Role of Secondary Metabolites and Phytohormones in Drought Stress Tolerance

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ABSTRACT

Various biotic and abiotic stresses affect plant growth and development. Among them, Drought stress also concerning abiotic stress that affects the growth and development of the plant. It can also affect the quality as well as quantity of agricultural produce and ultimately leads to plant death in severe stress conditions. Plants have different mechanisms to cope with these stresses. Secondary metabolites and phytohormones are the structures that play a major role in the plants surviving in that environment and overcoming the stressed conditions. Different plant hormones like Cytokinins, Ethylene, Brassinosteroids, Jasmonates, Abscisic acid, and Salicylic acid induces the accumulation of Osmolytes in the plant tissues, which helps the plants to survive under various abiotic stress conditions. In this review, we will discuss various roles and pathways of secondary metabolites and phytohormones along with their functions in the plants under drought stress.

Keywords: Agriculture, Biotic, Drought, Secondary metabolites, Phytohormones

INTRODUCTION

Secondary metabolites are organic compounds that are not directly involved in the growth and functioning of the plants. Bacteria, fungi, and plants produce these compounds. Secondary metabolites, this term is coined by Albrecht Kossel 1st time in 1910. After 30 years, these are described as the product of nitrogen metabolism by Polish botanist Friedrich Johann Franz Czapek (Bourgaud et al., 2001). Phytohormones are chemical compounds that are involved in the cellular activities of plants. They help the plant in adverse conditions especially in stress conditions to survive under environmental stress. Secondary metabolites emote the main part to survive the plant under stressful environment and help the plant to overcome stressed conditions like temperature, humidity, high and low light intensity, excess and scarcity of water, minerals, and carbon dioxide influence, etc. which affect the growth and development of the plant and induce secondary metabolite production. Drought stress is one of the most important abiotic stresses, which affect the development, quality, or quantity of agricultural produce, and ultimately leads to the death of the plant in severe stress conditions. Plant secondary metabolites do not have the basic role of maintaining the plant different life processes but it is a most important compound in protecting the plant against adverse biotic and abiotic conditions and helps in survival and interaction with the environment. Primary metabolites are carbohydrates, lipids, and amino acids, which directly interact with the growth and development in every stage of plant life. In higher plants, these undergo the synthesis of widely distributed secondary metabolites, which are required in plants against stress tolerance (Seigler, 1998). Phytohormones like abscisic acid (ABA), salicylic acid (SA), jasmonic acid (JA) are involved in the stress tolerance in the plants. They play a major role in the physiological and biochemical mechanism of the plant and provide a shield to tolerate and protect the plant from a stressful environment. There are three main groups of secondary metabolites based on biosynthetic pathways and activities of the plants. These groups are viz., nitrogen-containing compounds, phenolic compounds, and terpenes (Fang et al., 2011).

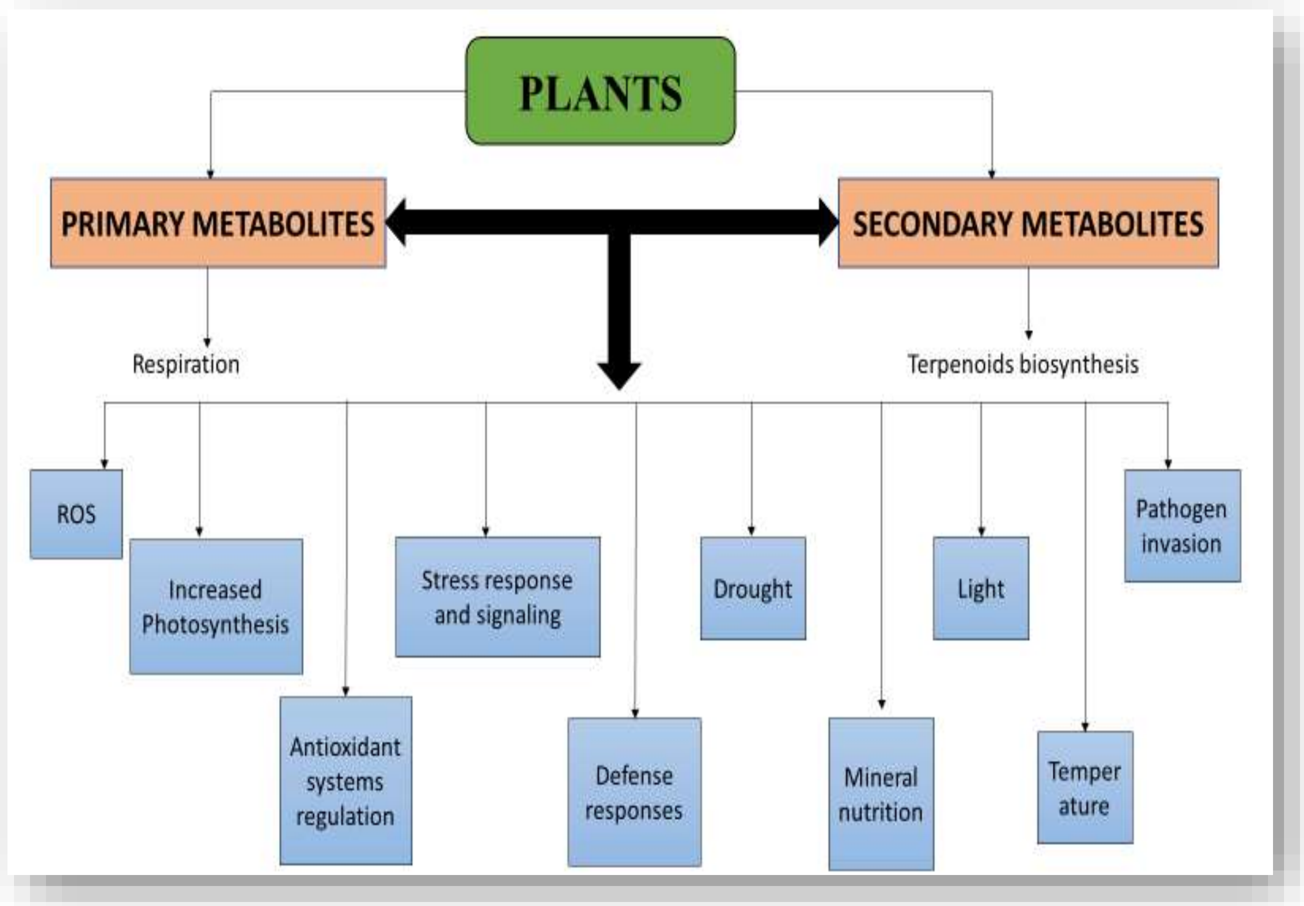
EFFECT OF DROUGHT STRESS ON PHYSIOLOGY OF PLANT

Under drought stress, plants face many challenges in the physiochemical and molecular functioning of plants, which can ultimately affect the growth, development, and yield in terms of both quality and quantity of the plants (Hussain et al., 2018, Ahmad et al., 2018). During drought stress, by light-harvesting mechanization, there is a comparable decrease in the activity of photosynthesis in the plants, which further decreases the functioning of the enzyme Rubisco. The photosynthetic performance also declined by the malfunctioning of the structure of the chloroplast. Drought condition stimulates the carbon dioxide level in the plants, which takes part in the photosynthetic electron transport generation. This process results in an increased degeneration of ROS activity, which directly affects the photosynthetic apparatus and damages the apparatus so that decreases the level of photosynthesis (Basu et al., 2016). Due to the dysfunctioning of photosynthetic apparatus in drought stress, there is a decline in photosynthetic rate, stomatal conductance, transpiration rate, photochemical efficiency of PSII, and photosynthetic electron transport. During drought or water deficit conditions, the closing of stomata is regulated by the increase in the level of abscisic acid (ABA). This acts as a molecule of signaling which regulates the functioning of various physiological and molecular processes. Due to drought, there is a decline in water potential and a decrease in the relative water content of the plants (de Campos et al., 2011). With the decrease in the water potential, there is a great decrease in the uptake of the many different macro and microelements, nitrogen transports and its metabolism, reduction in compounds like ammonium transporter, nitrate reductase, nitrite reductase, and glutamine synthetase. During water stress at the root zone, there is a great decline in the growth of the root tissues, which affects the nutrient uptake by the roots and their translocation to the target sites from roots to shoots.

SECONDARY METABOLITES UNDER ENVIRONMENTAL STRESSES

In response to biotic and abiotic factors, there is variability in the accumulation of secondary metabolites. The variability in accumulation leads to the biosynthesis of the secondary metabolites (Zhi-lin et al., 2007). Plants often brought to damage due to biotic and abiotic stresses while growing under natural environmental conditions and the variability in the concentrations of the secondary metabolites also takes place as if plants are grown under the above conditions (Radusiene et al., 2012). Environmental stresses such as drought, salinity, high and low temperature, etc. target the synthesis of these secondary metabolites and harm the functioning of the plant species. In this way, these biotic and abiotic stresses serve a crucial role in the synthesis of the secondary metabolites in the plants. With the synthesis of secondary metabolites, plants perform a task of tolerance against pathogen attack. For example, phytoalexins have some antimicrobial activities, which perform the task of defence against the attack of pathogens and protect the plant under abiotic stresses (Taiz and Zeiger, 2006). The plants show enhanced biosynthesis and accumulation of secondary metabolites when under pathogen attack.

Fig.1: Functions of primary and secondary metabolites



INFLUENCE OF DROUGHT STRESS ON SECONDARY METABOLITES

Drought stress adversely affects plant growth and development. It is most crucial among abiotic stresses, which affect the overall productivity of the crop and affect both its quality as well as quantity (Xu et al., 2010). Drought stress occurs when there is not a sufficient supply of water to the plants. Atmospheric conditions continue a great loss of water and there is a reduction in the available water utilized by the plants. All plants have a different mechanism to tolerate these stresses but it varies from species to species. Usually, the reason behind drought stress occurrence is water deficit followed by the high temperature, which ultimately affects the growth and quality of the produce (Xu et al., 2010). Drought stress and salinity stress are a big problem in the field of agriculture to ensure the survival of crops and sustainable food production (Gosal et al., 2010). Drought stress leads to oxidative stress and shows a great increase in the level of flavonoids and phenolic acids (Larson, 1988). Drought stress also causes an alteration in the carotenoids, chlorophyll “a” and chlorophyll “b” ratio (Anjum, et al., 2003). Drought stress conditions decrease the amount of chlorophyll, saponins in the plants cotton, Chenopodium respectively, and accumulation of anthocyanin occurs under drought stress at very low temperature (Soliz-Guerrero et al., 2002). Anthocyanin usually provides resistance against drought stress in the plants and secondary metabolites play a role in maintaining the growth of the plant even under stressful environments. Flavonoids also have functions to protect the plants under drought stress. Anthocyanin present in plant tissues helps in protecting the plants against drought stress. The various influence of drought stress on plant secondary metabolites is given in table 1.

Table 1: Influence of drought stress on various plant secondary metabolites

Secondary Metabolites	**Plant Species**	**References**
Glycosides	*Scrophularia ningpoensis*	Wang et al. (2008)
Morphine alkaloids	*Papaver somniferum*	Szabo et al. (2003)
Trigonelline	*Glycine max*	Cho et al. (2003)
Glucosinolates	*Brassica napus*	Jensen et al. (1996)
Chinolizidin alkaloids	*Lupinus angustigolius*	Christiansen et al. (1997)
Epicatechins	*Camellia sinensis*	Hernaendez et al. (2006)
Betulinic acid	*Hypericum Brasiliense*	de Abreu et al. (2005)
Rutine	*Hypericum Brasiliense*	de Abreu et al. (2005)
Flavonoids	*Prisms sativum*	Larson (1988)
Anthocyanins	*Prisms sativum*	Noguees et al. (1998)
Chlorogenic acid	*Helianthus annuum*	Del Moral (1972)
Rosmarinic acid	*Salvia miltiorrhiza*	Liu et al. (2011)

Source: Bartels and Sunkar 2005

ROLE OF SECONDARY METABOLITES UNDER DROUGHT STRESS

Water plays an important role in the plant life cycle. All the processes from germination to the maturation phase require water. It plays a vital role in the transportation of minerals, nutrients, and metabolites in different parts of the plant. Drought stress creates the unavailability of an adequate amount of water and a higher transpiration rate, which ultimately causes a change in the production of secondary metabolites. Drought stress or water deficit negatively affects the plant growth and physiological processes of the plant, which ultimately causes a great decrease in the quality and quantity of the produce (Lisar et al., 2012). Drought stress decreases the photosynthetic rate, the activity of enzymes and causes changes in the morphological, physiological, and biochemical processes of the plants. Drought stress also affects the productivity of the various important cereal, pulses, and vegetable crops (Valentovic et al., 2006). There are several secondary metabolites synthesized in the plant body, which help protect the plant under drought stress conditions and creates drought tolerance capacity (Verma and Shukla, 2015). The interior increasing level of secondary metabolites was observed in various medicinal plants. Water scarcity increase in phenolic compounds, photosynthetic pigment and decreases in the plant biomass (Azhar et al., 2011). Drought stress resulting in the enhanced quality of secondary metabolites viz, rutin, quercetin, and botulinic acid (Verma and Shukla, 2015). Similarly, when plants are exposed to extreme drought stress, it results in a great decrease in photosynthetic activity and consistently a great increase in the concentration of secondary metabolites, which includes pseudo hypericin, hypericin, and hyperforin (Zobayed et al., 2007). The concentration of total flavonoids also increased due to drought stress conditions faced by the plant. In *Ocimum americanum* and *Ocimum basilicum* the concentrations of different macronutrients, proline, carbohydrates, and essential oils are significantly affected by water scarcity or drought stress conditions (Khalid, 2006).

Table 2: Drought-Induced changes in the Biosynthesis and Storage of Plant Secondary Metabolites

NAME OF THE PLANT	LEVEL OF THE DROUGHT	EFFECT OF THE CONC. OF SECONDARY METABOLITES	REFERENCE
Grapevine	70 and 30% soil moisture	Grapevine plants show various changes in the biosynthesis of different compounds, which mainly affect the concentration of secondary metabolites. The referred author did the experiment and he observes that there are ester-bound forms of all acids in the leaves and roots of the grapevine while caffeic acid is present in free form. The amount of phenolic caffeic acid is maximum as compared to the amount or concentration of ferulic acid, which is less in the amount present in the experimented plant. Under drought stress or water deficit conditions, the amount of these compounds decreased eventually in the plants. Hence, from his experiment, he concluded that there is a significant decrease in the concentration of secondary metabolites under drought stress.	Kroel et al. (2014)
Achillea species	Field capacity 25%, 50%, 75, and 100%	The author experimented with a trial to find out the effect of drought on secondary metabolites and their compounds. He mainly focuses on antioxidant activity, proline, flavonoid, and phenolic compounds. Under normal to severe water deficit conditions, there is an increase in the concentration of total phenols and flavonoids. There is a change in the concentration of secondary metabolites under severe drought conditions.	Gharibi et al. (2016)

Triticale	Field capacity 70% and 25%	An experiment was conducted on triticale at the flowering stage on drought-sensitive and drought-resistant varieties. The phenolic compounds and other acids were observed in this experiment. The author observed that under drought stress, there is a significant increase in the amount of ferulic acid and other phenolic compounds in the genotypes, which were drought-resistant, and in drought-sensitive varieties, there is a decrease in the level of ferulic acid. The experiment shows that the accumulation of these phenolic compounds can lead to drought resistance in the plant.	Hora et al (2009)
Rice	soil moisture 85, 65, 45%, and 25%	The author on various genotypes of the rice crop observes the effect of drought stress. It had been observed that there is a significant increase in the accumulation of secondary metabolites under drought stress in the different genotypes of the rice plant, which creates drought tolerance ability in them. The author takes two genotypes Q2 as the drought-sensitive and Q8 as the drought-tolerant rice genotype. Due to drought stress, the level of antioxidant activities and different phenolic compounds increases in drought-tolerant genotype while there is a great decrease in sensitive varieties. Vanillic acid and p-hydroxybenzoic acid is the determinates of drought stress which was only seen in the Q8 type genotype which is drought-tolerant varieties.	Quan et al. (2016)
Maize	PEG-induced stress (−0.6 MPa)	An experiment was conducted on the maize plant to know the various changes in the concentration of secondary metabolites. Drought stress with PEG-induced causes a great decrease in the phenolic compounds ultimately, which causes a great decrease in the structure and biomass of the maize plant.	Asgari and Shiri (2015)

Safflower	100, 50%, and 25% water deficit conditions	There is a great reduction in the number of carotenoids and phenolic compounds, which affect the growth of the sunflower plant. There is a sufficient increase in the phenolic compounds in mild and moderate drought stress and on the other hand, there is a great decrease when there is a problem of severe drought stress. The level of carotenoids also higher in mild to moderate water deficit conditions.	Saleem et al. (2014)
Maize	Field capacity 30%–35%	Severe drought stress in maize plant decrease the growth and development of the plant and level up the accumulation and regulation of secondary metabolites in the maize plant under drought stress conditions.	Latif et al. (2016)
Maize	Field capacity 30%– 35% and 70%	Accumulation of phenolic compounds shows drought tolerance in the plant, conducted another experiment on the maize plant. During this experiment, he do various changes in the level of phenolic compounds, flavonoids, ferulic acids, etc. The low water potential was found in the varieties under the accumulation of ferulic acid and total phenolic compounds in the maize plant. Total phenols absorb light and convert it into blue light, which is helpful for the photosynthesis and regulation of stomatal conductance. Phenolic compounds work as photoprotection as it reduces the excitation of chlorophyll content during drought stress.	Hura et al. (2008)
Glysine max	Drought stress (−90 and −100 kPa)	During drought stress conditions, there is a great increase found in the level of total phenols and lignin, which help them to survive underwater deficit conditions.	Nacer (2012)

GLUCOSINOLATES

Secondary metabolites play a major role in protecting the plants under various environmental stresses. Among these Glucosinolates comes under a nitrogen-containing compound is very important to take part in a defence mechanism and to improve the immunity of the plants under stressed conditions (Katz et al., 2015). The various enzymes involved in this process of breakdown and synthesis of new compounds. The enzyme myrosinase break glucosinolates into thiohydroximate-O-sulfonates, which rearranges itself, and make isothiocyanates (ITC), nitriles, and related compounds (Bednarek et al., 2009). To determine that a decrease in drought tolerance is due to the lower amount of glucosinolates an experiment was conducted on mutants and glucosinolates levels, which show that a reduction in glucosinolates results in lower drought tolerance. The plants having a great concentration of glucosinolates generally tolerate drought stress.

PHENOLICS

To resist the negative effects of the environment under stress conditions, phenolic compounds play a major role. Accumulation of Phenolic compounds is very important to neglect the effect caused by the drought stress on plants (Naikoo et al., 2019). Various metabolic studies, especially on the Arabidopsis plant, show that under drought stress accumulation of flavonoids takes place, which provides protection against drought stress and makes plants survive under adverse conditions (Nakabayashi et al., 2014). Biosynthesis of flavonoids occurs in the plants helps them to increase resistance against drought stress. Biosynthetic actions of these phenolic compounds lead to an increase in the accumulation of flavonoids and phenolic acids, which are regulated by drought stress and protect the plants against drought stress by acting as antioxidants (Nichols et al., 2015). In the tomato plant, increased concentration of flavonoids like kaempferol and quercetin increases the tolerance against drought stress. Because of drought stress, the accumulation of flavonoids in the cytoplasm can detoxify the harmful hydrogen peroxide molecules. These harmful H_2O_2 molecules are generated by the action of drought stress in the plants. After the oxidation of flavonoids, there is a reconversion of flavonoids by ascorbic acid into primary metabolites, which increases the tolerance capacity of the plants against drought stress conditions (Hernandez et al., 2009). The reason behind the accumulation of these phenolic compounds in the formation of phenylpropanoid biosynthetic pathway, which results in the biosynthesis of phenolic compound and regulates many enzymes and genes in the plant cells to protect them from drought stress.

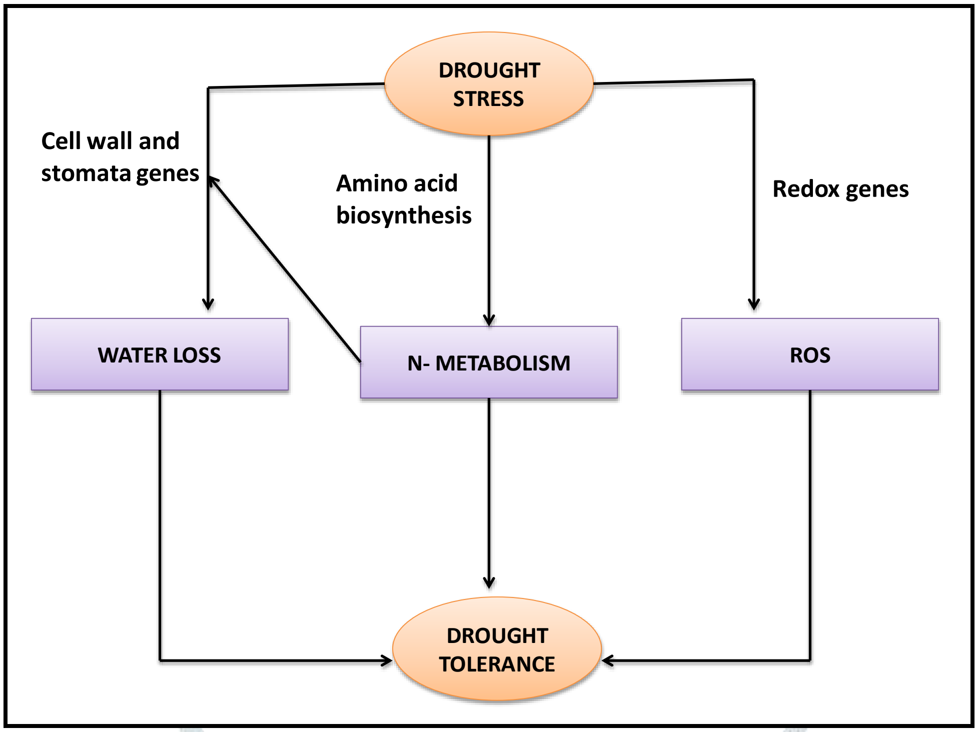
Table 3: The impact of drought stress on the accumulation of phenolic and related processes

Name of the Plant	Endogenous Phenolic and Related Parameters response	References
Achillea spp.	The significant increase in the contents of chlorogenic acid, caffeic acid, rutin, luteolin-7-O-glycoside, 1,3-di caffeoylquinic acid, luteolin, apigenin, and kaempferol under 21 days exposure of drought in Achillea spp. Enhanced transcript levels of PAL, CHS, CHI, F3H, F30H, F305 0H, and FLS	Gharibi et al., 2019
Brassica napus	The significant increase in the contents of total phenols, flavonoid, and flavonol. Increase in PAL enzyme activity followed by enhanced expression of PAL.	Rezayian et al., 2018
Cucumis sativus	Up-regulation of phenolic metabolites including vanillic acid and 4-hydroxycinnamic acid.	Li et al., 2018
Nicotiana tabacum	The significant increase in PAL enzyme activity and lignin content.	Silva et al., 2018
Triticum aestivum	The significant increase in the content of total phenols Increases the total contents of phenolics, flavonoids, and anthocyanins. Enhanced expression of genes like CHS, CHI, F3H, FNS, FLS, DFR, and ANS.	Ma et al., 2014

TERPENES

The stimulation of terpenoids is mainly dependent upon temperature. Under low to moderate drought stress conditions, the plant accumulates carbon, which stimulates the synthesis of terpenoids helps in the defence mechanism of the plant against severe drought stress or water deficit conditions (Lluisa and Penuelas, 1998). Temperature plays a major role in the synthesis of terpenoids because higher temperature increases their volatility (Lerdau et al., 1997). Terpenoids functions decrease with the increase in the duration of drought stress i.e. prolonged drought stress decline the functioning of terpenoids whether seasonal mild and moderate drought stress conditions increase the stimulation and functioning of the terpenoids and help in protecting the plants under abiotic stress. Therefore, for terpenoid stimulation, severe drought stress serves as a determining factor to determine the relative reduction in the synthesis of terpenoids. There is no direct link between carbon assimilation and terpenoid synthesis shown in some plants. The carbon assimilation increases with an increase in the drought stress and relative concentration of terpenoids depleted by high temperature and prolonged drought stress over a long time (Lluisa et al., 2006, Staudt et al., 2017).

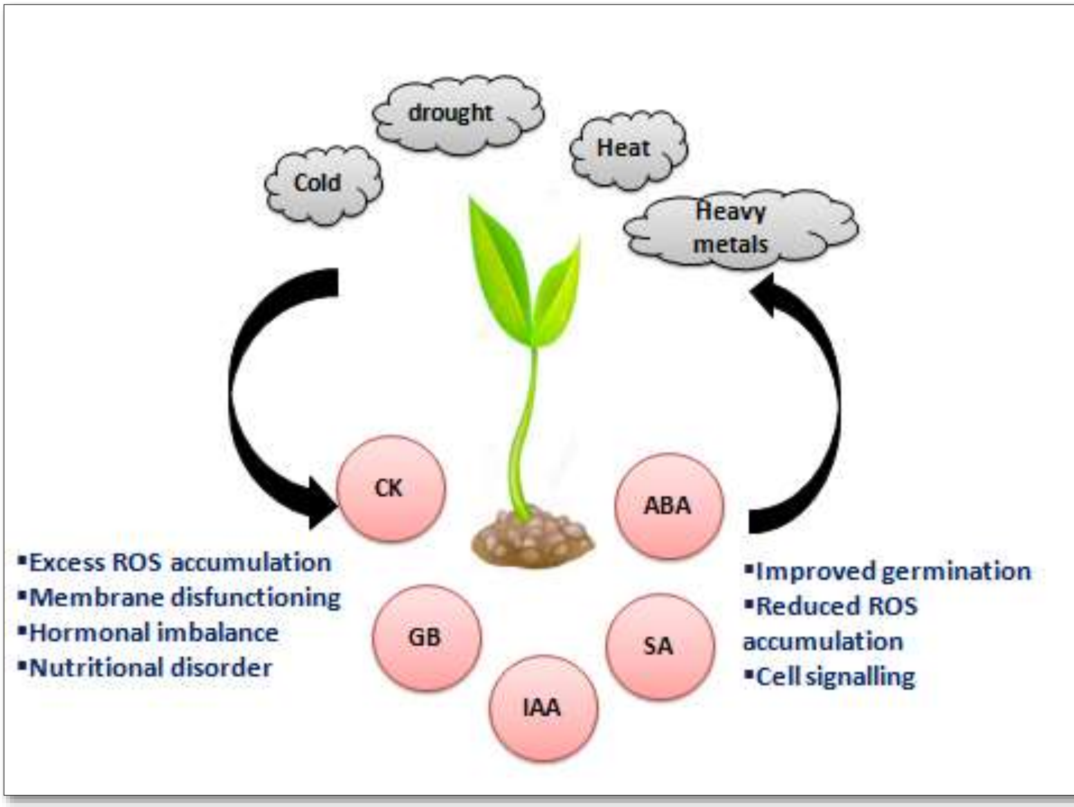
Fig.2: Role of Secondary Metabolites in Drought stress tolerance



PHYTOHORMONES IN DROUGHT STRESS

Natural conditions alone do not cause any type of pollution as manmade activities like desertification, industrialization, utilization of natural resources vigorously lead to cause pollution of water, air and soil and causes fluctuation in the climatic conditions. It leads to climatic changes and causes problems in the agriculture field for the development of agricultural produce (Ullah et al., 2015). These climate changes cause various abiotic stresses to the plants in which drought stress is received more attention recently because of the increase in global temperature due to anthropogenic activities and greenhouse emissions of various gases. Drought is the main factor that worldwide decreases crop production and yield (Agarwal et al., 2013). Severe drought conditions affect the quality and produce in high amounts and lead to an increase in food prices. It becomes difficult to feed the overall population in the coming years. To short out this difficulty, our agriculture sector needs to increase up to 70-80% to meet the food items to the demanded population (Sah et al., 2016). There is a need to develop scientific technologies and social policies to protect the plants from various internal and external damages caused by natural climatic conditions such as drought and other biotic and abiotic stresses and to enhance the resistivity of the crops against diseases and insects – pests. For this, the task which should come into existence is reforestation, efficient use of natural resources, control on increasing human population, producing tolerant and resistant crops, etc. various morphological and biochemical modifications adversely affects the growth and productivity of the crops under drought stress (Ullah et al., 2018). The effect of drought stress on the plants mainly depends upon the factors that are, plant species, plant genotype, age and size of the plant, the period for growing, and stress tolerance capacity (Gall et al., 2015). Plant hormones play a vital role in the growth and development of plants at various life stages of the plant. Besides, to take an important part in growth and development phytohormones play another important role in protecting the plant against various biotic and abiotic stress conditions and influencing the defence mechanism of the plants. Plant growth hormones are very important for the plants mainly in response to drought-stress conditions. Drought stress cause changes in the synthesis of the different plant growth hormones and alters the functioning and behaviour of compounds such as Jasmonic acid (JA), Abscisic acid (ABA), Salicylic acid (SA), Auxin, Gibberellins (GA), and Cytokinin (CK). After the drought effect, Abscisic acid is the major growth hormone, which at once produced and starts its synthesis against drought tolerance. Abscisic acid (ABA) is the main important for the regulation of stomatal aperture, other growth activities, and expression of ABA-responsive genes (Kazan, 2015; Mori et al., 2006). ABA is firstly synthesized in the root part and after that transferred to the leaves and branches for acting. Rather than ABA, many such plant hormones play an important role in response to drought stress and help plants to survive under drought stress conditions. This includes Jasmonic acid (JA) and Salicylic acid (SA). Drought stress leads to the stimulation of various enzymes, which performs functions in the accumulation, and reduction of reactive oxygen species [ROS] (Bandurska et al., 2013). To overcome various biotic and abiotic stresses, plant growth hormones play the role of chemical messengers in response to stress. Phytohormones help in activating the various plant physiological, developmental, and biochemical processes when they get released from drought stress perception. These plant processes include stomatal closure, enhancement of root and shoot growth, and aggregation of osmolytes to cope with drought stress (Fahad et al., 2014; Lim et al., 2015).

Fig 4: Phytohormones in abiotic stress



ABSCISIC ACID

ABA is derived from zeaxanthin, which is a plant pigment and is synthesized in the cytoplasm and plastids. It is found in young cotton fruits and is a weak acid that takes part in the stress tolerance mechanism in the plant system. The main function of abscisic acid is in the fruit abscission (Cracker and Abeles, 1969). ABA is not only involved in the abscission process but also involves the stress response at various physiological stages of the plant. It plays an important role in stress response, development, and reproduction (Dong et al., 2015; Zhu, 2002). Due to high drought, stress or salt stress osmotic stress also comes into existence. This stress occurs due to loss in water and reduction in turgidity. These acids stimulate the plant tissues and functions to tolerate various abiotic stresses. This osmotic stress leads to the synthesis of abscisic acid and activates the enzymes and gene expressions (Yamaguchi-Shinozaki and Shinozaki, 2006). When there is a reduction in the water content in the plants then the synthesis of abscisic acid going to produce which ultimately helps the plant to survive under high drought stress conditions and when the drought stress is reduced, there is a reduction in the level of ABA. The concentration or level of the Abscisic acid is higher in the young leaves as compare to the older or matured leaves and when they grow up, they transfer abscisic acid to the younger leaves of the plant and the process continues. ABA also increases the sensitivity of stomata during the leaf developmental stage (Chater et al., 2014). Abscisic acid is generally synthesized in the root zone and from there is transported through the vascular bundles to the different cells to perform the different tasks. They play a major role in stomatal sensitivity as a response to guard cells. Guard cells are the main pathway through which CO_2 enters and H_2O is released. Synthesis of ABA occurs due to the signalling of drought stress. In response to abscisic acid produced during drought stress guard cells reduced the amount of water to be lost by stomatal regulation. ABA suppresses the loss of water from the guard cells by the activation of K^+ ions and anions and thus helps the plant to survive under drought stress conditions. ABA mediates seed germination and regulates the stomatal opening and closing which help plant in response to drought stress.

JASMONIC ACID

Jasmonic acid is a plant hormone that is helpful in the growth and development of the plant. It also takes part in the stress response in plants. It is synthesized from the α linolenic acid and forms jasmonates which plays a very important role in stress tolerance in plants. Jasmonic acid is very helpful in regulating abiotic and biotic stress in plants. JA is a plant growth regulator and involves the growth of root, shoot, pollen development, food ripening, and tendril coiling in most of the climbers (Delker et al., 2006, Wasternack, 2007). Plant growth hormones work in a team in regulating biotic and abiotic stress in the plants. The jasmonates are similar to abscisic acid; they perform the same function as performed by the ABA in tolerating the drought stress. Jasmonic acid regulates the stomatal closure as performed by the abscisic acid, act as a scavenger of relative oxygen species and functions in root development and thus help plant in drought tolerance and help them to survive under severe drought stress. Jasmonic acid forms precipitate in the regulation of stomata under drought stress conditions (Munemasa et al., 2007). Exogenous application of jasmonic acid can also be done in response to plants under drought stress. The exogenous application can increase the antioxidant activity of the plants under water deficit conditions and simultaneously enhance the enzymes glutathione reductase and ascorbate peroxidase, which helps in response to drought stress (Ai et al., 2008; Bandurska et al., 2003; Nafie et al., 2011, Shan et al., 2015). It has been observed that the accumulation of jasmonic acid in the root zone leads to an increase in the level of abscisic acid in the plants and they together function to survive plant under drought stress conditions. Better tolerance against drought stress can be done when the phytohormones function together to achieve tolerance.

Table 3: Different phytohormones under drought stress

Plants	Phytohormone	Changes in metabolism
Triticum aestivum	IAA	Decrease endogenous concentration
Cicer arietinum	GA and Kinetin	Increase under PEG-induced water stress
Zea mays	GA and Zeatin	Improves drought tolerance
Arabidopsis	Ethylene	Increase stomatal aperture
Brassica	Jasmonic acid	Drought tolerance by increasing antioxidant metabolism
Solanum Lycopersicum	Salicylic acid and acetyl salicylic acid	Enhance drought tolerance
Solanum Lycopersicum	EBR	Induced level of endogenous ABA concentration and photosynthesis and activities of antioxidant enzymes
Vicia faba	Brassinolide	Promotes stomatal closure by inhibiting the stomatal opening
Oryza sativa	Brassinosteroids	Improves the leaf water economy and CO_2 Assimilation, and enabled rice to withstand drought
Ctenanthe setosa	Salicylic acid	Alleviates the damaging effect of drought stress by decreasing water loss and inducing the antioxidant system
Triticum aestivum	Salicylic acid	Alleviates effect of drought stress on wheat seedlings growth by influencing the ASA-GSH cycle gene by enhancing the transcription of glutathione-S- transferase GST1, GST2, glutathione reductase, and monodehydroascorbate reductase genes

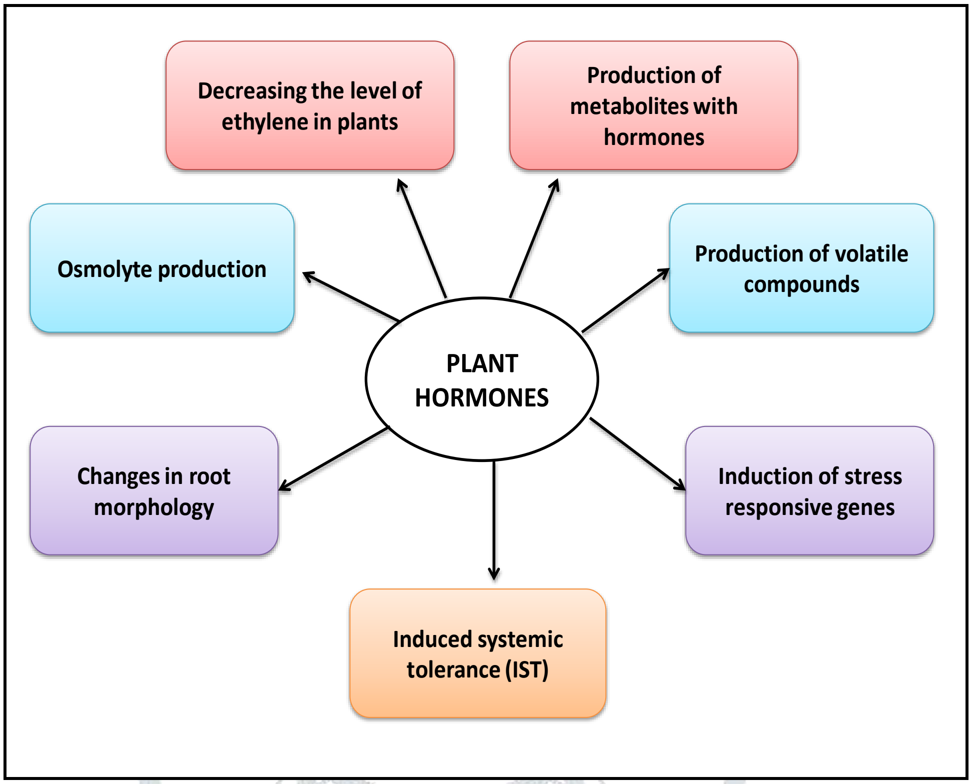
SALICYLIC ACID

Salicylic acid is a phenolic compound that performs different functions in the plant system. It plays an important role in the growth and development of the plant and has a great response to drought stress. Salicylic acid forms signalling molecules that are helpful in the growth of the plant at various physiological stages of the plant. It plays a crucial role in the defence mechanism of the plant and influences its immune system to fight against drought stress. Salicylic acid also plays a role in fruit ripening and development of all parts of the plant. It secures the plant system and protects against various biotic and abiotic stresses caused by the environment. Salicylic acid is reported as a defence tool and is significantly function in the abiotic stress tolerance in the plants. It functions as a biosynthetic pathway and works in response to drought tolerance. Salicylic acid regulates the synthesis of (ICS) isochorismate syntheses and increases the drought tolerance in most of the plants (Hunter et al. 2013). Salicylic acid also involves in drought stress improvement of the plants and influences the defence system of the plants. Salicylic acid synthesis takes place in the chloroplast, cytoplasm and is translocated in various plant cells and vacuoles. The transfer of salicylic acid is similar to auxin or other hormones. The content of salicylic acid increases in the drought stress e.g. five times increase occurs in the salicylic level due to water deficit conditions in most of the shrubs (Phillyrea Angustifolia) (Munne-Bosch and Penuelas, 2003).

ETHYLENE

Ethylene is the only plant hormone that is present in the gaseous form. It is a naturally occurring hormone and performs various functions in the growth and development of plants. It plays a major role in fruit ripening, seed germination, pollen development, and anthesis. Ethylene also plays a role in response to drought stress in plants and makes them survive under water deficit conditions. Drought regulating genes were observed in the cotton crop due to the presence of ethylene in the plant cells; these genes also regulate the heat stress in the plant cells (Liu and Zhang, 2017). The phytohormones ABA, JA, SA, ET works together in the plant system to protect them from excessive drought and heat stress. Phytohormone ethylene is produced from methionine by the action of certain enzymes. The drought in the tobacco plant is observed due to an increase in the expressions of genes regulated by ethylene (Burstenbinder et al., 2007).

Fig.-5: Role of Phytohormone under drought stress



AUXINS

Auxin is the most popular plant growth hormone, which is very important in the whole life cycle of the plant system. It plays a vital role in growth and development, root and shoots growth, apical dominance, fruit, and flower synthesis, etc. it is well known for its stress tolerance activity. It performs necessary functions in response to drought stress. Biosynthesis of auxin takes place in the young leaves, developing shoots, germinating seeds, and primordia of the leaves. Auxins in the group of hormones play an efficient role in protecting plants under drought stress. These are transported from one place to another and from one cell to another cell through the xylem and phloem (Chai and Subudhi, 2016). Some studies also said that auxin increases drought stress, but this is not true for most of the aspects. Auxin plays a role in drought tolerance in the plants and synthesizes various enzymes, which protect the plants from severe drought or heat stress.

GIBBERELLINS

Gibberellins are carboxylic acids and function in the development of plants in a great way. A tetracyclic diterpenoid plays a functional role in abiotic stress tolerance. They are important in the whole life cycle of the plant life and help to enhance cell division, cell elongation to cell maturity in every phase of the plant life processes. The plant requires gibberellins at every stage from seed germination to the adult phase for its proper development (Colebrook et al., 2014, Wang et al., 2008). A reduction in the level of gibberellin can increase drought tolerance in the plants. Gibberellins form GA 2-oxidase, which enhances the drought tolerance in plants. During drought stress, GA stops its function as a growth promoter and stop the utilization of more water and nutrient for excessive growth. It synthesizes some enzymes and regulates the action of some genes to increase the drought stress tolerance in the plants and influence the defence mechanism of the plant to survive under high-temperature conditions.

CYTOKININS

Cytokinin is one of the most important plant hormones which is required for the regulation of growth and development and is utilized by the plant as a stress tolerance i.e. drought stress tolerance (Lubovska et al., 2014, Li et al., 2016). Various studies show that against drought stress cytokinins have both positive as well as negative effects (Ha et al., 2012; Kieber and Schaller, 2014, Li et al., 2016, Zwack and Rashotte, 2015). A cytokinin is an important group of plant growth regulators, which is involved in cellular maintenance and prevents premature leaf senescence. Under drought stress, at the grain filling stage under water deficit, the green genotypes can tolerate or bear the drought stress. Overexpression of phytohormone cytokinin increases the drought tolerance ability in the plants and helps them to survive under drought stress conditions. Cytokinin is translocated from one cell to another through the vascular bundles and then promotes the enzymes to cope with the drought stress.

CONCLUSION

The demanding population day by day challenges crop production. It becomes difficult to produce agricultural production under environmental stress conditions. Various biotic and abiotic stresses affect both qualities as well as the quantity of the agricultural produce, which creates a problem to meet the need of our future demanding generation. In future aspects, it can become a big problem if attention is not given to this field. In most abiotic stress, drought stress is most cursive and affects the plant if the plant may go on any stage of its life cycle. Drought stress affects the growth of the plants and causes a great decrease in yield. Drought stress results in affected low yield or affected yield. Plants have some defence mechanism so that they can tolerate these environmental stresses. Secondary metabolites and plant growth hormones play a vital role in plants to protect them from drought stress or water deficit conditions. Secondary metabolites are organic compounds that are not directly involved in the growth and functioning of the plants. Bacteria, fungi, and plants produce these compounds. Phytohormones are chemical compounds that are involved in the cellular activities of plants. They help the plant in adverse conditions especially in stress conditions to survive under environmental stress. Secondary metabolites emote the main part to survive the plant under stressful environment and help the plant to overcome stressed conditions like temperature, humidity, high and low light intensity, excess and scarcity of water, minerals, and carbon dioxide influence, etc. which affect the growth and development of the plant and induce secondary metabolite production. Various secondary metabolites like glucosinolates, phenols, and terpenes are synthesized in the plants in response to drought stress tolerance. Phytohormones also play a major role to protect them from abiotic stresses especially from drought stress. Therefore, from this paper, we conclude that secondary metabolites and phytohormones in plant systems are necessary for response to survive under drought stress and some modifications are required in the field of agriculture to make suitable production even under stress conditions. There is a need to modify the plant system in such a way so that they cannot be affected by these stresses and can achieve efficient Production and yield.

Acknowledgement

The authors gratefully acknowledge the support provided by Lovely Professional University, Punjab, India

Authors Contribution

M.S. and P.K., contributed equally to this work.

Conflict of Interest Statement

The authors state that they have no interest in conflicts

List of Abb.

CK- Cytokinin, GB- Gibberellins, IAA- Indole Acetic Acid, SA- Salicylic Acid, ABA- Abscisic Acid

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