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Use of antitranspirants and plant growth regulators in stress management of horticulture crops

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Abstract
Plants under its natural condition were exposed to various abiotic stresses such as drought, salinity, heat, cold, and freezing stress, nutrient deficiency, and mineral toxicity. Abiotic stresses interrupt essential metabolic and signaling pathways, limiting plant growth, development, and its productivity. It is therefore crucial that novel management strategies to make more resistant towards stress are which are based on a good understanding of plant stress responses and how these interface and combine with growth responses. Antitranspirants, materials that reduce transpiration, could potentially result in greater food production by realizing more of a crop's potential yield during drought. Plant Growth Regulators, are a diverse class of chemicals that act at very low concentrations to control plant growth and development as well as stress responses by activating signal transduction pathways which terminate in the induction of genes, proteins, and metabolites important for stress tolerance.

Keywords: Abiotic stress, plant growth, tolerance, antitranspirants, PGR

Introduction
Future crop productivity and world food security will be undermined by severe and more frequent droughts and other abiotic stresses (IPCC, 2018) [70], and reducing transpiration with antitranspirants (ATs) may have a role in ameliorating drought. About 80% of the total cropped area globally is under rain-fed agriculture (Huang *et al.*, 2019) [29] supplementary information, and prone to droughts. Under a frequent drought scenario predicted for the future, reducing transpirational water loss will be required to obtain improvements in grain yield. The rapidly increasing world population, projected to reach 9.8 billion by 2050 (United Nations, 2017), will put pressure on food demand. Cereal production must increase by 26% from 2.8 to 3.5 billion tonnes, as from the 2014 baseline (Hunter *et al*., 2017) [30] supplementary data in order to avert global food insecurity. One neglected agronomic technique that has potential to significantly contribute to drought stress amelioration in food crop production is the use of ATs. ATs are substances that are applied on leaves to reduce transpiration and hence improve plant water potential (del Amor *et al*., 2010) [17]. However, past research has shown that as ATs can reduce grain yield due to depression of transpiration, they are only effective during drought (De and Giri, 1981) [24] In addition, a comprehensive study by (Kettlewell *et al.*, 2010) [33] showed that ATs should target the most drought sensitive stage to avoid counterproductive effects. The potential of ATs to 'waterproof' the most critical crop development stages (Kettlewell *et al*., 2014) [33] through reduced transpiration and improved water use efficiency (WUE) during drought is an active area of research. Transpiration is the loss of water in the form of vapor from the stem and leaves of the living plants. The process of gaseous diffusion is responsible for the loss of water from plant to atmosphere through the leaf stomata. This gaseous diffusion of water is directly controlled by the regulation of stomata aperture. The stomata movement is controlled by plant and atmospheric factors (Kramer, 1969) [37] Antitranspirants have shown to reduce transpiration (Davenport and Hagan, 1973) [16]. Plants have to deal with various and complex types of interactions involving numerous environmental factors. In the course of evolution, they have evolved specific mechanisms allowing them to adapt and survive stressful events. Exposure of plants to biotic and abiotic stress induces a disruption in plant metabolism implying physiological costs (Heil M *et al.*, 2002) [27] and (Swarbrick *et al*., 2006) [54]. Thus leading to a reduction in fitness and ultimately in productivity (Shao H.B *et al.*, 2008) [49]. Abiotic stress is one of the most important features of and has a huge impact on growth and, consequently, it is responsible for severe losses in the

field. The resulting growth reductions can reach >50% in most plant species (Wang W *et al*., 2003) [59]. Stress can be defined as any change in environmental conditions that might adversely change a plant's growth or development. According to Strasser 1998 [52], he define stress "as a condition caused by factors that tend to alter an equilibrium". Stress can have drastic impact on plant reproduction, productivity, agriculture and biodiversity. Biotic stress is stress that occurs as a result of damage done to plants by other living organisms. It includes bacteria, fungi, nematodes, viruses and insect- pests. 600 insect and mite pests are present in temperate fruits alone in India (Sharma and Singh 2006) [71]. Diseases both in field and storage accounts for 25-30 percent losses in fruit crops (Mahadeva Kumar *et al*., 2016) [41]. The negative impact of environmental factors on plant growth and yield. Any adverse factor acting on physiological processes/ biochemical activity of the plants is called as abiotic stress. 10 million ha under Stalinization in India (Singh *et al.,* 2006) [50].

Suitable horticulture crops for different Stress condition

Abiotic stresses, such as drought, salinity, extreme temperatures, chemical toxicity and oxidative stress are serious threats to agriculture and result in the deterioration of the environment. Abiotic stress is the primary cause of crop loss worldwide, reducing average yields for most major crop plants by more than 50% (Boyer 1982) [7] and (Bray *et al.* 2000) [8]. Drought and salinity are becoming particularly widespread in many regions, and may cause serious salinization of more than 50% of all arable lands by the year 2050.

Abiotic stress leads to a series of morphological, physiological, biochemical and molecular changes that adversely affect plant growth and productivity (Wang *et al*., 2001a) [72]. Drought, salinity, extreme temperatures and oxidative stress are often interconnected, and may induce similar cellular damage. For example, drought and/or salinization are manifested primarily as osmotic stress, resulting in the disruption of homeostasis and ion distribution in the cell (Serrano *et al*., 1999) [73] and (Zhu *et al*., 2001a) [74].

Antitranspirants

Antitranspirants are compounds applied to the leaves of plants to reduce transpiration. They are used on Christmas trees, on cut flowers, on newly transplanted shrubs, and in other applications to preserve and protect plants from drying out too quickly. They have also been used to protect leaves from salt burn and fungal diseases. They block the active excretion of hydrogen cation from the guard cells. Due to presence of carbon dioxide, a rapid acidification of cytoplasm takes place leading to stomata closure. (Milbarrow 1974) [42] has described the formation of these chemicals in the chloroplast. It moves to the stomata, where it is responsible for checking the intake of Potassium ion or induces loss of potassium ion from the guard cells.

Antitranspirants are of two types

1. Metabolic inhibitors

2. Film-forming antitranspirants

Metabolic inhibitors reduce the stomatal opening and increase the leaf resistance to water vapour diffusion without affecting carbon dioxide uptake. Examples include phenyl mercury acetate, abscisic acid (ABA), and aspirin. Film-forming antitranspirants form a colorless film on the leaf surface that allows diffusion of gases but not of water vapour. Examples include silicone oil, waxes. These chemicals reduce shoot growth and increase root growth and thus enable the plants to resist drought. They may also induce stomata closure. Cycocel is useful for improving water status of the plant The ATs are categorically classified on mode of action in the following four types:-The assumptions behind the use of antitranspirants are that an increase in resistance at the leaf surface will decrease transpiration more than it will decrease CO uptake (Kramer, 1983) [37]. Antitranspirants have shown to reduce transpiration (Davenport and Hagan 1973) [16]. Antitranspirant affect water loss more than CO exchange in leaves (Fuehring and Finkner 1983) [21] and (Wendt *et.al.*, 1973) [75] obtained slight increase in yield of potatoes by use of antitranspirants. Since stomata serve as portals for both the loss of water vapor and for the intake of carbon dioxide (which is necessary for photosynthesis), an antitranspirant barrier against water loss also may reduce plant growth When Reflecting materials are applied to the upper surfaces of leaves they do not cause blockage of stomata pores due to occurrence of stomata exclusively on the lower surfaces.

However, such coatings may restrict photosynthesis on dull days when light is limited. Film-forming antitranspirants can cause large reductions in transpiration rates, but since the HzO.C0$_2$ permeability ratios tend to exceed unity for currently available film materials, the transpiration ratios may not be reduced (Davenport *et al*., 1969) [76]. As growth can be retarded by natural stomata closure when an untreated plant wilts, due to low soil water potentials and/or high evaporative demand. Antitranspirants will help by slowing down the rate at which water is lost, to prevent or at least delay wilting Therefore treatment with an antitranspirant must be made as a preventive measure before the onset of wilting.

Role of antitranspirants in stress management on horticulture crops

Antitranspirants were grouped into three categories, namely film-forming types (which coat leaf surface with films that are impervious to water vapor) (Kalil, Soha *et al*., 2012) [32] reflecting materials (which reflect back a portion of the incident radiation falling on the upper surface of the leaves) and stomata closing types (which affect the metabolic processes in leaf tissues (Prakash *et al*, 2000) [46]. Kaolin (surround WP) is a non-abrasive, non-toxic alumino silicate (Al_4Si4O_{10} $(OH)_8$) clay mineral that has been formulated (Engelhard Corporation, Iselin, NJ) as a wet table powder for application with conventional spray equipment (Cantore *et al*., 2009) [11].

In viticulture, anti-transpirants are implemented to avoid water dispersion of the plant with consequent effects on the composition of the fruit, the yield elements and in part also on the final product, wine (Song *et al*., 2012) [51]. When implemented on Cabernet Sauvignon field vines, growing in hot environment, it has been found that a kaolin-based film enhances the water conditions of the plant and intrinsic water use efficiency; however, a di-1-*p*-menthene based film did not give the same results (Brillante *et al*., 2016) [9] whereas when implementing this last one on Sangiovese, growing also in a warm environment, intrinsic water use efficiency was enhanced when implemented on Barbera growing in a mild climate, it was not detected any change in the immediate water use efficiency.

(Cantore, *et al*., 2009) [58], investigated the underlying mechanism asserted by kaolin on tomato physiology by evaluating its effect on leaf, canopy and inner fruit temperatures, gas exchange at the leaf and canopy scales, above ground biomass, yield and fruit quality. In treated plants, stomatal conductance decreased by 53%, resulting in reductions of 34 and 15% in transpiration and internal CO2 concentration, respectively. Marketable yield in kaolin-treated plants was 21% higher than those measured in control plants; this is possibly related to the reduction in sunburned fruit and those damaged by insects, respectively, and to the 9% increase in mean fruit weight, Kaolin treatment increased lycopene fruit content by (Moftah *et al*., 2005) [43], in study of the effect of kaolin and Vaporware on the photosynthesis and water relations of potato plants concluded that by the use of both antitranspirants efficiency and photosynthetic activities increased in plants under drought stress. Their results showed that water use efficiency (WUE) in plants treated with kaolin were significantly higher than plants treated with Vaporgard.

Chitosan is a natural, biodegradable polysaccharide polymer which serves as major structural component of the exoskeleton of crustaceans and insects (Muzzarelli *et al*., 1977) [44]. Chitosan is commercially derived from shells of crabs, shrimp, and lobsters. (Bittelli *et al*., 2001) [6], were found that foliar application of chitosan reduced water use of pepper plants by 26–43% while maintaining biomass production and yield. Castor bean oil as a film forming material and magnetic water were used in this study. One of the changes in magnetic water is the arrangement of electrical charges causes water molecules change to magnetic water. In the water, over 70% of the water molecules form irregular and they have positive and negative charges in their natural position if the water molecules cations and anions. (Lepri *et.al*., 1977) [40] change from disorder to order the charge of water molecules in these circumstances will be different than regular water and the formation of smaller molecules of water, increase the number of water molecules per unit volume also increase the water solubility.

Plant growth regulators (PGRs)

Plant growth regulators are chemicals used to modify plant growth such as increasing branching, suppressing shoot growth, increasing return bloom, removing excess fruit, or altering fruit maturity. Numerous factors affect PGR performance including how well the chemical is absorbed by the plant, tree vigour and age, dose, timing, cultivar, and weather conditions before, during, and after application. Plant growth regulators can be grouped into five classes: compounds related to auxins, gibberellins and inhibitors of gibberellin biosynthesis, cytokinins, abscisic acid and compounds affecting the ethylene status.

Various categories of plant growth regulators used in horticulture crops include

Auxin: It is a plant hormone which is found naturally as well as synthetically, that is routinely used for the vegetative propagation of plants from stem and cutting. The effect of NAA on plant growth is greatly dependent on the time of admission and concentration. NAA has been shown to greatly increase cellulose fiber formation in plants. In majority of fruit plants fruit drop is controlled by spraying of NAA in different fruit crops in different concentration. It is applied after blossom fertilization.

Fruit dropping in mosambi is reduced by the application of NAA (synthetic auxin) at a dose of 15ppm (Ghosh *et al*., 2012) [23] which results in doubling of fruit production as compared to control. (Ingle *et al*. 2001) [31] revealed that foliar application of NAA @ 30 ppm increased the fruit weight, acidity, juice percent peel and yield over control in Nagpur mandarin. (Baghel and Tiwari 2003) [5] concluded that spray of 6 percent urea and 150 ppm NAA in mango found superior for increasing the total number of flowers/panicle and percentage of hermaphrodite flowers. However, maximum flowering and fruiting and number of fruits/tree was recorded under combined application of 4 percent urea and 150 ppm NAA.

Gibberellins: Gibberellins control fruit development in various ways and at different developmental stages. Fruit development is a complex and tightly regulated process. Growing fruits are very active metabolically and act as strong sinks for nutrients with hormones possibly modulating the process (Brenner and Cheikh, 1995) [77]. The successful fertilization of the ovule is followed by cell division and cell expansion resulting in the growth of the fruit. Gibberellins are known to influence both cell division and cell enlargement (Adams *et al*., 1975) [3]. The discovery of gibberellins was done by a Japanese pathologist in the 1920s who studied the foolish rice disease, a disease that causes growth of rice plants rapidly with a weak stem. That disease was caused by fungus *Gibberella fujikuroi*. (Tejpal *et al*., 2018) [56]. Seed dormancy is most commonly found in temperate fruit crops after the ripening of fruits (Campoy *et al*., 2011) [10]. Scarification is a mechanical method of reducing the seed coat dormancy, whereas internal seed dormancy can be overcome by the stratification (Usberti and Martins, 2007; & Gusano *et al*., 2004) [57, 26].

Cytokinins: Cytokinins act in cell division, cell enlargement, senescence, and transport of amino acids in plants.

2,4-D Endogenous hormones and their balance play a modulating role in the mobilization of nutrients to the developing organs and can influence the longevity of a bud. The dependence of abscission relative to the endogenous content of auxins has been proven by exogenous application of 2,4-D or NAA, as the transportation of auxins by the plant lasts for a long time without ethylene appearing to affect it.

Paclobutrazol: Paclobutrazol is probably the most widely used PGR in the production of fruit crops because of its wide range of efficacy and moderate- to long-lasting response. Applications of paclobutrazol, particularly when delivered as a spray, delay flower development and reduce flower size. Paclobutrazol is absorbed by roots and stems, and to a lesser extent, by leaves. Therefore, it can be applied as a spray, sprench, drench, or bulb or young-plant dip. Sprays are more effective when they penetrate plant canopies so that there is contact with stems. The postharvest application of a small amount of paclobutrazol to the soil significantly promotes flowering and fruiting in the following year. Therefore, early and proactive applications are strongly recommended, and late applications should generally be used as a last resort.

Ethylene: Ethylene is a naturally occurring plant growth substance that has numerous effects on the growth, development and storage life of many fruits crops. Harvested fruits may be intentionally or unintentionally exposed to biologically active levels of ethylene and both endogenous and exogenous sources of ethylene contribute to its biological activity. Ethylene synthesis and sensitivity are enhanced during certain stages of plant development, as well as by a number of biotic and abiotic stresses.

Use of plant growth regulators: Foliar application of plant growth regulators, both natural and synthetic, has proven worthwhile for improving growth against a variety of abiotic stresses. Drought stress alone inhibited increases in length and fresh weight of the hypocotyls, while applied levels of gibberrelic acid reversed this effect. In this case, gibberrelic acid partially increased the water status of the seedlings and partially sustained protein synthesis (Taiz and Zeiger, 2006) [55]. Ethylene is known as the 'ripening' hormone. Manipulations of fruits and vegetables are done by either exogenous ethylene or inhibitors of ethylene production. However, other plant growth regulators are also used in horticultural production and have ramifications for postharvest quality (Suman *et al*., 2017) [53]. Many of the commercially available plant growth regulators are used in stone fruit production. Auxins are used to enhance the size of stone fruits. Gibberellins are used for increasing fruit size and firmness of cherries and peaches. In addition, when peaches are treated at the end of pit hardening, gibberellin can delay storage disorders such as internal browning and woolliness development (Kumari *et al*., 2018) [39]. Under water stress conditions, plant growth regulator treatments significantly increased water potential, and improved chlorophyll content (Zhang *et al*., 2004) [62]. Jasmonates, including jasmonic acid and its related compounds, are a group of naturally occurring growth regulators rather recently discovered in higher plants (Creelman and Mullet, 1995) [14]. Jasmonates play an essential role in the signaling pathway, triggering the expression of plant defense genes in response to various stresses (Koda, 1997) [35]. Exogenously applied jasmonic acid induced drought tolerance by increasing the betaine level in pear (Gao *et al*., 2004) [25]. Exogenous application of brassinolide, uniconazole and methyl jasmonate in maize improved drought tolerance owing to increased activities of superoxide dismutase, catalase and ascorbate peroxidase, abscisic acid and total carotenoid contents (Li *et al*., 1998). Benzyl adenine is an active cytokinin, which can increase the drought resistance of different plants (Shang, 2000) [48]. Salicylic acid can also effectively improve plant growth under drought conditions (Senaratna *et al*., 2000) [47]. In a recent study, exogenous application of salicylic acid improved the drought tolerance of winter wheat, which was correlated with an increased catalane activity (Horváth *et al*., 2007) [28]. Both salicylic acid and acetyl-salicylic acid (a derivative of salicylic acid), applied at various concentrations through seed soaking or foliar spray protected muskmelon (Cucumismelo) seedlings, subjected to drought stress. However, the best protection was obtained from seedlings pretreated with lower concentrations of salicylic acid (Korkmaz *et al*., 2007) [36].

Role of plant growth regulators (PGRS) in stress management in horticulture crop

Some plant characters such as moderate canopy development (moderate values for LAl), less reduction in photosynthesis, deeper root system, higher root/shoot ratio and delayed senescence will perform better under water stress conditions These characters can be utilized in water saving or improving water uptake by application of some of the PGRs These may prove beneficial for better crop growth and development when grown under water deficit situations Some of the PGRS and their effects on crops in order to suit to the water stress conditions are:

Abscisic acid (ABA)

The ABA is a phytohormone discovered in young fruits of cotton in 60 years, since then it has been reported in numerous species of plants and mosses. The ABA described functions are related to the maturation processes, the acquisition of tolerance to desiccation and seed dormancy (Wasilewska *et al*., 2008) [78]. It is also very important in the development of the plant as well as in response to biotic and abiotic stresses (Klingler *et al*., 2010) [34].

Plant's responses to stress under ABA biosynthesis

ABA hormone nmajorily provide resistance under abiotic stress, specially drought and salinity (Hossain *et al*., 2010) [68]. Within abiotic stress; drought, low temperatures, and salinity lead to cell dehydration. Plants respond to stress by exhibiting a wide variety of responses that involve rapid physiological changes such as stomatal closure to avoid plant water loss; biochemical changes etc. In higher plants, under water and saline stress, the ABA allows to maintain the water balance in the plant through the regulation of the degree of opening of the stomata. In drought conditions, ABA concentrations in the leaves increases. This increase in the ABA acts as a signal that can amplify the initial signal and start another signaling cascade (Chavez, & Ramirez, 2010) [69]. ABA also control ion homeostasis in plants.

Ethylene: Ethylene (C2H4) is the natural gas belonging to hydrocarbons, which occurs in the majority of tissues and cells of plants. It plays a significant role in physiology and development of the plants. It also participates in physiological processes such as the germination of the seed, the inhibition of elongation of the stem and the root and leaf expansion, the formation of the flower, the development of the hairs and nodulation of the root, leaf abscission, senescence, and the ripening of the fruits (Kumar *et al*., 2009) [38]. The synthesis of ethylene oxide can be induced by an environmental stress such as hypoxia, wounds, and attack by pathogens (Das *et al*., 2015) [15].

In agriculture, the ethylene is very important in the post-harvest stage of a great variety of fruits and vegetables (Ansari *et al*., 2015) [4] Ethylene is the simplest plant hormone (relative to the chemical composition) and stands from others to be a gas. This characteristic masked for many years its effect on plants. Studies on the physiological role of ethylene in the various development stages of the plants were carried out after the '60s (Abels *et al*., 1996) [2] and (Wang *et al*., 2002) [79].

In 1934, ethylene was considered a natural plant product capable of influencing and modulating many physiological processes during the entire cycle vital expounding its effect at very low concentrations, in the order of nanomoles. This trend can be observed in the different organs of growing plant.

Plant's responses to stress under ethylene biosynthesis

Under the stressful condition it was observed in plants that there is enhanced production of Ethylene. It is synthesized from S-adenosyl L methionine. For ethylene biosynthesis two majorily involved enzymes are- 1-amino cyclopropane 1-carboxylate synthase (ACC) and ACC oxidase. It has been observed by Bar *et al*. 1998 that the rootstocks of Citrus were exposed to increasing levels of chloride a dramatic increase in ethylene production in leaves was found only in chloride sensitive genotype, which was associated with increased level of ACC in leaves.

Production of ethylene increases with temperature within determined intervals under water stress conditions (Morgan & Drew, 1997) [63], salt (Kamei *et al*., 2005) [64], mechanical injury (Morgan *et al*., 1993) [6] and in the presence of pollutant ozone (Vahala at al., 1998) [66]. However, in some cases, it was also observed a decrease in production, as in conditions of thermal excesses (Field, 1981) [65], and prolonged water shortage conditions (Morgan & Drew, 1997) [63].

Conclusion

Endogenous growth regulators are vital components of plant growth and development under water stress conditions. Several reports have shown that water stress alters the level of growth regulators, and the resulting balance of growth regulators helps in providing better stress adaptability to plants. Antitranspirants can be used to protect plants against cold drying winds of winter and hot drying winds of summer. To protect plants when their roots are frozen in the winter depriving them of their normal moisture intake as well as during periods of drought.

The use of materials or chemicals which reduce the transpiration losses or helps in improving water uptake are realized in dry farming areas, in nursery and some high value materials. These are used to save crops and help to get marginal yield when the expectations are near zero. However, applications for this purpose would be justified only if water costs are sufficiently high and if possible water savings are sufficiently high to save.

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