Role of Plant Phenolics Against Reactive Oxygen Species (ROS) Induced Oxidative Stress and Biochemical Alterations

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Abstract

Plants being embedded into the environment have to develop into it and to adjust with the fluctuating environments because of the abiotic stresses. Environmental factors including adverse temperatures, flood, light, drought, salt, and heavy metals come under abiotic stressors that greatly effects plant development and crop productivity. Changes in plant growth and its natural habitat conditions can be recognized as environmental stress which interrupts its metabolic balance. Likewise, we differentiate two dissimilar kinds of environmental tension: biotic stress (brought by viruses, bacteria, or insects) and abiotic stress. Polyphenols are secondary metabolites comprising the major and the supreme predominant assembly of metabolites. These polyphenols are having significant morphological and biological significance in plants. Polyphenols impact the source and movement of organic and inorganic nutrients present in soil accessible to plant or microbes. They also respond to nutrient deficiency therefore offering means for detecting nutrients disorder before the onset of symptoms. The aim of this chapter is to summarize the updated literature about abiotic stress, and its management by polyphenols.

Keywords

Abiotic stress · Environment · Factors · Plants · Polyphenols

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7.1 Introduction

From the last 20–30 years, increased research-based proof has established in support of the fact that atmospheric and climatic deviations can promptly change the diversity of living beings (Hajam et al. 2020; Malik et al. 2020) and crop production (Kumar and Meena 2016) globally. Changes in plant growth and its natural habitat conditions can be recognized as environmental stress which interrupts its metabolic balance. Likewise, we differentiate two dissimilar kinds of environmental tension: biotic stress (brought by viruses, bacteria, or insects) and abiotic stress. Environmental factors including adverse temperatures, flood, light, drought, salt, and heavy metals come under abiotic stressors that greatly effects plant development and crop productivity (Gautam et al. 2020). During stress conditions, the "expression pattern" of the gene in the plant proteins takes place which is responsible for the regulation of the biogenesis of metabolites convoluted in communication amid plants and surroundings. Polyphenols are an essential class of specific metabolites that perform fundamental physio-biological functions during the entire life span of plants, comprising stress responses. Previous studies reported that the pathway of phenylpropanoid biosynthesis is generally stimulated during adverse environmental conditions like extreme temperatures, salinity, drought, ultraviolet radiations, and heavy metal pollution which results in various phenolic compound accumulation (Kumar et al. 2020; Mohamed et al. 2020; Sharma et al. 2019a; Linić et al. 2019). In constantly changing environmental conditions plants are revealed to multiple abiotic stresses that are inauspicious for the development and growth of the plant (Zhu 2016). These abiotic stresses are "salinity, heavy metals, excess or deficiency of nutrients, water (drought and flooding), high and low temperatures (chilling and freezing), ozone, sulfur dioxide, extreme levels of light (high and low), radiation (ultraviolet, UV-A and UV-B)," mechanical components and additional regularly arising stress conditions (Gutiérrez-Grijalva et al. 2020; Pereira 2016) (Fig. 7.1).

Plants being embedded into the environment have to develop into it and to adjust with the fluctuating environments because of the abiotic stresses and increase in phenolic compounds in plant cells are deliberated as a compatible reaction of plants towards these negative ecological situations (Hoque et al. 2020; Pereira 2016). Various chemicals are blended in plants and are characterized as primary and secondary metabolites. "Nucleic acids, fatty acids, amino acids, and sugars are the primary metabolites" which are necessary for the development of plants (Fiehn 2002; Wu and Chappell 2008). As compared to the "primary metabolites" secondary metabolites are much more divergent. These are organizationally and chemically specialized compounds and are indirectly used for the basic metabolism of the plant but are essential for the persistence of plants in the surroundings. Polyphenols groups are the extensively present secondary metabolites having significant morphological and biological significance in plants. These compounds are aromatic having more than one OH group derived from "shikimate pathway," leading to the generation of "monomeric, polymeric phenols, and polyphenols units" (Randhir and Shetty 2004). In plants, these "phenolic compounds" perform an important function in plant development, growth, and reproduction (Gautam et al. 2020). These also

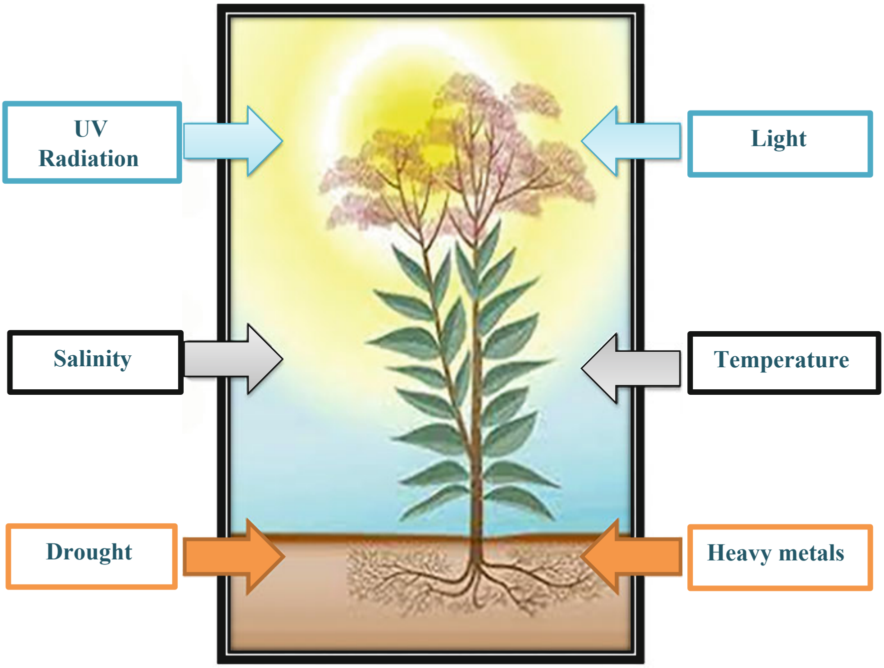

Fig. 7.1 Showing different types of abiotic stresses

impart a substantial role as defense compounds during different abiotic stresses including low temperatures, heavy metals, high light, "UV-B radiations, and nutrient deficiency", constructing sensory and color appearances of vegetables and fruits (Alasalvar et al. 2001), fortification in contrast to predators and pathogens (Bravo 1998), further demonstrating additional important properties such as antimicrobial, antiallergenic, and antioxidant activity (Balasundram et al. 2006). Bacteria, algae, and fungi synthesize aberrant phenolic composites; however, bryophytes are producing polyphenols, such as flavonoids, on the other hand, in vascular plants a complete assortment of phenolic complexes are present (Swain 1975; Harborne and Green 1980). An approximation of around 2% of the total carbon photosynthesized by plants is transformed into "phenolic complexes" (Robards and Antolovich 1997). Numerous phenolic complexes are recognized to be produced by developed plants and the classification of these complexes is constantly growing. Plant foliage comprises "amides, esters, and glycosides of hydroxycinnamic acids (HCAs); glycosylated flavonoids, mainly proanthocyanidins and flavonols and their by-products."

Polyphenols are the major and supreme premeditated assembly of metabolites which is plant-specific and assimilate over 8000 molecules (González-Sarrías et al. 2012). These are biosynthesized by utilizing a phenylpropanoid or shikimate pathway that yields an extensive range of monomeric and polymeric polyphenols units (Sharma et al. 2019b). Phenolic compounds organizations are fluctuating comprehensively, even if their communal property is the occurrence of a single or more hydroxyl groups, involved openly in more than one benzene ring. Conferring to their arrangements, they might be assembled into “flavonoids, stilbenoids, phenolic acids, and lignans.” Generally, phenolic complexes might exist in plants as unrestricted systems; however, further frequently, they are established in associated arrangements with a single or more sugar remains associated by “β-glycosidic links with a hydroxyl group (O-glycosides) or a carbon atom of the aromatic ring (C-glycosides).” Andreasen et al. (2000) reviewed that connected sugars may be “monosaccharides, disaccharides, or even oligosaccharides.” In the past 50 years, an estimated 1–2% per decade reduction has been observed in the production of wheat and maize, ultimately disturbing food provisions for livestock and humans (Myers et al. 2017). Therefore, global production of food must be sustained or if possible, increased in order to feed a continuously rising human population, under gradually unbalanced climatic situations and growing high temperatures (Myers et al. 2017). Novel methods are required to come across this most important agronomic problem although consuming prevailing or even condensed regions of cultivated land (Kassam and Friedrich, 2011). A significant agronomic objective is to recover the production of crops developing below stages of abiotic along with “biotic stress.” The enzyme polyphenol oxidase is located in maximum all plant species and the leaves articulated gene output might partake a function in response to stress, directed by conditional proof including localization of enzyme and its response against various “environmental factors.” Polyphenol oxidase has been described in all terrestrial plants measured to date with the exemption of Arabidopsis. Conversely, no polyphenol oxidase-like arrangements were recounted in “chlorophytes (green algae)” (Tran et al. 2012). It is hypothesized that this enzyme is associated intensely with the development of terrestrial plants signifying a function in alteration to abiotic tension linked with desiccated/nonaquatic surroundings. Though, at present, there is no convincing indication for the presence of an indispensable method clarifying the association between polyphenol oxidase and abiotic tension; certainly, it is inexact if the occurrence of polyphenol oxidase action is valuable or damaging to the plant (Mayer 2006). Although polyphenol oxidase movement is perhaps associated with accretion of ROS (Thipyapong et al. 2004; Mayer 2006) and complete redox potential standards (Webb et al. 2014), its occurrence might moreover be favorable as a suggested oxygen shield barrier (Vaughn and Duke 1984) or through dejected-modifiable photosynthesis (Trebst and Depka 1995). The present form of whatever is frequently conflicting proposed and investigational proof concerning the polyphenol oxidase latency in foliage to deliberate a benefit in crop yield, predominantly for the period of abiotic stress, including heat, cold, and drought. Polyphenol oxidase enzymes from plants consist of three provinces, such as an N-terminal plastid transport peptide, a greatly preserved type-three “copper center, and a C-terminal section” (Tran et al. 2012). Polyphenol oxidase enzymes family conduce the monophenols and *o*-di-phenols to *o*-quinones oxidation. Polyphenol oxidase are extensively scattered in “bacteria, fungi, plants, and animals” (Mayer 2006; Tran et al. 2012) but are frequently tangled with one more subclass of phenol oxidases which is the laccases “benzenediol: oxygen oxidoreductase [EC 1.10.3.2] or *p*-diphenol oxidase]," which corrode an extensive series "of *o*-, *m*-, and *p*-diphenols" (Griffith 1994). "Plant laccases are frequently extracellular proteins containing 22–45% glycosylation" (Solomon et al. 1996) while polyphenol oxidase are "intracellular proteins" (Steffens et al. 1994). Both subclasses are, conversely frequently mentioned as polyphenol oxidase (Mayer and Harel 1979; Yoruk and Marshall 2003; Marusek et al. 2006).

Polyphenol oxidase facilitated production of *o*-quinones are associated with secondary "production of reactive oxygen species as" tributary products of the reaction (Steffens et al. 1994). Even though the comprehensive procedure prevails to be recognized, the opposite unbalanced of *o*-quinones can give rise to the development of semi-quinone radicals in cytoplasm (O'Brien 1991; Thipyapong et al. 1997). Collaboration between O_2 and these free radicals will affect the superoxide anions production and the redevelopment of *o*-quinone (O'Brien 1991). Superoxide anions are immensely deranged and rapidly dismutate, either by enzyme action through superoxide or without enzymes to form H_2O_2 (Grant and Loake 2000). Accretion of cytotoxic reactive oxygen species requisites to be below constricted switch as oxidative alterations such as protein criss-cross linking "lipid peroxidation," and impairment to nucleic acids can eventually cause death of the cell (Grant and Loake 2000; Bhattacharjee 2005; Gill and Tuteja 2010; Foyer and Noctor 2012). Though, in theory, Polyphenol oxidase might also give rise to a declining quantity of oxygen nearby accessible by the O_2 reduction into water (Yoruk and Marshall 2003). Polyphenol oxidase management is multifarious and the enzyme may be existed equally as an active and a suppressed (frequently precursor or an inactive state) condition in a similar basis substance (Mayer and Harel 1979). Succeeding passage to the cavity and the breakdown of the transit N-terminal peptide bond, polyphenol oxidase is primarily present as a two-dominion biomolecule comprising a copper adhesive region and a C-terminal dominion (Flurkey and Inlow 2008). An additional comprehensive conversation, comprising deliberation of the three-dimensional construction of catechol oxidases, may originate in Gerdemann et al. (2002). The C-terminal is associated with an elastic arbitrary peptide organization which is anticipated to shield the active spot and go through structural variation due to some situations (Leufken et al. 2015). Various confirmations have been reviewed for proteolytic C-terminal handling of dormant polyphenol oxidase towards the active state and these have been verified for *Vitis vinifera*, *Vicia faba,* and *Ipomoea batatas* polyphenol oxidase (Flurkey and Inlow 2008). The amount of inactivity is not common and varies with plant types along with its tissue type. For example, polyphenol oxidase movement was identified in both the dynamic and dormant types in red clover root tissue however in white clover roots it has only observed in the dormant state (Trifolium repens); this compares with aerial tissues wherever polyphenol oxidase movement was identified in both the dynamic and dormant states in both white and red clover (Webb et al. 2013). "The perplexity of polyphenol oxidase in leaves 3573 (trypsin), acid and base shocks, mild heat, and detergents including sodium dodecyl sulfate and ammonium sulfate" (Steffens et al. 1994; Yoruk and Marshall 2003). It has been perceived that the C-terminal province regulates the optimum pH levels of polyphenol oxidase in non-proteolytic stimulated enzyme and they hypothesize that non-proteolytic stimulation as well happens in plants (Leufken et al. 2015). Winters et al. (2008) have confirmed the possibility to trigger dormant polyphenol oxidase from red clover in the occurrence of its endogenous *o*-di-phenols substratum. It has been anticipated that *o*-diphenol-facilitated instigation is an ancillary method of stimulation, along with the resultant *o*-quinones correlating with the dormant polyphenol oxidase group, by this means changing their arrangement and revealing the active regions (Winters et al. 2008). Meyer and Biehl (1981) reported that increased activity of phenolase enzyme leads to the reduction in the dormant state through foliage deteriorating in spinach (*Spinacia oleracea*). More in recent times, a recognized quinone binding region has been identified in the polyphenol oxidase enzyme, aurone synthase, from Coreopsis grandiflora, which might be accountable for the detected allosteric stimulation of dormant polyphenol oxidase (Molitor et al. 2015).

7.2 Phenolic and Abiotic Stress Management

The interaction between plants and environment contributes to the production of definite natural products. "Accumulation of phenolics" in the plant tissues provided "adaptive response" with respective continuous changes in the environment. The accumulation of phenolic compounds is major because of the "PAL (phenylalanine ammonia lyase), CHS (chalcone synthase) and other enzyme activity." Increased activity of "*Phosphoenolpyruvate* carboxylase" indicates that the process becomes reverse, i.e., production of sucrose decreases while repairing and defense processes started. Plant phenolic contributes to different physical activities like enhanced survival rate and helps plants to adapt under extreme environmental circumstances (Lattanzio et al. 2012). Any kind of environmental stress leads to the increased activity of herbivores, pathogen infection, low temperatures, high light or UV radiation, heavy metals, and nutrient insufficiency and result "in the production of free radical's species." "Plants are having the potential to combat abiotic and biotic stress conditions by neutralizing reactive oxygen species" (Khan and Khan 2017). The genes of secondary metabolites show their expression during unfavorable environmental conditions and lead to the synthesis of different signaling elements like jasmonic acid, salicylic acid, and their by-products (Winkel-Shirley 2002; Gould and Lister 2006; do Nascimento and Fett-Neto 2010; Khan and Khan 2013; Khan et al. 2013, 2014, 2015; Per et al. 2018). Abiotic stress leads to the turned off/on (Ahmad et al. 2008; Jaleel et al. 2009). Abiotic stress responsible for increased active oxygen species production inside the cells which leads to great damage to the plants (Dar et al. 2017). Phenolics such as flavonoids, tannins, hydroxyl-cinnamate esters, and lignin provide protection against biotic and abiotic stresses. Under stress conditions production of phenolic compounds increases in higher quantity under certain stress conditions as compared to the non-stressed or normal conditions (Selmar 2008). The antioxidant property of phenolic compounds helps in the neutralization of free radicals and chelation of redox-active metal ions which are able to affect the peroxidation of lipids molecules (Schroeter et al. 2002). Phytophenolic compounds including polyphenols contribute significantly to detoxification system which primarily includes ascorbate and also acts as a stoppage resistance machinery for vascular plants in contrast to monophenols (Yamasaki et al. 1995, 1999). Under in vitro studies, polyphenols exhibit operative antioxidant relative to ascorbate and tocopherol and have a supreme organizational interaction to perform the activity of scavenging free radicals. Due to the antioxidative property of polyphenols, they delocalize and balance the solitary electron, their raised reactivity as "electron donors and from their ability to chelate transition metal ions (termination of the Fenton reaction)" (Rice-Evans et al. 1997). It has been studied that phenolic compounds are oxidized univalently to their corresponding phenoxyl radicals by directly scavenging the free radicals or enzymatic operations (Kagan and Tyurina 1998) (Fig. 7.2).

"Plant produces phenolic compounds to endure in conditions of stress (drought, salt, UV radiation, metal, and low temperature)." A maximum number of plants produce phenyl propanoids comprising flavonoids and HCAs (hydroxy citric acid);

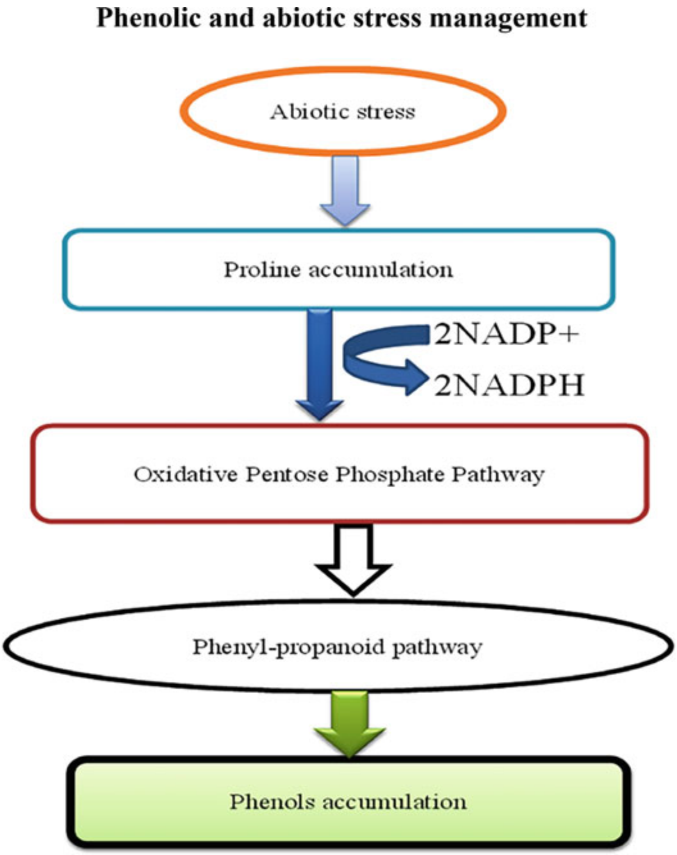

Fig. 7.2 Showing plant response towards environmental stress and accumulation of phenol

however, phenolic accretion in plants occurs only during the “abiotic and biotic stresses, including UV radiation, low temperatures, high light illumination, wounding, pathogen attack, and low nutrients” (Dixon and Paiva 1995; Yamasaki et al. 1995). Assured tributary metabolic composites are manufactured excessively during abiotic stress conditions resembling drought, where they function as antioxidants (do Nascimento and Fett-Neto 2010). “Phenolic compounds are divided into five subgroups, such as phenolic acids, flavonoids, lignins, coumarins, and tannins,” (Gumul et al. 2007) and are manufactured through chorismic acid and shikimic acid pathways (Solecka 1997). Mainly involved in defense under stress conditions but are also beneficial for other organisms such as human beings as diet supplement and alternate source of medicines (França et al. 2001; Amarowicz and Weidner 2009). Due to diverse environmental conditions, production of phenolic compounds is detected to be either overexpressed (Wróbel et al. 2005; Weidner et al. 2009) or less expressed (Weidner et al. 2007) consequently give rise to the amplified or reduced amount of the phenolic compounds in plants. Various studies have shown that under abiotic stress conditions, production of phenols was increased. In *Rehmannia glutinosa* for the period of water scarcity and chilling stress situations, total content of phenolic compounds has increased as reported by Chung et al. (2006). “Additional approval has come from the studies of Posmyk et al. (2005) in soybean subjected to chilling stress.” “Accretion of phenolic compounds caused an improved activity of PAL, CHS, and other enzymes that are convoluted in the synthesis of phenolic compounds.” “Plants reaction to abiotic stress by dehydration, hydration, and methylation of cinnamic acid, phenolic acids synthesis induces” (Dixon and Paiva 1995) numerous tributary metabolic substances in plants that display antioxidant properties related to this class of compounds. As phenolic are antioxidants, they are involved in scavenging reactive oxygen species, helps in catalyzing oxygenation reactions through complex formation with some metals, and reduces or inhibit certain oxidizing enzyme activity. “G6PDH a carbohydrate metabolism enzyme that delivers substrate to the shikimate pathway, and 3-deoxyarabinoheptulosonate 7-phosphate synthase, which is a ‘shikimate pathway enzyme is also necessary for phenylalanine synthesis’ ‘against various stress conditions.’ Researchers have interpreted that stress can stimulate increased chance of reducing parallels into synthesis of proline cytosolic.” From above points, we can conclude that different environmental disturbances around plants induce primary as well as secondary metabolic activities in them. These activities result in the deposition of bioactive components which in turn provides protection. This signaling pathway provides a connection between primary and secondary metabolic pathway, which provides a pathway for the synthesis of phenylpropanoid coupled to mass production of proline with the energy transfer through the oxidative pentose phosphate pathway (Cheynier et al. 2013). Under adverse conditions, the plants accumulate a large amount of free proline. Synthesis of proline can be “done de novo or it can be released by protein degradation with the NADPH oxidation.” Activity of oxidative pentose phosphate pathway is increased when the ratio of NADP1/ NADPH is increased, generates resource to synthesize polyphenolics through the “shikimic acid pathway” (Cheynier et al. 2013; Lattanzio et al. 2009).

7.3 Phenolic as Ultraviolet Sunscreens

Somatic cells receives the light and then initiates the synthesis of metabolites in plants. Disclosure of environmental solar ultraviolet-B radiation to plants in exposed grounds badly disturbs proteins, DNA, and cell membranes, it also led to the formation of “reactive oxygen species” which modifies metabolic breakdown in the cells. However, plant phenolic work as a guard which intimate the layer of epidermal cells to protect themselves from these destructive rays and by regulating the antioxidant organizations at the cell and entire animal level, “along this interrupting gene mutation and cell death by thymine units’ dimerization in the DNA, and probable light obliteration of co-enzymes NAD (nicotinamide-adenine-dinucleotide) or NADP (nicotinamide-adenine-dinucleotide phosphate).” Flavonoids can act as good UV guards with their great absorptivity at 250–270 and 335–360 nm. Flavonoids are phenolic compounds having a substantial function in protection against UV radiation (Li et al. 1993). It has been observed that humid plants and “high-altitude plants have” a greater flavonoid percentage than plants present in temperate zones. The variation in the amount of flavonoid arrangement of plant foliage is because of excess ultraviolet rays chiefly because of the stimulation of specialized flavonoid biosynthetic genes (Kolb et al. 2001). Plants utilizing polyphenols as defense mechanisms in contrast to ultraviolet rays as a direct screen has been observed as an important function by a number of researchers. It has been found that anthocyanin (a phenolic compound) can mount up in the epidermis and can function as a blackening screen and shield the mesophyll cells from excess rays (Lake et al. 2009). According to Ryan et al. (2001) flavonoids are important in protection against ultraviolet rays utilizing Arabidopsis mutants, ultraviolet-oversensitivity. Synthesis of anthocyanin was prompted through ultraviolet light ranges between “280 and 320 nm” collectively when joined with red light in apples. It was exposed that flavonoid upgraded in barley and also observed augmented amount of poly-amines in cucumber by ultra violet-B rays. It has also been discovered that flavonoids in the pea plant roots were improved on ultraviolet revelation. Production of flavonol molecules was prompted by ultraviolet-B in leaves of silver birch and grape plant. Furthermore, in numerous species of plant, improved levels of flavonoid have been restrained at higher altitudes. “It has been demonstrated in numerous plant species that the appearance of CHS (Cannabinoid hyperemesis syndrome) is transcriptionally stimulated by ultraviolet light, which is the first enzyme in the biosynthesis pathway of flavonoid.”

7.4 Plant Phenolics and Their Role in Heavy Metal Stress

Toxicity of “heavy metal is one of the significant abiotic stresses that can change biological metabolic pathways therefore give rise to destructive impacts on plants” (Villiers et al. 2011). It has been described that heavy metal stress protection has been provided by convinced flavonoids as they display the chelation of transition metals (e.g., Zn, Cu, Fe, Ni), which produces radicals of hydroxyl utilizing Fenton’s reaction (Williams et al. 2004). In addition to this, the "chelation of these metals into the soil can be an operational state of shield in contrast to the impacts of elevated metals concentration toxins." Biosynthesis of phenolic compounds that are predecessors of lignin increases under stress conditions, let us say, in plants exposed to the stress of heavy metal as observed by Michalak (2006). "Investigation on corn plants (*Zea mays* L.) stated that these plants, when developed on soil polluted with aluminium ions and root diffusion, were observed along with high concentrations of quercetin and catechin." However, flavonoids are convoluted in plant defense, growing in topsoil that is amusing in poisonous metals say aluminum. The fabrication of betalains in *Beta vulgaris* is enthused by Cu. The hairy root systems were uncovered to metal ions to progress the production of betalains. The accretion of betacyanins in Amaranthus caudatus callus cultures is promoted by Cu. Accumulation of flavonoids was also detected in Ginkgo biloba cell cultures treated with $CuSO_4$ as related with nontreated cells. In the same way, connection between levels of flavonoid and $CuSO_4$ level in Digitalis lanata cell cultures was reported (Bota and Deliu 2011). Nickel stress gives rise to an imperative reduction in anthocyanin concentrations (Hawrylak et al. 2007). Plants with raised number of tannins, for example, tea, are capable of enduring high levels of "manganese in soil, as they are shielded by the direct ions chelation." "Heavy metal ions binding with polyphenols in Nymphaea where heavy metals such as Hg, Pb, and Cr were chelating by the polyphenols rich methanolic extract."

7.5 Plant Phenolic and Their Role in Cold Stress

Many researchers have found that nonfreezing low temperatures promote the phenolic breakdown in foliage (Akula and Ravishankar 2011). "Metabolism of phenol is promoted at an acute "low temperature, which is called as the inception temperature at which unnerving damage is also prompted" (Janská et al. 2010). "Cold stress proliferates the production of phenolic compounds into the cell wall either as lignin or suberin." Suberin deposition and lignification upsurge opposition to cold stress conditions. A proliferation in thickening of cell wall might decrease cell collapse throughout mechanical stress, "freezing-induced dehydration" and therefore given the plant freezing resistance. Apple trees are perceived to be associated with elevated chlorogenic acid levels to a commutable degree towards cold climate. Christie et al. (1994) described the "accumulation of anthocyanins during cold stress and Pedranzani et al. (2003) stated that water and cold stresses introduced variations in endogenous jasmonates in Pinus."

7.6 Mechanism of Polyphenols on Abiotic Stress Management

The proteins of foliage are immensely perilous in the progress, reproduction, and definitive grain produced out of the plants. The decrease in the amount of protein inside the leaves of plant because of salt stress is not astounding meanwhile it is well recognized that the early objectives of reactive oxygen species are proteins in biological systems. The chloroplast come under as one of the principal objectives of reactive oxygen species, which bring about noticeable modifications in an extensive diversity of proteins including thylakoid and stromal. Consequently, the concentration of leaf protein is some of the critical pointers of the cause of salt stress (Isayenkov and Maathuis 2019). Furthermore, the result bearing of salinity is a consensual problem, which changes extensively in the writings. For example, Radi et al. (2013) testified that, in wheat, whole protein gratified into the leaves of two cultivars (lenient and delicate) was reduced analogously by salt stress (Afzal et al. 2006).

Augmented accretion of harmonious solutes such as proline has been advised to improve tolerance against salt. Ultimately, proline, similarly to osmolytes, moderate redox potential by deliberating osmotic modification, shielding cellular sheaths, and alleviating enzymes beneath abiotic stress. Arabbeigi et al. (2018) recommended that developed communication of the gene accountable for biosynthesis of proline (P5CS) in *Aegilops cylindrica* may associate with salt tolerance. These findings are in contract with Kumar et al. (2017a) with respect to wheat. As a result, the osmo-adaptive reaction includes the accretion of proline, which emphasize an undefined function in the forbearance to abiotic stress (including drought and salinity) is a substance of debate. There are many possible explanations for this discrepancy. The utmost conspicuous among them are stress intensity, stress duration, genotype or species, and biological stage alterations amid research (Ebrahim et al. 2020).

The salvation of plasmid membrane integrity in plant cells is a serious adaptive approach in contrast to free radicals (Isayenkov and Maathuis 2019; Kaya et al. 2019). It has been found that greater electrolyte escape was established in the wheat cultivars as compared to the agitated-salt forbearing *Aegilops cylindrica* and amphidiploid genotypes during stress environments. These outcomes are helpful and upkeep the indication that plasma membrane may possibly epitomize a capable approach for refining the effectiveness in adaptable metabolite fluxes and transmembrane ions throughout the period of environmental stress. Radi et al. (2013) witnessed a rise in EL in the genotypes of wheat because of salt stress and also establish that the salt-sensitive genotype had higher EL values as compared to the "salt-forbearing plants. There are numerous biochemical methods that defend plants alongside the destructive effects of salt stress." Phenolic complexes are the utmost copious "secondary metabolites in the plant kingdom as well as the most essential antioxidants against scavenging the too much free radicals that is produced by the bulk of stressors." Flavonoids are also recognized to have antioxidant properties (Hichem and Mounir 2009; Tohidi et al. 2017).

"During the course of earlier decades, investigators have constantly institute that the resilient connotation among polyphenols and abiotic stress forbearance is an exceptional prognostic of the degree of patience, and therefore can be utilized as a sign of upkeep of the redox state inside the cells (Hodaei et al. 2018). Though there are massive organizations of writings that in detail discourse phenolic compounds of the appetizing parts of the plant (e.g., seeds in cereals), chiefly due to the curiosity in well-being remunerations of polyphenol feeding, scarcity leftovers on examination that examines the incentives in arrears the improving influence of polyphenols on the phyto-noxiousness of photosynthetic tissues bring about by salt stress. Martinez et al. (2016) described a rise in the accretion of flavonoids in tomato plants in answer to abiotic stress corresponds with double defensive consequence as antioxidant in contrast to oxidative impairment prompted by the stress, and consequently as the health-endorsing complexes of edible plants."

The consequences of the investigation evidently indicate that Aegilops and wheat genotypes vary in case of the polyphenol's accumulation in their foliage. These complexes remained suggestively amplified against "salt stress." It has been described that salt stress-prompted a substantial rise in TPC (total phenolic content) in the "salt-forbearing genotype of wheat" (Kumar et al. 2017a). A substantial genotypic variance was detected in the TPC (total phenolic content) in durum wheat grains (Boukid et al. 2019). The outcome of the study commonly showed that "*Aegilops cylindrica* (male parent) had greater antioxidant property than female parents (wheat cultivars) in both control and salt stress situations. Additionally, the outcomes also spectacle that in association with female parent, amphidiploid plants had sophisticated antioxidant activities expressed by DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) (IC50)." In detail, the examination accessible "here is not only encouraged but also sustained our preliminary mechanism conferring genotypic alterations for antioxidant enzymes, malondialdehyde (MDA), and H_2O_2 in the same set of genotypes" (Kiani et al. 2021).

In the mechanism of oxidative stress, it has the ability to donate electrons and maintain electrons' redox reaction. The inactivation of antioxidants by reducing agents in redox reactions reduces reactive oxygen species at the expenditure of oxidative ions known as nonenzymatic antioxidants. The estimation of reducing power ions explores the homeostasis of redox reactions in the natural polyphenolic extract. Synthetic samples were compared with "ferric reducing antioxidant power" with IC50 equal to 0.3 mg/ml. These samples were capable of donating electrons to the process of "oxidative stress and produces reactive oxygen species." It has strongly reduced power which donates an electron to the reactive oxygen species. "The most plentiful polyphenols are ellagic acid, gallic acid, vanillic acid, chlorogenic acid, caffeic acid, etc." Accumulated phenolic acids increases the salt stress in the leaf tissues. The previous study reported that mostly abundant flavonoids are found in the leaf tissues (Sarker and Oba 2018a, b). Instead of this, these detected polyphenols deteriorate yield loss "under salt stress conditions." Therefore, the accumulation of total polyphenolic content plays a fundamental, biochemical, and physiological role in plant cell tissues. It helps to ameliorate Abiotic stress conditions (Sharma et al. 2019a). Besides, ferulic acids account for total phenolic content (87.10–90.60%) which ranges from 21.8 to 37.3 μg/g in the wheat grain." The yield of grains is an association between biochemical and physiological response to the plants, anthropogenically obligatory stressor conditions. In addition to this, these factor influences the genetic variety of plants. It depends upon yield grain variation and genetic diversity of wheat genotypes, and the degree of difference to ubiquitous in the environmental conditions. It affects negatively on yielding of grains both biochemical and physiological alterations. Salt stress effects on yield of grains and salinity of irrigated water reduces sodium chloride which decreases the yield of grains (Chamekh et al. 2016; Araus et al. 2008).

"Besides this, adverse and sturdy correlation coefficient of TPC (total phenolic content) and TFC (total flavonoid content) with IC50 (Half Maximal Inhibitory concentration) of DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) radicals revealed that there is contribution of phenolic compound to antioxidant potential in the known genotypes." Dykes and Rooney (2006) reported a similar correlation among RSA and TPC in cereals. It was also studied "that the hyper salt-tolerant genotype" has the considerable inhibition on the "DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) radicals between the known genotype. Also, it has been found that the genotypic variation and substantial increment in foraging of DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) (%) in the flowering plant of two among four wheat varieties in response to salinity stress and antioxidant activity of TPC (total phenolic content)" has also been confirmed by Kumar et al. (2017b). Additionally, a significant correlation was found between FAC (ferulic acid content) and TPC. Hura et al. (2007) revealed that a significant relationship occurs between "FAC (ferulic acid content) and TPC (total phenolic content) in triticale genotypes under drought stress circumstances. The present study revealed the CAC was correlated considerably through DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) scavenging rate. According to Yan et al. (2016) there is an increase in CA (chronological acid) associated with DPPH scavenging response induced by water stress in case of *Origanum vulgare*."

Ferulic acid or hydroxycinnamic acid is the originator of biogenesis of "lignin and vanillic acid" having antioxidant and age-defying roles. It serves as a restrictor of the enzyme that speed up the construction of unrestricted radical species and intensify the activity of scavenging enzyme as well as free radical scavengers. Hence, the activation of lignification inhibitors might be performed by salt stress which results in the accretion of ferulic acid (Boz 2015). No evidence is available till now, that explain the role of these phenolic acids to facilitate the stress in wild plant species. The biosynthetic pathways may explain the affirmative relation between chlorogenic acid and luteolin, ferulic acid and apigenin, and apigenin and luteolin as well. There is a significant contribution of multivariate regression analysis, "RAS (reticular activating system), TFC (total flavonoid content), and DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate)." It has been reported that "phenolic and flavonoid compounds are basic nonenzymatic antioxidants that contain scavenging of reactive oxidation species" (Tohidi et al. 2017; Sharma et al. 2019c). Additionally, particularly these compounds are induced through oxidative stress throughout stress (Chen et al. 2019a, b, c).

7.7 Plant Phenolics

"Plants are exposed to different types of abiotic stresses during their life cycle and different genes are turned switched on and off, leading to the risen the level of different "metabolites and proteins, some of which might be responsible for discussing certain degree of defense against these stresses" (Ahmad et al. 2008; Jaleel et al. 2009). "Abiotic stress promotes the formation of active oxygen species within the cells" (Dar et al. 2017). "Phenolics comprises diverse secondary metabolites, viz., flavonoids, tannins, hydroxycinnamate esters, and lignin presently in large quantities in plant tissues and are actively associated in defense mechanisms combat the biotic and abiotic stress." In comparison to nonstressed conditions, the plant sometimes produces phenolic in large quantities "under certain stress conditions" (Selmar 2008). "Phenolic compounds act as an antioxidant, stops the production of free radicals, and chelate the redox-active metal ions that are having the potential to catalyze lipid peroxidation" (Schroeter et al. 2002). "Phytophenolics, specifically polyphenols, act as antioxidants and support the primary ascorbate dependent detoxification system as an alternate defense mechanism of vascular plants in comparison to monophenols" (Yamasaki et al. 1995, 1999). "Polyphenols are most effective antioxidants in vitro than ascorbate and tocopherols and have an ideal chemical structure to neutralize the free radicals." This antioxidant activity of polyphenols might be because they resonate the unpaired electrons (chain-breaking function) and "(termination of the Fenton reaction)" (Rice-Evans et al. 1997). Kagan and Tyurina (1998) "evidenced that phenolics are univalently oxidized to their individual phenoxyl radicals when they act as antioxidants either by enzymatic or direct radical scavenging mechanisms."

Plants manufacture polyphenolics to adapt themselves under various "stress environments" such as UV radiation, drought, salt, metal, and low-temperature stress. Most plants commonly produce "phenylpropanoids" such as flavonoids and HCAs. Nevertheless, deposition of phenolics in plants can be induced by exposing them to abiotic and biotic stresses such as "UV radiation, high light illumination, low temperatures, wounding, low nutrients, and pathogen attack" (Dixon and Paiva 1995; Yamasaki et al. 1995). However, synthesis of some bioactive components becomes modulated under abiotic stress situations "drought where these act as antioxidants" (do Nascimento and Fett-Neto 2010). Phenols are the most common metabolites produced in plants, which are further divided into five subgroups "coumarins, flavonoids, lignins, phenolic acids, and tannins" (Gumul et al. 2007), produced in plants through "shikimic acid and chorismic acid pathways" (Solecka 1997). Along with the beneficial role of phenolic in plants they are also beneficial for animals (França et al. 2001; Amarowicz and Weidner 2009). During a stressful environment, some genes of the biosynthetic pathways are upregulated and some pathways are downregulated (Wróbel et al. 2005; Weidner et al. 2007, 2009; Dixon and Paiva 1995). In *Rehmannia glutinosa* under water scarcity and chilling condition the biosynthetic pathway of phenolic becomes upregulated Chung et al. (2006). Posmyk et al. (2005) reported that soybean exposure to cold stress increases the activities of enzymes, "PAL, CHS, and other enzymes involved in their biosynthesis and also phosphoenolpyruvate (PEP)-carboxylase activity also increases." Therefore, after analyzing all these findings it may be concluded that phenolic helps the plants to adopt them under different environmental stressful conditions like "hydration, dehydration, and methylation of cinnamic acid" (Lattanzio et al. 2009; Dixon and Paiva 1995).

7.8 Role of Plant Phenolic Against the Abiotic Stresses Induced ROS Production and Their Toxic Effects

Many changes in physio biochemical machinery of plants can lead reduction in the growth and yield of plant. These stress result in the quick alteration in the redox balance of cells along with the increased "production of oxygen species (ROS)" which causes damage to cellular organelles and affects the ROS-promoted signaling pathways. The excessive generation of ROS interferes with the normal physiological redox and hampers normal cellular functions as well as adversely suppresses the immune system, which indicates that plant requires the threshold quantity of ROS to carry out fundamental metabolic functions. "Unnecessary ROS formation during abiotic stresses increases itself leads to the production of ROS in exponential manner, which leads to the "peroxidation and destabilization of biological membranes." Rehman et al. studies that "heat stress and Zn deficiency leads to the decrement in growth (shoot and root biomass, and root length), subsequently decreases uptake of nutrients, increases peroxidation of lipids, and impairs the photosynthetic ability." "In plants, ROS generated from 1% to 2% of entire O_2 consumed in highly active cellular organellar such as chloroplast, mitochondria, and peroxisomes." Common ROS includes "singlet oxygen ($^1O_2$), superoxide radical (O_2^-), hydrogen peroxide (H_2O_2), and hydroxyl radical (^-OH)." Abiotic stresses disrupt the balance between the production and neutralization of ROS and favors the accelerated production of ROS which in turn damages fundamental macromolecules (nucleic acids, proteins, carbohydrates, and lipids) and sometimes causes the death of the cells. ROS induces damages to proteins due to the "oxidation of amino acid residues (e.g., cysteine) for the formation of disulfide bond of arginine, lysine, and threonine residues and finally results in the irreversible breakage in side chains and oxidation of methionine residues to sulfoxide." Generation of ROS also restricts the CO_2 fixation in chloroplast which are the major site for generation of ROS in green plants. "These ROS reacts with chlorophyll during photosynthesis and forms the chlorophyll triplet state which can rapidly produce $^1O_2$, and hence causes damage to photosynthetic complexes (principally PSII) and also interferes the photosynthetic molecular reaction cascade." Moreover, under abiotic stress, ROS production also increases in mitochondria which affect the cellular process in plants (24). It has been reported during Fenton reaction in mitochondria about 1–5% of O_2 consumed leads to the production of H_2O_2 which in turn gets converted into ^-OH. In addition to this, higher respiratory/photorespiratory metabolism requires higher electron transfer which leads to the excessive production of ROS and results in peroxidative damage to proteins (61). Peroxisomes are the principal sites for the generation of ROS, especially H_2O_2, having 2–50-fold higher load of H_2O_2 load than chloroplast and mitochondria, respectively. "H_2O_2 is involved in stress-induced oxidative damage and can pass easily across the lipid membranes." Under the physiological limit, various antioxidant defense mechanism neutralize these ROS. Whereas, excessive generation of ROS can downregulate the defense system, resulting in the generation of oxidative stress, cellular damage, and cell death (Fig. 7.1).

7.9 Protective Role of Phenolics Against Abiotic Stress Produced Reactive Oxygen Species in Plants

Under abiotic stress synthesis of secondary bioactive components such as polyphenols increases in plants. Phenolic compounds provide protection against the different types of abiotic stress because these compounds possess the antioxidative potential and free radical scavenging activity and ultimately result in the reduction in peroxidative damage in biomembrane systems thus protecting the cells against the ill effect of oxidative stress. The synthesis of phenolic compounds during environmental stress is controlled by the modified activities of different key enzymes of phenolic biosynthetic pathways including PAL and CHS (chalcone synthase). Increased activities of enzymes along with the upregulation of the gene transcription which encodes major enzymes of biosynthetic pathways, viz., "PAL, C4H (cinnamate 4-hydroxylase), 4CL (4-coumarate: CoA ligase), CHS, CHI (chalcone isomerase), F3H (flavanone 3-hydroxylase), F30H (flavonoid 3 0-hydroxylase), F305 0H (flavonoid 305 0-hydroxylase), DFR (dihydroflavonol 4-reductase), FLS (flavonol synthase), IFS (isoflavone synthase), IFR (isoflavone reductase), and UFGT (UDP flavonoid glycosyltransferase)."

Metals also induce oxidative stress in plants by accelerating the production of deleterious ROSs and finally lead to toxic manifestations and retardation of growth (1,18,788). Nonetheless, increased synthesis of plant phenolics under metal-induced stress protects the plants against "oxidative stress." "Flavonoids can increase the chelation process in metals and helps in reduction of deleterious hydroxyl radicals in plants," and this provided strong evidence that biosynthesis of flavonoids increases during the metal toxicity-induced oxidative stress. Metal stress-induced toxicity leads to the accumulation of particular flavonoids which are associated with the defense of plants is increased including anthocyanins and flavonoids. "Accumulation of phenolics occurs due to the upregulation of genes involved in the synthesis of phenylpropanoid enzymes such as phenylalanine ammonia lyase, chalcone synthase, shikimate dehydrogenase, cinnamyl alcohol dehydrogenase, and polyphenol oxidase," which depend on the modulation of the level of transcript genes coding the enzymatic biosynthesis due to metal stress. Flavonoids are having predominant free radical scavenging ability such as H_2O_2 and play a significant role in the phenolic/ascorbate-peroxidase cycle (98.99). "Two major enzymes, Viz., Shikimate dehydrogenase (SKDH) and glucose-6-phosphate dehydrogenase (G6PDH) contribute in catalyzing the biochemical reactions required for the generation of essential precursors of phenylpropanoid pathways." "Cinnamyl alcohol dehydrogenase

(CADH) catalyzes biochemical reactions required for the biosynthesis of lignin." Metal-induced oxidative stress leads to the production of free radicals, in response to this plant stimulates the phenylpropanoid biosynthetic pathway and upregulation of various enzymatic activities such as "PAL, SKDH, G6PDH, and CADH." Additionally, polyphenol oxidase (PPO) neutralizes the ROS species and increases the tolerance in plant against metal-induced abiotic stress.

Accumulation of phenolics is important to compensate for the adverse effect of stressors like drought. Transcriptomic and metabolomic investigations revealed that synthesis and accumulation of flavonoids increase under drought stress to increase the survivability of the plant. Drought stress initiates the biosynthesis and accumulation of flavonols to protect the plant against the toxic effect of free radicals. These flavonoids work as antioxidants and prevent the negative effect of ROS species and these flavonoids are also indicators of water deficit example tomato. Accumulation of flavonoids in the cytosol can effectively detoxify the H_2O_2 molecules produced due to the "drought stress and at the end oxidation of flavonoids along with ascorbic acid-mediated reconversion of flavonoids into primary metabolites. The major cause for the drought-induced deposition of polyphenols is due to the activation of phenylpropanoid biosynthetic pathway."

"Reactive oxygen species (ROS) such as superoxide anions, hydrogen peroxide, and hydroxyl" ions during salt stress needs the stimulation of a well-orchestrated and well-tuned antioxidant system in a plant to downregulate the production of ROS. Phenolic compounds being strong antioxidants helps in the neutralization of harmful ROS in plants under salt stress. Furthermore, during salt stress in plants, phenylpropanoid biosynthetic pathway becomes activated and leads to the generation of different phenolic compounds which acts as powerful antioxidative capability. "Various genes including VabHLH1 are associated in the increased generation of flavonoids by controlling the genes of the biosynthetic pathways and confers the salt stress to plants." NtCHS1 contributes to the biosynthesis of flavonoids under salt stress as reported in tobacco plants; however, accumulation of these flavonoids directly increases the free radicals. Under the saline conditions biosynthesis of flavone increases by upregulation of the flavone synthase gene expression in glycine max GmFNSII-1 and GmFNSII-2 and in some plants under the saline stress various phenolic acids becomes accumulated such as "caffeic acid, caftaric acid, cinnamylmalic acid, gallic acid, ferulic acid, and vanillic acid." It has been reported that the synthesis of anthocyanins increases in growing plants under saline environment.

7.10 Conclusion and Future Perspectives

The plant phenolic are considered as communal and extensive tributary metabolites. They contain significant pool of biological organic variety with an enormous number of enzymes and compounds and an extensive range of procedures for the regulation of genes as well as transportation of enzymes and metabolites. Phenolic compounds are gathered in the plant tissue and provide a robust reaction towards hostile ecological stresses such as pathogen attack, wounding, deficiency of minerals, and temperature stress. Development of plant is enhanced by polyphenols that interact with ethylene which is a plant growth hormone. Also, these compounds act as indicators for lignin and suberin that are polymerized into the cell wall. Recent studies have shown that cell wall thickening helps the plant in preventing freezing stress. An elevation in the thickening of the cell wall reduces the risk of cell collision for the period of cold prompted mechanical strength and dehydration therefore preventing cold stress in plants. Polyphenols impact the source and movement of organic and inorganic nutrients present in soil accessible to plant or microbes. They also respond to nutrient deficiency therefore offering means for detecting nutrients disorder before the onset of symptoms. In spite of few works done on phenolic compounds biosynthesis and their deposition as adaptive feedback in contrast to abiotic stresses, a thorough study dealing with the mechanism behind their deposition and their connections between other cell metabolites should be done in order to have a better indulgent of their elevated expression and carrying forbearance under such conditions.

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