas, A.K. Development of NaCl-tolerant strain in *Chrysanthemum morifolium* Ramat through in vitro mutagenesis. Plant Biology, 2006, 8(4): 450–461. https://doi.org/10.1055/s-2006-923951

Huang, Q., Liao, X., Yang, X., Luo, Y., Lin, P., Zeng, Q., Bai, H., Jiang, B., Pan, Y., Zhang, F., and Zhang, L. Lysine crotonylation of *DgTIL1* at K72 modulates cold tolerance by enhancing *DgnsLTP* stability in chrysanthemum. Plant Biotechnology Journal, 2021, 19(6): 1125–1140. https://doi.org/10.1111/pbi.13533

Hura, T., Szewczyk-Taranek, B., Hura, K., Nowak, K., and Pawłowska, H. Physiological responses of *Rosa rubiginosa* to saline environment. Water, Air, and Soil Pollution, 2017, 228(2): 81. https://doi.org/10.1007/s11270-017-3263-2

Itai, C., Richmond, A., and Vaadia, Y. The role of root cytokinins during water and salinity stress. Israel Journal of Plant Sciences, 1968, 17(2): 187–195. https://doi.org/10.1080/0021213X.1968.10667660

Jaleel, C.A., Gopi, R., Manivannan, P., Gomathinayagam, M., Murali, P., and Panneerselvam, R. Soil-applied propiconazole alleviates the impact of salinity on *Catharanthus roseus* by improving antioxidant status. Pesticide Biochemistry and Physiology, 2008, 90(2): 135–139. https://doi.org/10.1016/j.pestbp.2007.11.003

Jiang, C., Xu, J., Zhang, H., Zhang, X., Shi, J., and Li, M. A cytosolic class I small heat shock protein, *RcHSP17.8*, of *Rosa chinensis* confers resistance to a variety of stresses to *Escherichia coli*, yeast, and *Arabidopsis thaliana*. Plant Cell and Environment, 2009, 32(8): 1046–1059. https://doi.org/10.1111/j.1365-3040.2009.01987.x

Jiang, L., Tian, X., Li, S., Fu, Y., Xu, J., and Wang, G. The *AabHLH35* transcription factor identified from *Anthurium andraeanum* is involved in cold and drought tolerance. Plants, 2019, 8(7): 216–225. https://doi.org/10.3390/plants8070216

Josine, T., Ji, J., Wang, G., Zhao, Q., Yang, H.L., Wang, Y.R., and Wu, W.D. *AtDREB2A-CA* gene over-expression in *Rosa Chinensis Jacq.* affects leaf ultrastructure response to salt stress. International Journal of Agriculture, 2015, 8(3): 463–476. https://api.semanticscholar.org/CorpusID:86054374

Kaicker, U.S., and Dhayani, D. Induced color mutations in roses through gamma rays. Indian Journal of Horticulture, 1986, 43(3–4): 282–290.

Küçükahmetler, O. The effects of salinity on yield and quality of ornamental plants and cut flowers. Acta Horticulturae, 2000, 573: 407–414. https://doi.org/10.17660/ActaHortic.2002.573.49

Labrada, F.P., Hernández, H.H., Pérez, M.C.L., Morales, S.G., Mendoza, A.B., and Maldonado, A.J. Nanoparticles in plants: morphophysiological, biochemical, and molecular responses. In: *Plant Life under Changing Environment*, 2020, pp. 289–322. Elsevier. https://doi.org/10.1016/B978-0-12-818204-8.00016-3

Larcher, W., and Bauer, H. Ecological significance of resistance to low temperature. In: Lange, O.L., Nobel, P.S., Osmond, C.B., Ziegler, H. (Eds.), Physiological Plant Ecology *I*, 1981, pp. 403–437. Springer. https://doi.org/10.1007/978-3-642-68150-9_14

Lau, J., Liang, S., Wu, X., Yan, M., Klein, P.E., Young, E.L., and Byrne, D.H. Heritability of flower size and heat stress in diploid roses. Acta Horticulturae, 2019, 1232: 51–55. https://doi.org/10.17660/ActaHortic.2019.1232.9

Li, P., Song, A., Gao, C., Jiang, J., Chen, S., and Fang, W. The overexpression of a Chrysanthemum WRKY transcription factor enhances aphid resistance. Plant Physiology and Biochemistry, 2015, 95: 26–34. https://doi.org/10.1016/j.plaphy.2015.07.002

Li, W., Wan, X.L., Yu, J.Y., Wang, K.L., and Zhang, J. Genome-wide identification, classification, and expression analysis of the Hsf gene family in carnation (*Dianthus caryophyllus*). International Journal of Molecular Sciences, 2019, 20(20): 5233. https://doi.org/10.3390/ijms20205233

Liang, S., Wu, X., and Byrne, D. Flower-size heritability and floral heat-shock tolerance in diploid roses. Hort Science, 2017, 52(5): 682–685. https://doi.org/10.21273/HORTSCI11640-16

Liu, R., Shi, H., Wang, Y., and Chen, S. Comparative physiological analysis of lotus (*Nelumbo nucifera*) cultivars in response to salt stress and cloning of *NnCIPK* genes. Scientia Horticulturae, 2014, 173: 29–36. https://doi.org/10.1016/j.scienta.2014.04.032

Liu, S., Chen, S., Chen, Y., Guan, Z., Yin, D., and Chen, F. In vitro induced tetraploid of *Dendranthema nankingense* (Nakai) Tzvel shows an improved level of abiotic stress tolerance. Scientia Horticulturae, 2011, 127(3): 411–419. https://doi.org/10.1016/j.scienta.2010.10.012

Liu, Y., He, M., Dong, F., Cai, Y., Gao, W., Zhou, Y., Huang, H., and Dai, S. The *Chrysanthemum lavandulifolium ClNAC9* gene positively regulates saline, alkaline, and drought stress in transgenic *Chrysanthemum grandiflora*. Journal of the American Society for Horticultural Science, 2019, 144(4): 280–288. https://doi.org/10.21273/JASHS04697-19

Lorenzo, H., Cid, M.C., and Siverio, J.M. Effects of sodium on mineral nutrition in rose plants. Annals of Applied Biology, 2000, 137(1): 65–72.

Lu, M., Sun, M., and Zhang, Q.X. Studies of drought resistance of different ground-cover chrysanthemum variety seedlings. Acta Horticulturae, 2012, 937: 329–335. https://doi.org/10.17660/ActaHortic.2012.937.40

Ludlow, M.M., and Muchow, R.C. A critical evaluation of traits for improving crop yields in water-limited environments. Advances in Agronomy, 1990, 43: 107–153. https://doi.org/10.1016/S0065-2113(08)60477-0.

Marissen, N. Effects of pre-harvest light intensity and temperature on carbohydrate levels and vase life of cut roses. Acta Horticulturae, 2001, 543: 331–336. https://doi.org/10.17660/ActaHortic.2001.543.40.

Marosz, A. Effect of soil salinity on nutrient uptake, growth, and decorative value of four ground cover shrubs. Journal of Plant Nutrition, 2004, 27(5): 977–989. https://doi.org/10.1081/PLN-120037531.

Mittler, R. Oxidative stress, antioxidants and stress tolerance. Trends in Plant Science, 2002, 7(9): 405–410. https://doi.org/10.1016/s1360-1385(02)02312-9.

Mittler, R. Abiotic stress, the field environment and stress combination. Trends in Plant Science, 2006, 11(1): 15–19. https://doi.org/10.1016/j.tplants.2005.11.002.

Moe, R. The effect of growing temperature on keeping quality of cut roses. Acta Horticulturae, 1975, 41: 77–92. https://doi.org/10.17660/ActaHortic.1975.41.7.

Munne-Bosch, S., and Alegre, L. Drought-induced changes in the redox state of α-tocopherol, ascorbate, and the diterpene carnosic acid in chloroplasts of Labiatae species differing in carnosic acid contents. Plant Physiology, 2003, 131(3): 1816–1825. https://doi.org/10.1104/pp.102.019265.

Navarro, A., Elia, A., Conversa, G., Campi, P., and Mastrorilli, M. Potted mycorrhizal carnation plants and saline stress: growth, quality, and nutritional plant responses. Scientia Horticulturae, 2012, 140:

131–139. https://doi.org/10.1016/j.scienta.2012.03.016.

Nawaz, K., Hussain, K., Majeed, A., Khan, F., Afghan, S., and Ali, K. Fatality of salt stress to plants: Morphological, physiological and biochemical aspects. African Journal of Biotechnology, 2010, 9(33): 5475–5480.

Nell, T.A., and Rasmussen, H.P. Blindness in roses: Effects of high intensity light and blind shoot prediction severity. Journal of the American Society for Horticultural Science, 1978, 104(1): 21–25. https://doi.org/10.21273/JASHS.104.1.21.

Niu, G., and Rodriguez, D.S. Responses of growth and ion uptake of four rose rootstocks to chloride- or sulfate-dominated salinity. Journal of the American Society for Horticultural Science, 2008, 133(5): 663–669. https://doi.org/10.21273/JASHS.133.5.663.

Niu, G., Rodriguez, D.S., and Aguiniga, L. Growth and landscape performance of ten herbaceous species in response to saline water irrigation. Journal of Environmental Horticulture, 2007, 25(4): 204–210. https://doi.org/10.24266/0738-2898-25.4.204.

Niu, G., Starman, T., and Byrne, D. Responses of growth and mineral nutrition of garden roses to saline water irrigation. Hort Science, 2013, 48(6): 756–761. https://doi.org/10.21273/HORTSCI.48.6.756.

Ottander, C., Campbell, D., and Oquist, G. Seasonal reorganization of photosystem II and pigment composition in Pinus sylvestris. In: Mathis, P. (Ed.), *Photosynthesis: From Light to Biosphere*, Vol. IV. Kluwer Academic Publishers, 1995, pp. 877–880. https://doi.org/10.1007/978-94-011-0451-7_156.

Ouyang, L., Leus, L., De Keyser, E., and Van Labeke, M.C. Cold acclimation and deacclimation of two garden rose cultivars under controlled day length and temperature. Frontiers in Plant Science, 2020, 327: 1–10. https://doi.org/10.3389/fpls.2020.00327.

Pennycooke, J.C., Jones, M.L., and Stushnoff, C. Down-regulating α-Galactosidase enhances freezing tolerance in transgenic petunia. Plant Physiology, 2003, 133(3): 901–909. https://doi.org/10.1104/pp.103.024554.

Perez, A.R.S. Characterizing salinity tolerance in greenhouse roses. *MS Thesis*, Texas A&M University, 2009.

Prasad, P.V.V., Pisipati, S.R., Momcilovic, I., and Ristic, Z. Independent and combined effects of high temperature and drought stress during grain filling on plant yield and chloroplast EF-Tu expression in spring wheat. Journal of Agronomy and Crop Science, 2011, 197(6): 430–441. https://doi.org/10.1111/j.1439-037X.2011.00477.x.

Qin, X., Liu, Y., Mao, S., Li, T., Wu, H., Chu, C., and Wang, Y. Genetic transformation of lipid transfer protein encoding gene in Phalaenopsis amabilis to enhance cold resistance. Euphytica, 2014, 177(1): 33–43. http://dx.doi.org/10.1007/s10681-010-0246-4.

Rahman, M., and Hoque, M.A. Quality of flower and bulb in tuberose under saline condition. *Research and Reviews:* Journal of Crop Science and Technology, 2019, 7(1): 1–9.

Ranney, T.G., and Peet, M.M. Heat tolerance of five taxa of birch (Betula): Physiological responses to supra-optimal leaf temperatures. Journal of the American Society for Horticultural Science, 1994, 119(2): 243–248. https://doi.org/10.21273/JASHS.119.2.243.

Rehman, A., Riaz, R., Iqbal, M., Shafi, J., and Ahmad, W. Responses of different morphological attributes of Rosa hybrida L. cv. Kardinal to saline water irrigation. Environment and Ecology Research, 2014, 2(1): 21–26.

Rhee, H.K., and Kim, K.S. Interspecific hybridization and polyploidization in lily breeding. Acta Horticulturae, 2018, 766: 441–446. https://doi.org/10.17660/ActaHortic.2018.766.59.

Richards, R.A., Rawson, H.M., and Johnson, D.A. Glaucousness in wheat: Its development and effect on water-use efficiency, gas exchange, and photosynthetic tissue temperatures. Functional Plant Biology, 1986, 13(4): 465–473. https://doi.org/10.1071/PP9860465.

Rogers, M.N. Air pollution effects on ornamental crops. In: Ball, V. (Ed.), *Ball Red Book*, 14th ed., Geo. J. Ball Publishing, 1985, pp. 213–223.

Sedibe, M.M., Khetsha, Z.P., and Malebo, N. Salinity effects on external and internal morphology of rose geranium (Pelargonium graveolens L.) leaf. Life Sciences Journal, 2013, 10(1): 109–115.

Shillo, R., Ding, M., Pasternak, D., and Zaccai, M. Cultivation of cut flower and bulb species with saline water. Scientia Horticulturae, 2002, 92(1): 41–54.

Shin, H.K., Lieth, J.H., and Kim, S.H. Effects of temperature on leaf area and flower size in rose. Acta Horticulturae, 2001, 547: 185–191. https://doi.org/10.17660/ActaHortic.2001.547.22.

Siddiqui, M.H., Al-Whaibi, M.H., Firoz, M., and Al-

Khaishany, M.Y. Role of nanoparticles in plants. In: *Nanotechnology and Plant Sciences*, Springer International Publishing, 2015, pp. 19–35. https://doi.org/10.1007/978-3-319-14502-0_2.

Smith, P.G., and Dale, J.E. The effect of root cooling and excision treatment on growth of primary leaves of *Phaseolus vulgaris* L. Rapid and reversible increases in abscisic acid content. New Phytologist, 1988, 110(3): 293–300. https://doi.org/10.1111/j.1469-8137.1988.tb00265.x.

Song, A., Zhu, X., Chen, F., Gao, H., Jiang, J., and Chen, S. A chrysanthemum heat shock protein confers tolerance to abiotic stress. International Journal of Molecular Sciences, 2014, 15(3): 5063–5078. https://doi.org/10.3390/ijms15035063.

Sonneveld, C., and Voogt, W. Studies on the salt tolerance of some flower crops grown under glass. Plant and Soil, 1983, 74(1): 41–52. https://doi.org/10.1007/BF02143618.

Strope, K. The effects of heat stress on flowering and vegetative growth of New Guinea impatiens (*Impatiens hawkeri* Bull.). *MS Thesis, University of Minnesota*, 1999.

Subbarao, G.V., Johansen, C., Slinkard, A.E., Rao, R.C.N., Saxena, N.P., and Chauhan, Y.S. Strategies for improving drought resistance in grain legumes. Critical Reviews in Plant Sciences, 1995, 14(6): 469–523. https://doi.org/10.1080/07352689509701933.

Sun, C.Q., Chen, F.D., Teng, N.J., Liu, Z.L., Fang, W.M., and Hou, X.L. Interspecific hybrids between *Chrysanthemum grandiflorum* (Ramat.) and *C. indicum* (L.) Des. Moul. and their drought tolerance evaluation. Euphytica, 2010, 174: 51–60. https://doi.org/10.1007/s10681-009-0117-z.

Suzuki, N., Koussevitzky, S., Mittler, R., and Miller, G. ROS and redox signaling in the response of plants to abiotic stress. Plant, Cell & Environment, 2012, 35(2): 259–270. https://doi.org/10.1111/j.1365-3040.2011.02336.x.

Taylor, A.F., Rylott, E.L., Anderson, C.W., and Bruce, N.C. Investigating the toxicity, uptake, nanoparticle formation, and genetic response of plants to gold. PLoS ONE, 2014, 9(3): e93793. https://doi.org/10.1371/journal.pone.0093793.

Terry, N.J., and Abadia, J. Function of iron in chloroplasts. Journal of Plant Nutrition, 1986, 9(3–7): 609–646. https://doi.org/10.1080/01904168609363470.

Thomas, B., and Vince-Prue, D. *Photoperiodism in Plants* (2nd ed., pp. 1–26). Academic Press, New York, NY, 1996.

Vaadia, Y. Plant hormones and water stress. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 1976, 273(927): 513–522. https://doi.org/10.1098/rstb.1976.0027.

Wahid, A., Gelani, S., Ashraf, M., and Foolad, M.R. Heat tolerance in plants: an overview. Environmental and Experimental Botany, 2007, 61(3): 199–223. https://doi.org/10.1016/j.envexpbot.2007.05.011.

Wahome, P.K., Jesch, H.H., and Pinker, I. Effect of sodium chloride stress on *Rosa* plants growing in vitro. Scientia Horticulturae, 2001, 90(2): 187–191. https://doi.org/10.1016/S0304-4238(00)00231-4.

Wang, C.H., Yeh, D.M., and Sheu, C.S. Heat tolerance and flowering-heat-delay sensitivity in relation to cell membrane thermostability in chrysanthemum. Journal of the American Society for Horticultural Science, 2008, 133(5): 754–759. https://doi.org/10.21273/JASHS.133.6.754.

Wang, K., Wu, Y.H., Tian, X.Q., Bai, Z.Y., Liang, Q.Y., Liu, Q.L., Pan, Y.Z., Zhang, L., and Jiang, B.B. Overexpression of *DgWRKY4* enhances salt tolerance in chrysanthemum seedlings. Frontiers in Plant Science, 2017, 8: 1592. https://doi.org/10.3389/fpls.2017.01592.

Warner, R.M. Genetic approaches to improve cold tolerance of petunia. *American Floral Endowment: Funding Industry Solutions through Research and Education*, 2010.

Warner, R.M., and Erwin, J.E. Photosynthetic responses of heat-tolerant and heat-sensitive cultivars of *Impatiens hawkeri* and *Viola* × *wittrockiana* to high temperature exposures. Acta Horticulturae, 2002, 580: 215–219. https://doi.org/10.17660/ActaHortic.2002.580.28.

Warner, R.M., and Erwin, J.E. High temperature developmentally reduces growth and flowering of twelve pansy cultivars. *IHC Program*, Toronto, Canada, 2003.

Warrington, I.J., and Stanley, C.J. Seasonal frost tolerance of some ornamental, indigenous New Zealand plant species in the genera *Astelia*, *Dicksonia*, *Leptospermum*, *Metrosideros*, *Phormium*, *Pittosporum*, and *Sophora*. New Zealand Journal of Experimental Agriculture, 1987, 15: 357–365. https://doi.org/10.1080/03015521.1987.10425582.

Wu, L., Guo, X., and Harivandi, A. Salt tolerance and salt accumulation of landscape plants irrigated by sprinkler and drip irrigation systems. Journal of Plant Nutrition, 2001, 24(10): 1473–1490. https://doi.org/10.1081/PLN-100106996.

Wu, S., Sun, Y., and Niu, G. Morphological and physiological responses of nine ornamental species to saline irrigation water. Hort Science, 2016, 51(3): 285–290. https://doi.org/10.21273/HORTSCI.51.3.285.

Xu, K., Hong, P., Luo, L., and Xia, T. Overexpression of *AtNHX1*, a vacuolar Na^{+}/H^{+} antiporter from *Arabidopsis thaliana*, in *Petunia hybrida* enhances salt and drought tolerance. Journal of Plant Biology, 2009, 52(5): 453–461. http://dx.doi.org/10.1007/s12374-009-9058-2.

Xu, Y., Zhao, X., Aiwaili, P., Mu, X., Zhao, M., Zhao, J., Cheng, L., Ma, C., and Gao, J. A zinc finger protein *BBX19* interacts with *ABF3* to affect drought tolerance negatively in chrysanthemum. Plant Journal, 2020, 103(5): 1783–1795. https://doi.org/10.1111/tpj.14863.

Yang, R., Chen, M., Sun, J.C., Yu, Y., Min, D.H., Chen, J., Xu, Z.S., Zhou, Y.B., Ma, Y.Z., and Zhang, X.H. Genome-wide analysis of LIM family genes in foxtail millet (*Setaria italica* L.) and characterization of the role of *SiWLIM2b* in drought tolerance. International Journal of Molecular Sciences, 2019, 20(6): 1303. https://doi.org/10.3390/ijms20061303.

Yang, X., Luo, Y., Bai, H., Li, X., Tang, S., Liao, X., Zhang, L., and Liu, Q. *DgMYB2* improves cold resistance in chrysanthemum by directly targeting *DgGPX1*. Horticulture Research, 2022, 9: uhab028. https://doi.org/10.1093/hr/uhab028.

Yang, Y., Ma, C., Xu, Y., Wei, Q., Imtiaz, M., Lan, H., Gao, S., Cheng, L., Wang, M., Fei, Z., and Hong, B. A zinc finger protein regulates flowering time and abiotic stress tolerance in chrysanthemum by modulating gibberellin biosynthesis. Plant Cell, 2014, 26(5): 2038–2054. https://doi.org/10.1105/tpc.114.124867.

Zhai, L., Zhu, X., Yang, S., Gu, C., Liu, P., Song, A., Jiang, J., Guan, Z., Fang, W., Chen, F., and Chen, S. Constitutive expression of a chrysanthemum phospholipase *Dα* gene in *Chrysanthemum morifolium* enhances drought tolerance. Ornamental Plant Research, 2021, 1: 1–10. https://doi.org/10.48130/OPR-2021-0008.

Zhang, L., Xu, Y., Liu, X., Qin, M., Li, S., Jiang, T., Yang, Y., Jiang, C.Z., Gao, J., and Hong, B. The chrysanthemum DEAD-box RNA helicase *CmRH56* regulates rhizome outgrowth in response to drought stress. Journal of Experimental Botany, 2022, erac213. https://doi.org/10.1093/jxb/erac213.

Zhang, T., Qu, Y., Wang, H., Wang, Z., Jiang, J., Chen, S., Fang, W., Guan, Z., Liao, Y., and Chen, F. *CmSCL4* and *CmR1MYB1* synergistically enhance drought tolerance by regulation of ABA signaling in chrysanthemum. Environmental and Experimental Botany, 2022, 199: 104886. https://doi.org/10.1016/j.envexpbot.2022.104886.

Zhang, W., Xu, H., Duan, X., Hu, J., Li, J., Zhao, L., and Ma, Y. Characterizing the leaf transcriptome of *Chrysanthemum rhombifolium* (Ling et C. Shih), a drought-resistant, endemic plant from China. Frontiers in Genetics, 2021, 12: 625985. https://doi.org/10.3389/fgene.2021.625985.

Zhu, W.Y., Jiang, J.F., Chen, S.M., Wang, L., Xu, L., Wang, H.B., Li, P.L., Guan, Z.Y., and Chen, F. Intergeneric hybrid between *Chrysanthemum* × *morifolium* and *Artemisia japonica* achieved via embryo rescue shows salt tolerance. Euphytica, 2013, 191(1): 109–119. https://doi.org/10.1007/s10681-013-0869-3.

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