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Stress management with anti-transpirants and plant growth regulators - A Review

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ABSTRACT

In the current climate change era, horticultural crops are exposed to multiple abiotic stresses. Stresses caused by abiotic factors, such as drought, extreme temperatures, salinity, and nutrient deficiencies, are resulting in increased yield and quality losses. The subtropical region will experience droughts and temperature increases due to this phenomenon. Therefore, the horticultural sector is seeking innovative and sustainable agronomic tools in order to improve crop tolerance. Antitranspirant is a chemical compound that reduces the number and size of stomata on plant leaves, leading to a decrease in transpiration rates. Antitranspirants, which reduce transpiration, may increase food production by realizing a crop's potential yield during drought conditions. Based on their mode of action, they are categorized as film-forming, stomatal regulating and reflective compounds. In plants, plant growth regulators act at very low concentrations to control their growth and development as well as to control stress responses. They operate by activating signal transduction pathways that lead to gene, protein, and metabolite induction.

1. Introduction

Crops which are grown under the open environments often passthrougha period of abiotic stress during their life cycle. Such stresses adversely affect the growth and productivity of the crops. Plants pass through a series of morphological, physiological, biochemical, and molecular changes in a search to mitigate such adversities of the abiotic stresses. It is reported by many work that the adaptive responses of crops plants to different abiotic stresses wherein emphasis has been laid on the individual stress factors (Wang *et al*., 2016; Anjum *et al*., 2017). Nonetheless, understanding the plant responses to combined stress factors is inescapable for enhancing the adaptation of plants under the field conditions (Pandey *et al.*, 2015).

Global crop productivity and food security will be threatened by severe and more frequent droughts (IPCC, 2018), and antitranspirants (ATs) may have a role in alleviating drought. Rain-fed agriculture accounts for about 80% of cropped land globally (Huang et al., 2019), and is prone to droughts (Singh *et al*., 2017).In arid and semi-arid areas of the world, soil water deficit and excessively high temperature are the most common yieldlimiting factors in crops. In many studies the main objectives have been to improve growth and yields by reducing the effects of drought and more efficient use of agricultural water. The amount of water vapour lost to the environment accounts for 99% of the plant water uptake and makes little direct contribution to plant growth (Anderson and Kreith, 2005; Lee and Kozlowski, 2006). Growing plants would transpire water equal to its weight each hour if water is supplied adequately in arid and semi-arid (Moftah, 1997). Plant tolerance to drought stress results from both the morphological adaptation and responses at biochemical and physiological levels (Batlang, 2006). Different mechanisms contribute to drought resistance in plants such as avoidance of water deficits by drought escape, water conservation, and more efficient water (Jones, 1983). Thus, plants adjust the loss of water from the canopy by closing their stomata apparatus and modulate their leaf area, (Passioura, 1997). Stomatal control is the first most important step in response to the drought, as stomatal conductance reduces the rate of water loss and also slows the rate of water stress development and minimizes its severity (Hanson and

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Hitz, 1982). Photosynthesis is strongly affected by water shortage as a decrease in stomatal conductance reduces the CO_2 assimilation (Cornic, 2000). Through transpiration water is also lost to the atmosphere and the potential for reducing thetranspirational water loss without reducing photosynthetic rate is based on the premise that resistance to the movement of carbon dioxide in the mesophyll is greater than the stomatal resistance that limits water loss to the atmosphere. Applications of antitranspirants reduce loss of water and enhance the water status of the plants. Such antitranspirants are classified into three categories. The first are reflective materials which are designed to reduce the amount of radiant energy absorbed, thus lowering therate of transpiration. The second category includes chemical compounds which affect guard cell metabolism causing the stomata to close. In the third category are the film-forming antitranspirants which create a hydrophobic barrier that restricts the diffusion of water vapour from the leaf (Anderson and Kreith, 2005; Lipe and Wendt, 2008).

What is Antitranspirants

Antiperspirants are chemical compounds that help to reduce the rate of transpiration from plant leaves by reducing the size and number of stomata and gradually strengthening them to stress (Ahmed *et al*., 2014). About 95-98% of the water absorbed by a plant is lost through transpiration from the plant (Prakash and Ramachandran, 2000). Foliar spraying significantly increases all growth parameters and relative water content, and can reduce transpiration in three different ways:(a) some chemicals reduce the absorption of solar energy and also reduce leaf temperature and transpiration rate; (b) some chemicals, such as wax, latex or plastics, form thin transparent films that reduce the escape of water vapor from the leaves but do not affect gas exchange and (c) some chemical compounds can control stomatal opening (affecting protection cells around the stomatal pores), thus reducing water vapor loss from the leaves (Besufkad*et al*., 2006). Lack of water significantly affects productivity. Therefore, application of antitranspirants before this stage can save water and also improve grain set, which can overcome photosynthetic limitations (Khalil *et al*., 2010). The three main types of antiperspirants are (i) film-forming (ii) stomatal regulating, and (iii) reflective compounds: (a) some chemicals reduce the absorption of the solar energy and also decreases leaf temperatures and transpiration rate; (b) certain chemicals like wax, latex or plastics form thin transparent films which decrease the escape of the water vapour from the leaves but not affect the exchange of gases and (c) certain chemical compounds can control opening of stomata (by affecting the guard cells around the stomatal pore), thus decreasing the loss of the water vapour from the leaves (Besufkad*et al*., 2006). Water stress are substantially impacting yield. Hence, the application of Antitranspirants prior to this stage may conserve water and it also improves grain set which could outweigh the photosynthetic limitations (Khalil *et al*., 2010). The three general types of antitranspirants are: (i) film-forming (ii) stomatal regulating and (iii) reflective compounds.

Types of Antitranspirant

- **Film-forming compounds**

Film-forming antiperspirants form a colorless film on the leaf surface that reduces the rate of transpiration but does not affect gas exchange (Gale, 1961). Studies by Slatyer and Bierhuizen (1964), Nitzshe (1991) led to the fact that the formation of a film on the surface of the leaves to a greater extent reduces transpiration, but slightly affects growth. Gale and Hagan (1966) also reported that most film-forming compounds arrest water vapor loss and are less effective for CO2 (Davenport et al., 1969) found that a 'CS-6432' leaf coating facilitated photosynthesis more than transpiration. When applied to the plant. Past studies have shown that film-forming antiperspirant is more effective in increasing grain yield and photosynthesis under both adverse and favorable conditions. The higher leaf turgor in WD (water deficit) plants sprayed with AT is consistent with the idea that the AT film reduces water loss and allows long-term maintenance of turgor under WD conditions under water stress conditions. Leaves maintain their firmness by applying an antiperspirant to them and reducing water loss under stress (Amor *et al*., 2010). The application of antiperspirant can improve the growth and physiological response of plants to water and high temperature stress (Leskovar*et al*., 2008, 2011), water stress at the flowering stage affects the yield component of the crop, it can decrease, so spraying the leaves with antiperspirant helps in improving photosynthesis, as well as reduce the rate of transpiration, which contributes to better crop production (Khalil *et al.*, 2010).

- **Reflectance compound**

Reflectors are a white material that reflects solar radiation and increases leaf albedo when applied to leaf surfaces. Reflectors do not cause clogging of stomatal pores when applied to the upper surfaces of leaves with stomata only on the lower surface. A chemical coating of the type of reflection reduces the temperature of the leaves. Hagan and Davenport (1970) experimentally demonstrated that transpiration rate was reduced by 22-28% and leaf temperature was reduced by 3o to 4o after coating with kaolinite (225 mg dm-2) Some chemical compounds reduce leaf temperature by reflecting solar radiation, which slows the rate of transpiration and increases the efficiency of water use by the plant (Jifon and Syvertsen, 2003).

- **Stomatal regulating compound**

Most antiperspirants act as a compound that closes the stomata when applied to the leaves. Some fungicides, such as phenylmercuric acetate (PMA), and herbicides, such as atrazine, act as an antiperspirant at low concentrations, causing stomatal closure (Zelitch, 1961). This can reduce photosynthesis. PMA was found to reduce transpiration more than photosynthesis (Zelitch and Waggoner, 1962). Initial studies reported that certain fungicides, including phenylmercuric acetate (PMA), copper oxychloride, and copper oxychloride, reduced transpiration in tomato and potato seedlings (Blandy, 1957). There are many effective stomatal regulating compounds, as well as their concentrations, percent reduction in transpiration and stomatal condition; phenyl mercuric acetate, 8-hydroxyquinoline sulfate, and decinyl succinic acid mono-methyl ester have been found to be highly effective compounds (Zelitch, 1968). Because stomatal openings affect CO_2 diffusion as well as water vapor flux, photosynthesis and growth can be altered when a stomatal-regulating compound is applied to the leaf surface. When stomata are reduced in size, transpiration should also be reduced to a greater extent than photosynthesis (Waggoner, 1965). Changes in transpiration (T) and photosynthesis (P) are due to changes in stomatal path length (S) described by Zelitch and Wagoner (1962).

Chemical which is use as antitranspirants?

- Chitosan
- Kaolin
- Abscisic acid (ABA)
- Salicylic acid
- Phenyl mercuric acetate
- Cycocel
- MgCO3
- CaCO3, etc.

Kaolin

Foliar application of kaolin has been shown to reduce the negative effects of water stress and improve plant physiology and productivity (Rosati et al., 2006). The use of kaolin increases the rate of photosynthesis in water deficit conditions by increasing photosynthetic pigments in plants, in low water conditions the application of kaolin can improve the photosynthetic response and increase photosynthetic pigments (Monroy, 2012) and help in increasing the water potential and osmotic potential in plants (Moftah and Humaid, 2005). It also increases the water use efficiency of plants by 25% (Glenn et al., 2010). Treatment with 1 to 6% kaolin produces a better response under adverse conditions, reducing transpiration rates and improving crop quality (Jifon and Syvertsen, 2003). Several treatments of kaolin clay create a colorless film on the surface of the leaves that reflects long wavelengths of solar radiation and slows down high temperature stress and water loss, and increases plant productivity (Mon, 2013). Kaolin helps to reduce the effect of heat and also protect the leaves from sunburn, but it can slightly affect the ion balance of the soil. Application of kaolin reduces leaf temperature by 3 to 4oC and also reduces leaf surface water loss by 22 to 28% in many species and increases relative leaf water content in plants and promotes photosynthetic activity, leading to increased biomass production (Khalil, 2012). Antiperspirants and percent soil moisture significantly affected daily transpiration rate, water use efficiency increased with low soil moisture and antiperspirants (Hagan and Davenport, 1970). The relative water content of leaves decreased due to low soil moisture, but increased with the use of antiperspirants, which relieved plant water stress (Patil, 1976).

Abscisic acid (ABA)

Abscisic acid is a plant growth substance that plays an important role in the response to environmental stress and plant pathogens (Giraudat, 1998). When the water potential of the soil decreases, it is produced in the roots and moves to the leaves, where it rapidly changes the osmotic potential of the stomatal cells, causing them to contract and the stomata to close. ABA induced stomatal closure slowed transpiration, thus preventing further water loss from leaves during low water availability (Kang, 2002). A concentration of ABA of 0.5 mg/L prevents chilling stress and helps reduce water loss in tomato plants, and also reduces the effect of water stress in artichoke after applying it to the leaf surface by closing the stomata (Takahashi *et al.*, 1993).

Salicylic acid (SA)

Salicylic acid increases chlorophyll, no. fruits, antioxidants, enzymes that perform the defence mechanism against moisture stress and all other growth parameters (Ahmed, 2014). Larque (1978) in his study reported that the application of salicylates can reduce the rate of transpiration and prevent stomatal water loss (Mishra, 2015), salicylic acid works as a signal transduction that activates ABA activity and is responsible for stomatal closure. in plants. This stomatal activity may affect another physiological phenomenon, such as stomatal closure, which may affect the process of photosynthesis. SA shows its effect on respiration, chlorophyll, but is most likely involved in the regulation of the photosynthetic reaction.

Chitosan

Chitosan is a mucilaginous polysaccharide that is non-toxic, has antimicrobial activity that helps the plant in its defence system. It is found by deacetylation of chitin, which is a structural component of the exoskeletons of crustaceans and some insects (Sanford, 2003). It has been experimentally proven that under drought conditions, chitosan increases chlorophyll pigments, it has been clarified that chitosan can induce the rate of photosynthesis and the accumulation of organic matter in wheat seedlings. Chitosan can enhance root development under water deficit conditions, which will aid in the absorption of more water to keep the moisture content stable (Zhang *et al*., 2002). Chitosan has strong potential value for agricultural applications. Examination of the stomata under an electron microscope and histochemical analysis prove that coating the leaf with chitosan partially or completely closes the stomata and prevents water loss from the leaf (Bittelli*et al*., 2001). Chitosan can take part in the biosynthesis of ABA, which is responsible for the convergence of stomata during water deficit in plants. The formation of chitosan films on the waxy surface of plant leaves determines their use as an antiperspirant. Chitosan acts as both a film compound and a physiological stomatal regulator through an ABA-dependent pathway (Kumar, 2013). Some film-forming compounds (chitosan) increase the reflectivity of the leaf surface, lowering the temperature of the leaf, reducing the absorption of radiant energy (heat), reducing the evaporation of water inside the leaf and its diffusion into the surrounding atmosphere (so-called transpiration). Stomata are the main way of exporting water vapor during plant growth. When emulsions of synthetic compounds are sprayed onto the leaf surface, they form thin films and limit gas exchange, increasing stomatal resistance to water vapor diffusion (Jardin, 2012).

Phenyl mercuric acetate (PMA)

Phenyl mercuric acetate is an example of such chemical compounds that affect stomatal regulation or control of stomatal activity by altering stomatal permeability and metabolic activity. Phenyl mercuric acetate is an organomercury compound, and in past studies, its activity was antitranspirant when applied to the surface of leaves (Ouda, 2007). In agriculture, mercury phenylacetate is used as a pesticide and should be used with caution because it is an inhibitor of mercury metabolism. PMA acts as stomatal proximal junctionPhenyl mercuric acetate is an example of such chemical compounds which affected on regulation of stomata or controlling the activity of stomata by changing their permeability andmetabolic activity. Phenyl mercuric acetate is an organ mercury compound and in past research its activity reported as anantitranspirant when applied to the leaves surface (Ouda, 2007). In agriculturephenyl mercuric acetate is use as a pesticide and it should be used with care since, it is mercury contain metabolic inhibitor. PMA act as stomatal closer compound

Cycocel

Stomata have been shown to play a significant role under water stress to cope with water stress, stomata converge to conserve water, and this stomatal activity affects gas exchange in PSII (Souza et al., 2004). These stomatal rules under drought stress slow down the actual rate of photosynthesis. The application of cicacel (CCC) under conditions of water stress reduces water loss from the plant's areal part and increases yield and vegetative growth, which is a useful tool to reduce transpiration losses, is becoming popular (Rouhi*et al*., 2007). Cycocel at a concentration of 500 ppm can help mitigate drought stress and significantly increase photosynthetic pigment (Memari*et al*., 2011). Cycocel also works as a growth inhibitor, foliar application of CCC reduces the transpiration rate but may slightly affect plant growth (Pandey *et al*., 2003).

Effect of Antitranspirants

Stomata are responsible for both photosynthesis (through CO_2 intake from the atmosphere) and transpiration (water loss). Antiperspirant plays an important role in reducing water loss and water conservation, but it may have some effect on plant growth (Obidiegwet et al., 2015). Some of the antitranspirants are not responsible for stomatal closure when applied to both upper and lower leaf surfaces, but they may be responsible for the reduction of photosynthesis when light is not adequately available (Latocha*et al*., 2009). Antiperspirant application has been experimentally proven to help reduce water loss, and these chemicals do not adversely affect or harm the plant's internal photosynthetic machinery. Mercuric phenylacetate, a chemical used as an antiperspirant that closes the stomata after application and an intermediate concentration of FMA (1-3.5 M) slows the rate of transpiration but may reduce the dry matter content of the plant. But it is also reported that higher concentration of FMA (10-13.2 M) shows a toxic effect on plants, which stops dry matter production and also increases transpiration (Abdullah, 2015). Generally, the growth and yield of field crops are highly dependent on photosynthesis. Therefore, currently available antiperspirants are unlikely to increase the yield of an annual crop unless the crop is stressed by insufficient water and/or very high evaporative demand, especially at a moisture-sensitive stage of development. When spraying stomatal-inhibiting or film-forming antiperspirants on field-grown sorghum under limited irrigation conditions, he found that grain yield increased by 5-17%, and application of the antiperspirant just before the loading stage was more effective, than later sprays (Fuahring, 1973).

Limitation of Antitranspirants

The possibility of using antiperspirants on grass to reduce the frequency of irrigation and mowing is an attractive prospect that deserves further study. The use of antitranspirants to reduce transpirational water loss from shrubs and trees in watersheds where increased water yield may be more important than any damage caused by reduced growth is a promising field for research and investigation (Davenport, 1970).Growth reductions from the use of antitranspirants should not be disadvantageous once the oleanders have attained a height effective for screening headlight glare. Growth retarded growth is retarded by natural stomata1 closure when an untreated plant wilts, because of low soil water potentials and/or high evaporative demand. By slowing down the rate at which water is lost, antitranspirants will help to prevent or at least will delay wilting. The use of an antitranspirant, and the resulting reduction in transpiration (which is unlikely to exceed 30 per cent under field conditions), should not reduce the rate of mineral supply to the leaves sufficiently to retard growth. Present evidence suggests that antitranspirants will affect growth much less by altering leaf temperature and mineral nutrient supply than by retarding carbon dioxide supply to leaves.

Plant growth regulators and their role in abiotic stress management

Abiotic stress, which includes factors such as salinity, drought and temperature extremes, causes enormous losses in agricultural production globally (Mickelbart et al., 2015). Plants respond to abiotic stresses to varying degrees (Hassan et al., 2015). It is necessary to use a combination of biotechnological tools for genetic improvement to increase plant resistance to abiotic stress (Mittler&Blumwald, 2010). This requires a detailed understanding of the mechanisms of plant resistance to adverse factors. A complex network of hormonal signals has been found to control plant response to abiotic stress (Bartsch & Bednarek, 2010; Lumba*et al*., 2010). Abscisic acid (ABA), ethylene and jasmonic acid (JA) are plant growth regulators with well-documented plant responses to abiotic stress (Grobkinsky*et al*., 2016). ABA is a central molecule involved in the response to drought and salinity (Suzuki *et al*., 2016). The action of these hormones in response to stressful situations can be developed through synergistic or antagonistic actions (Fujita *et al*., 2006).

Abscisic Acid (ABA)

The ABA is a phytohormone which is discovered in young fruits of cotton in 60 years, since then it has been reported in different 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). It is very important in the plant development as well as in response to various biotic and abiotic stresses (Klingler, Batelli& Zhu, 2010).

ABA Biosynthesis

The ABA biosynthetic pathway is known with accuracy (Marion-Poll & Leung, 2006). The *Arabidopsis thaliana plant* has been used as a model for the identification of the main enzymes involved in the metabolic pathway (Widemann*et al*., 2016). Precursor of ABA is isopentenyl diphosphate which is synthesized primarily in plastids (Yu &Assmann, 2014). Isopentenyl pyrophosphate leads to the formation of zeaxanthin, then the anteraxanthin, then the trans-violaxanthin, then the 9-cis-neoxanthin and finally xanthoxin. The 9-cis-neoxanthin is then cleaved to form a 15C compound called Xanthoxine. This step is the limiting step of the route. The xanthoxine is then oxidized at the cytosol to ABA-aldehyde, a reaction catalyzed by xanthoxine oxidase, and then this aldehyde is converted to ABA by the enzyme ABA-aldehyde oxidase (Wasilewska*et al*., 2008). The efficacy of the enzyme adjustment, its release, and the quantity of ABA contributes towards signal strength (Jiang & Hartung, 2008). The rupturing process can activate the ester of glucose as the first line of defense against the changing environment. It supports the fact that *Arabidopsis mutants* deficient in ß-glucosidases, contains lower levels of ABA in the leaves and develops phenotypes sensitive to stress. Vacuole or the apoplast stores the ABA-glucose ester and dehydration results in its transportation towards endoplasmic reticulum, where it denatures to produce the ABA (Lee *et al*., 2006).

ABA and the response of the plant to abiotic stress

ABA is the main hormone that provides tolerance to abiotic stresses, especially to salinity and drought (Hossain *et al*., 2010). It is known that the salinity, drought and low temperatures, ameliorates the biosynthesis of ABA. The activated genes that encrypt the enzymes mandatory for the biosynthesis of this growth regulator may be catabolised at the end of the stressful time (Chavez & Gonzalez, 2009). Within abiotic stress; salinity, drought and low temperatures 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; changes in the development patterns; or biochemical changes in the expression and accumulation of various response proteins that are speculated to perform a function in stress tolerance. In higher plants, ABA is involved in the control of various physiological processes which includes development of seed and adaptations of a plant according to various types of environmental stress. Under conditions of 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 increase. This increase in the ABA acts as a signal that can amplify the initial signal and start another signalling cascade (Chavez& Ramirez, 2010). The production of ABA in the roots and its transportation to the leaves is a mechanism of response to soil water deficit. It is a well-known role of ABA in the closure of stomata to prevent desiccation (Schachtman&Goodger, 2008). From tolerance to salinity and other types of stress, the role of the ABA appears to be the regulation of water balance in the plant and the osmotic stress tolerance. Numerous experiments indicate that there are dependent and independent pathways of ABA for the induction of the genes associated with abiotic stress (Li *et al*., 2010). The prompted expression mostly depends on the presence of *opens*, to which *bZIP*transcription factors are attached known as proteins that bind opens (RAEB) or factors RAEB (Wasilewska*et al*., 2008).

Numerous studies of *Arabidopsis* mutants deficient in ABA, appointed aba1, aba2, aba3 (Koornneef*et al*., 1998), and aba4 (North *et al*., 2007). ABA-deficient transgenic tobacco, tomatoes, and corn have also been reported (Liotenberg, North, & Marion-Poll, 1999). The role of the ABA in the osmotic stress tolerance is well known (Roychoudhury et al., 2013;), and there is some evidence of the role of the ABA in the control of ion homeostasis. For example, the contents of ABA increased slightly only in the leaves of the rice cultivars tolerant to salinity versus sensitive cultivars. This increase in the content of ABA was accompanied by a better relationship Na+ /K+ (Wei *et al*., 2015). Also, the transport and the accumulation of K+ in roots of higher plants is regulated by the ABA.

Many plants respond to the high levels of the salt abducting ions within the vacuole (Deinlein*et al*., 2014). This process is mediated by a vacuolar antiporter Na+/H+ that uses the proton gradient to concentrate ions against their gradient (Bassil&Blumwald, 2014). A characterization of five Antiportes of Na^+/H^+ showed that two transcripts of them, AtNHX1 and AtNHX2, accumulate in response. However, this accumulation does not occur in mutant aba1-2, which indicates that the stress response of these genes depends on the ABA (Yokoi *et al*., 2002). Numerous complementary genes have been isolated that encode ion pumps such as membrane ATPases and V-ATPase (Eisenach et al., 2014). The accumulation of these transcripts is triggered due to salinity; some of them are regulated by the ABA (Zhang *et al*., 2014). It is also important for the ion homeostasis, which is the increase in cytoplasmic free Ca^{++} that is induced by the ABA, an event covered by the cyclical ADP-ribose (Jiao, Yang &Gu, 2016). The identification of mRNA induced by stress or by the ABA, which encodes a membrane protein that binds to calcium (Kosová *et al*., 2013), and a specific phospholipase C to the phosphatidylinositol in *A. thaliana* (Hirayama *etal*., 1995), respectively. The insulation of the gene RD20, a protein that binds calcium that is induced by the ABA and the saline stress, suggests a link between the saline stress, the ABA, and calcium signal pathways (Chavez & González, 2009). Many salt tolerant plants share common genes that may help them to confront stress by the production of Proline, Glycine betaine, and the pinitol/ononitol (Debnath*et al*., 2011). The gene P5CS (proline carboxylate synthase), responsible for proline biosynthesis from glutamate, is expressed in *Oryza sativa* and *A. thaliana* in response to salt stress and ABA (Kishor*et al*., 2014).

Ethylene

Ethylene (C_2H_4) 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). The synthesis of ethylene oxide can be induced by an environmental stress such aswounds,hypoxia and attack by pathogens (Das *et al*., 2015). In horticulture, the ethylene is very important in the post-harvest stage of a great variety of fruits and vegetables (Ansari &Tuteja, 2015).

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 (Wang *et al*., 2002). In 1934, ethylene was considered as 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 a growing plant.

Biosynthesis of ethylene

The ethylene synthesis begins with the amino acid methionine and proceeds via S-Adenosyl methionine (SAM), 1-Aminocyclopropane-l-Carboxylic Acid (ACC) (Mao *et al*., 2015). The conversion of the ACC is carried out by the enzyme ACC oxidase (ACO). The SAM is also used in the synthesis of certain polyamines by the enzyme SAM decarboxylase. Multigene families encode enzymes, the ACC synthase, and ACC oxidase in many plants. The expression of the ACS and ACO genes is regulated and shows different patterns of expression and response to biotic and abiotic stress. The regulation of these genes may occur beyond the level of gene expression (Yoo *et al*., 2009). In plants, Ethylene has not a preferred site of biosynthesis but is produced by all the organs. However, the biosynthetic capacity and the amount produced varies from tissue to tissue, from organ to organ, from plant to plant. The biosynthesis is mainly induced by stress biotic and abiotic factors, so it is often called Hormone stress. Physiological studies on the interaction hormone and plant have shown that the productivity of a plant is inversely proportional to the concentration of ethylene in the environment. Usually, a sharp decrease is visible when the concentration ethylene ranges from 50-100 nmol mol^{-1} air (Klassen & Bugbee, 2004). The biosynthesis of this hormone is characterized by three key enzymes which catalyze sequential reactions. The ethylene formation begins with the methionine which it is converted into S-adenosine methionine by of an enzyme called S-adenosine methionine (SAM synthase). Subsequently, the S-adenosine Methionine is converted into acid 1-amminociclopropa- no (ACC) via the 1-amminociclopropano synthase (ACC synthase). Finally, the last step is catalyzed 1st-amminociclopropano oxidase (ACC oxidase) which leads to the formation of ethylene releasing animal carbon dioxide and cyanide (HCN). Ethylene production can be easily modulated, given the availability of wide range inhibitors of both biosynthesis and action (Mensuali-Sodi*et al*., 2005). The plants during the phase of development and differentiation are characterized by a production of ethylene high; then it decreases when they reach matured authority and increases again during senescence (Wheeler *et al*., 2004).

Ethylene and the response of the plant to abiotic stress

Synthesis of ethylene increases due to numerous stress factors such as injuries, salinity (Zhang *et al*., 2016), drought (Larrainzar*et al*., 2014), cold (Klay *et al*., 2014), the ozone layer (Das et al., 2015), and the waterlogging (Steffens & Sauter, 2014). In mature plants of wheat, changes in the biosynthesis of ethylene differ in terms of the tolerance of the variety, and the degree of water deficit imposed (Grzesiak*et al*., 2013). In the drought-tolerant varieties, ACC oxidase activity increases in the first 24 hours of stressful treatment, while in sensitive varieties, it decreases. There are variations in the biosynthesis of ethylene in the susceptible and tolerant varieties of wheat (Valluru*et al*., 2016).

The radical level oxygen deficiency can be a good physiological and biochemical model for com- take the correlation between the abiotic stress and pro- ethylene production. In fact, in asphyxia radical for water excess or compaction soil the roots increase the production of ethylene. Their first observation was determined in roots and stems Tomato under hypoxic conditions (Bradford & Dilley, 1978). In conditions of oxygen deficiency, ACC cannot be oxidized but is translocated in the shoots where it is rapidly transformed into ethylene.

Production of ethylene increases with temperature within determined intervals under water stress conditions (Morgan & Drew, 1997), salt (Kamei *et al*., 2005), mechanical injury (Morgan *et al*., 1993) and in the presence of pollutant ozone (Vahala*et al*., 1998). However, in some cases, it was also observed a decrease in production, as in conditions of thermal excesses (Field, 1981), and prolonged water shortage conditions (Morgan & Drew, 1997). Other authors suggest that ethylene may not play a major role in the plant's response to water deficits because significant accumulations were observed in the content of this regulator in sorghum (Cao *et al*., 2007), or in wheat plants of six weeks (El-Khallal*et al*., 2009). Recent studies have elucidated almost completely the role of ethylene in the plant have been identified the receptors with which it interacts, and some transcription factors mediated by ethylene were characterized (Guo & Ecker, 2004). There have been no reported alterations in the signalling of ethylene in plants affected by saline stress. A homolog of the ethylene receptor gene NTHK1 of tobacco, suggests sensitivity to salinity of Arabidopsis plants by phenotypic transformation, the electrolyte equilibrium, and the comparative growth of the root under saline stress (Zahra *et al*., 2011). The physiological and biochemical responses to conditions anoxia and hypoxia are very rapid, and the production of ethylene can be about 8-15 times higher than the level normal them. Molecular biology studies have shown that the low oxygen conditions determine the AT- ACC synthase activation of specific stress-dependent both in tomato than in rice (Zarembinski&Theologis, 1993). These results show that the end, i.e. the production of ethylene, does not vary, but the activated genes coding for the same route. This genetic organization probably gives the plant flexibility which makes it able to respond in a specific way to every type of stress.

Jasmonic Acid (JA)

The Jasmonic Acid Methyl Ester (JAME) was first isolated from the essential oils of *Jasminum grandiflorum* in 1962 (Demole *et al*., 1962). Jasmonates are phytohormones lipid-derived oxygenated fatty acids, linoleic and linolenic acids mainly, that act as signaling molecules the plant's reaction to numerous situations of biotic and abiotic stress and participate in various processes of the development of the plant (Avanci*et al*., 2010). The conditions of stress that regulate are the injuries (biotic or mechanical), exposure to ozone, drought and the attack by pathogens and pests. Jasmonates plays a significant role in the growth and development of roots and tubers, the maturation of fruits, senescence (Sudan *et al*., 2014), and development of pollen (Wasternack*et al*., 2013).

Biosynthesis of Jasmonic Acid

The Jasmonic Acids are compounds that possess structural and functional homology with steroids and prostaglandins originated in animals from arachidonic acid (Kazan & Manners, 2008). The Jasmonic Acid is a cyclopentenone that has a string and a Carboxylic pentenyl glucosinolate. Vick and Zimmerman (1984) explained the biosynthesis of Jasmonic acid. Fatty acids esterified membrane, the phosphatidic acid (PA) and inositol triphosphate (IP3) are involved in calcium signaling in response to stress (Bargmann&Munnik, 2006). Fatty acid residues such as the *oxylipins* include the Jasmonates which comprises the Jasmonic acids, JAME, conjugates of Jasmonic acids with amino acids, and other metabolites of Jasmonic acids. Lipoxygenase (LOXs) initiates the production of *oxylipin* form hydroperoxides of linolenic acid or the linoleic acid (Feussner&Wasternack, 2002).

The conversion of the 13HPOT in an oxide of unstable Allene, catalyzed by the enzyme 13 AOS initiates the biosynthesis of the JA (Bargmann&Munnik, 2006). The Allene oxide cyclase AOS belongs to CYP74A enzymes. It exhibits a low affinity for the CO2 and uses the hydrogen peroxide as oxygen source and reduction equivalent (Brash et al., 2013). The enzyme, Allene oxide cyclase (AOC), is also located in the plastids (Hause et al., 2003). The AOC establishes a structure in the enantiomeric cyclopentenone ring that appears in the Jasmonic Acid. Lack of AOC results in the development of the racemic OPDA and the cleavage to α- and γ-ketol (Wasternack, 2015). The product of the AOC, cis 12 Oxo-phytodienoic acids (OPDA) is the end product of the part of the synthesis of Jasmonic acid that takes place in the chloroplasts. Peroxisomal reductase (OPDA reductase) OPR catalysis the reduction of cyclopentenone ring (Strassner*et al*., 2002).

Except for the steps of ß-oxidation, which take place in peroxisomes (Strassner*et al*., 2002), the specific enzymes for the biosynthesis of Jasmonic Acids (13-LOX, AoS, and AOC) have been cloned (Schaller, Schaller &Stintzi, 2005). The three proteins, "acyl-CoA oxidase (ACX)," "the multifunctional protein (MFP)," and "the L-3-ketoacyl-CoA thiolase (CAT)" catalysis the ß-oxidation. Possibly the activity of an additional *Thioesterases*would be involved in the release of jasmonic acid of AJCoA, final product of the ß-oxidation (Schaller*et al*., 2005). Therefore, the biosynthesis of JA and metabolism occurs in the chloroplast, the peroxisome, and the cytoplasm where they occur and various modifications of JA: methylation, hydroxylation, and conjugation (Li *et al*., 2005). Biosynthesis of Jasmonic acid is inducible through the genes responsible for their production (Wasternack*et al*., 2006), and the analyzed promoters increase their activity after treatment with JA. The biosynthesis of JA not is induced by the endogenous JA, which suggests that the perception of the JA is extracellular.

The JA and the plant Response to abiotic stress

The Jasmonic acid and its derivatives are considered to be components of the transduction of signals in the defense mechanisms of the plants and increases have been recorded in their endogenous levels in plants subjected to water stress (Fonseca*et al*., 2009). They induce the expression of genes that encode specific proteins, which may include protease inhibitors, enzymes involved in the biosynthesis of flavonoids, osmotics, and lipoxygenase, and different proteins associated with the pathogenesis (Andrade *et al*., 2005). In relation to the role played by the JA and its derivatives in the responses to stress, there is evidence that tolerant plants have higher levels of these compounds than the sensitive ones (Boex-Fontvieille*et al*., 2016). In tomato, the cultivar Pear tolerant of salinity presented higher endogenous levels of JA and its precursor, 12- Phytodienoic Acid (cis-OPDA), than the sensitive cultivar *Fruhstammhellfrucht*. In addition, both cultivars responded to salt stress by changing their levels of JA. On the other hand, in response to the saline treatment, the accumulation of enzyme proteins involved in the synthesis of JA, such as lipoxygenase (LOX) and Allene oxide synthase (AOS), and protein induced by JA, the protease inhibitor (pin2) was observed. The accumulation of LOX was pronounced in plants of *Fruhstammhellfrucht*under stress. On the other hand, the accumulation of mRNA of Allene oxide synthase (AOS- mRNA) and protease inhibitor mRNA (Pin2- mRNA) was observed with treatment with NaCl and JA, indicating that the saline stress causes a differential response in sensitive and tolerant plants (Pedranzani*et al*., 2003).

Hashimoto *et al*. (2004) found a pathogen-related protein PR10 in rice, RSOsPR10, who's mRNA was induced rapidly in the roots due to salt stress and drought. In soybean leaves subjected to the loss of 15% of the fresh weight, the levels of JA increased five times after two hours of stress, while it decreased the levels of control around four hours. In this research, it was noted that the implementation of the methylated JA, had no effect on the rate of transpiration. Creelman and Mullet (1995) concluded that the rapid induction of JA levels observed in the leaves with water deficit is due to the loss of turgor and changes related to the transport of ions, while it had no influence on the closure of stomata (de Ollas& Dodd, 2016). On the other hand, other authors like Reinbothe*et al*. (1992) and Wasternack (2014) noted that several peptides induced by the methyl ester of the JA share homology with the proteins read (late embryogenesis abundant) that are induced by the stress or the ABA.

The Jasmonic acid and its cyclic precursors or derivatives are found in different stages of the biological cycle of a plant; from the development of seeds and pollen, the elongation of the roots. Moreover the Jasmonic acid forms in response to stress chemical or physical and attacks of pathogens. JA is involved in the regulation of some genes responsible for defence mechanisms such as chitinase B, thionine 2.1 and others. In the promoter of the gene encoding PDF1.2 in *A. thaliana* was demonstrated the presence of reasons GCC responsible for the recognition by the Jasmonate (Brown *et al*., 2003). Some of these genes are used as markers for the study of the response of defense mediated by JA (Kunkel & brooks, 2002).

Salicylic acid and abiotic stress tolerance

As a phytohormone, the role of SA in the regulation of plant growth and development is well known. The role of SA in mitigating abiotic stress has been extensively studied since the last few decades. A large body of research reports indicates that both endogenous SA synthesis and exogenous application increase plant tolerance to salinity, drought, and temperature extremes (Singh *et al*., 2016), toxic metals and metalloids, etc. Exogenous SA has shown enhanced plant growth, photosynthesis, and reduced ROS production under various abiotic stresses.

- **Salinity**

Among the predominant catastrophic abiotic stresses, salinity or salt stress can be considered the most destructive. It shows enormous negative effects, both direct and indirect, on the morphological, physiological and biochemical characteristics of plants. When plants are exposed to salt, they face not only osmotic and ionic stress, but water scarcity and other consequent stresses can also occur. This ultimately reduces the quality and quantity of the desired crop. However, the good news is that there are some species that show some tolerance mechanisms, as well as some defences that can help plants develop tolerance to salt stress. In the recent era, when global warming and sea level rise are the most alarming issues, these may be promising facts to consider for further research. There are a number of studies proving the protective role of SA against salt stress in many plant species.

- **Drought**

Drought stress is one of the most destructive abiotic stresses that negatively affects the processes of plant growth and development. Drought stress affects physiological processes, introduces biochemical changes, leads to the formation of secondary metabolites, significantly accumulates endogenous reactive oxygen species (ROS) and increases toxins (eg, methylglyoxal). Drought stress that interferes with reproductive development dramatically reduces plant yield or productivity (Hasanuzzaman*et al*., 2014). Several studies have demonstrated and proven the key role of SA in reducing drought damage and increasing plant tolerance to drought stress.

- **Extreme temperatures**

Temperature is one of the vital factors that determine the establishment, growth, development and productivity of plants. Due to climate change, the average global temperature fluctuates very rapidly and threatens the survival of living things. Thus, among the various abiotic stresses, extreme temperature has become a topic of conversation in recent decades due to its devastating and destructive effects on plants (Hasanuzzaman*et al*., 2012).Extreme temperature includes both high temperature (HT) and low temperature (LT) that can damage plants. High temperature is an increase in temperature beyond a critical threshold level that can deplete plant growth and metabolism depending on a sufficient period of time (Wahid, 2007). Heat stress is often exacerbated by its combination with other stresses, including drought (Mittler, 2006). High temperature seriously changes the physiological processes of plants, including germination, photosynthesis, respiration, transpiration, distribution of dry matter, etc. (Nahar *et al*., 2015). In addition, HT leads to enzyme inactivation, protein denaturation, protein and membrane disruption, which ultimately affects plant growth. Low temperature consists of both freezing temperatures (<0 ^{0}C) and freezing temperatures (0–15 0C). During chilling stress, the plant is damaged without the formation of ice, whereas during freezing, the formation of ice occurs in the tissues of the plant. Chilling and freezing stress are collectively referred to as cold or LT stress. Low temperature stress exhibits various deleterious symptoms in plants, including faster senescence and decay (Sharma and Dubey, 2007; Solanke and Sharma, 2008), impaired germination, cell membrane disruption, photosynthesis, water and nutrient uptake, reproductive development, and growth and productivity (Hasanuzzaman*et al*., 2013). HT or LT conditions at the molecular level lead to overproduction of ROS, which ultimately leads to oxidative stress (Hasanuzzaman*et al*., 2012; Suzuki and Mittler, 2006). Nowadays, for the development of temperature and stress resistance, the use of exogenous SA is one of the common approaches. Salicylic acid, being an endogenous growth regulator or phytohormone, acts as an important signaling molecule and develops resistance to abiotic stress in plants (Suzuki and Mittler, 2006).

- **Toxic metal/metalloids**

In the industrial age, the most important and potential threat to crop production is abiotic stress. Among them, toxic metal stress is one of the major problems. Population growth and rapid industrialization coincide together, resulting in the creation and distribution of huge amounts of toxic metals in the environment (Hasanuzzaman*et al*., 2012). Toxic metal consists of a set of harmful elements that have no biological role in organisms, such as Cd, Pb, Hg, St, Al, etc. Although toxic metals and heavy metals (HM) are often considered synonymous, some lighter metals such as Al can also cause toxicity. Toxic and TM differ in biological role. Some TMs that have biological roles in plants are also considered toxic when used in high concentrations, ie. Ni, Cu, Zn, etc. On the other hand, a metalloid includes those elements that behave as both metals and non-metals, including B, Si, Ge, St, As, Sb, etc. The parent material and the atmosphere are the two main sources of toxic metals. Metals are readily absorbed and accumulated by plants, causing toxicity in plant tissues. They directly interact with proteins, enzymes and cause phytotoxicity. Inhibition of growth rate is the most definite consequence of metal toxicity (Sharma and Dubey, 2007). Leaf curling, chlorosis, necrosis, stunted growth, stomatal dysfunction, cation efflux, reduced water potential, changes in membrane, photosynthesis, metabolism and various key enzymes are some other toxic effects of metals in plants (Sharma and Dubey, 2007; Dubey, 2011). . Toxic metals also manipulate nutrient homeostasis, water uptake, transport, transpiration, respiration and can ultimately lead to plant death (Fodor, 2002; Poschenrieder and Barceló, 2004). Metal toxicity at the cellular level leads to overproduction of ROS (Hasanuzzaman and Fujita, 2012). To mitigate the stresses caused by metals in plants, plant biologists are trying to develop new strategies. Salicylic acid is a very important molecule that induces protective responses against various toxic metals/metalloids.

2. Conclusion

Currently, water stress is very common and italso substantially impacts yield. A transpiration suppressant agent, i.e. antitranspirant, not only reduces transpiration rate, but it also improves a number of physiological attributes, including several vegetative and reproductive parameters, disease resistance, qualitative characteristics, and, most importantly, greatly increases yields and yield contributing traits in cereal crops. A variety of growth, qualitative, and yield attributes have been improved by the application of antitranspirants such as stomatal closing (PMA, potassium chloride), film forming (chitosan), reflectance type (kaolin) and growth retardant (cycocel). Hence, antitranspirants and PGR's can mitigate water stress conditions and improve crop productivity under climate change conditions.

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