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Role of Phenolic compounds in plant defense mechanism: An updated review

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Abstract

Being immovable, plants have to face all types of abiotic and biotic stress conditions. In response to various stress conditions, different plants accumulate different phenolic compounds. The phenolic compounds accumulated to counter various stresses depend on the type of stress conditions. In general, light stress induce the synthesis of phenolics and flavonoids; temperature extremes inducethe accumulation of osmoprotectant compounds which eventually stimulate the synthesis of antioxidants such as flavonoids, tannins, and phenolics in plants. In nearly all types of stress conditions plants increase the production of reactive oxygen species (ROS) and also to counter this, the plant produces phenolic acids, polyphenols, flavonoids, anthocyanins, and other compounds with similar properties to counter ROS such as (H_2O_2). In case of biological stresses, the plants accumulate phenolics at the infection site to restrict microbes' growth. Sometimes, they also induce the synthesis and accumulation of Salicylic acid (SA) and H_2O_2 at the site of infection. It's important for plants as they develop systemic acquired resistance (SAR). The synthesis and accumulation of phenolic compounds were also recorded immediately after post-infection; indicating their crucial role in plant defense mechanisms against various types of stresses. The present review focuses on current updates on the role of phenolics and their physiological functions as a response to stress conditions and their probable applications in stress counter.

Key words : Abiotic and biotic stress, Phenolic compounds, Plant defense.

Every time, when plants are exposed to any abiotic or biotic stress conditions, these stresses negatively impacted the plant's growth, development, and yield[12,13]. During the course of evolutions,plants have developed a variety ofbiochemical or metabolic pathways

to respond to different abiotic and biotic stress conditions,especially through induced biosynthesis of secondary metabolites. These metabolic pathways are important and integral parts of plant growth, survival, development, reproduction, and defense.

During stress conditions, plants divert more energy towardthe synthesis of secondary metabolites resulting accumulation of various secondary metabolites in plants[23,35,132]. These secondary metabolites are essential toregulate the plant's defense mechanism and other developmental processes. Among various plant metabolites, phenolic compounds constitute a special class of natural secondary metabolites synthesized through various pathways likepentose phosphate, shikimate, and phenylpropanoid pathway[16,29,51]. The plants use these pathways to produce either monomeric phenolic compounds (flavonoids, phenolic acids, and phenylpropanoids) or polymeric phenolic compounds (tannins, lignins, lignans, melanins, etc.). Phenolic compounds show high structural as well as functional diversity. In terms of their occurrence, some phenolic compounds are widely found frequently in many plant species while others are only observed in a fewplant species[67]. Nearly all known phenolic compounds are reported to have a defensive function against abiotic and biotic stress conditions[36,67].

Most common abiotic stress includes extreme environmental conditions such as high or low light conditions and temperature, ultraviolet (UV) radiation, deficiency of nutrients, drought or flood-like conditions, etc. while the biotic stress includes infection by microbial pathogens, attack by herbivorous organisms, nematodes, larvae, etc.

The capability to synthesize specific phenolic compounds in response to particular abiotic or biotic stress is developed by plants through adaptive evolutionary phenomena over a period of time. To respondto different environmental challenges, plants have developed a variety of arrays to synthesize various phenolics to defend against the stresses[27]. Flavonoids and isoflavones accumulate heavily in plants exposed to very low temperatures, nutrient deficiency, UV- B radiations, pathogenic attack, and herbivorous activities[87,109,114]. Phenolics were also known to accumulate in plants as a response to metallic stress in the soil[82,86] and microbial infection[15,70,127,133]. Fig. 1. is the schematic representation of various types of abiotic stress conditions, which stimulates the biosynthesis of phenolic compounds and later increased accumulation of phenolic compounds helps to counter the abiotic stress conditions.

This article is a compiled presentation of various research work related to the synthesis and accumulation of various phenolic compounds by plants exposed to various kinds of stresses and their role in plant defense mechanisms as understood so far.

Fundamentals of Phenolic compounds :

Phenolic compounds are a diverse group of plant chemicals having phenol moiety in their structure. These compounds are basically classified into two categories as simple phenolics and polyphenolics (Fig. 2) which are groups of structurally and functionally allied phenol-containing compounds. They are abundant in plants and found in all parts of

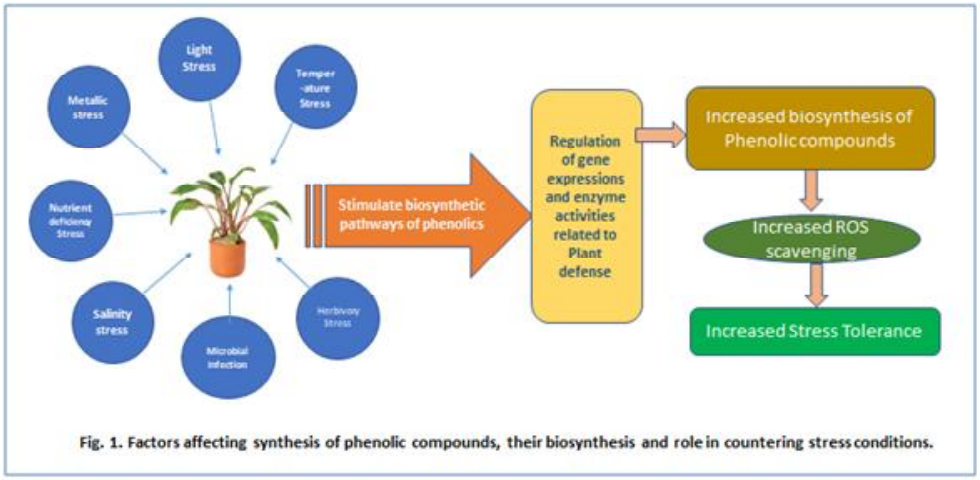

Fig. 1. Factors affecting synthesis of phenolic compounds, their biosynthesis and role in countering stress conditions.

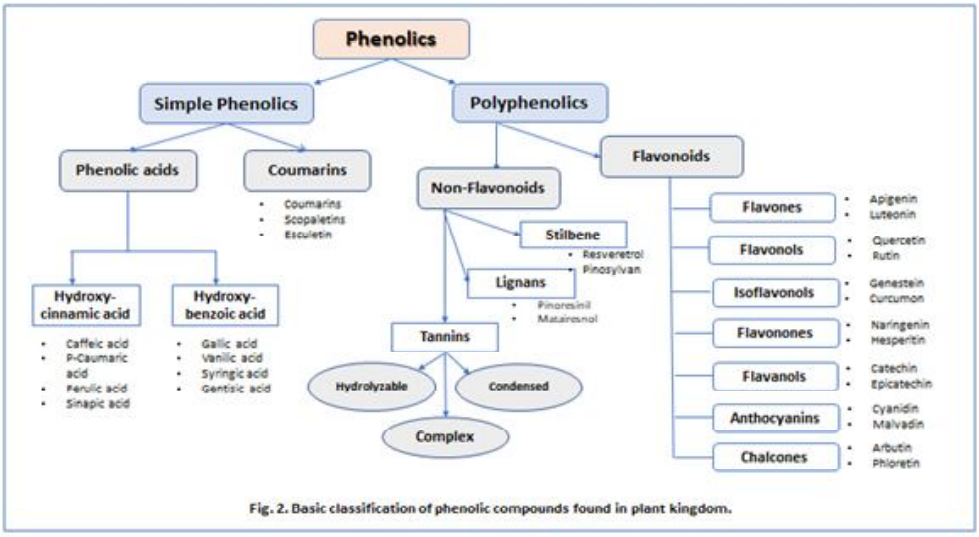

Fig. 2. Basic classification of phenolic compounds found in plant kingdom.

plants. These compounds display a wide variety of biological activities. The most important biological properties of phenolics include antioxidant, antimicrobial, anti-inflammatory etc.[29,77].

Role of plant phenolics in countering light stress :

Phenolic compounds in plants play an important role in growth control and have antioxidant, structural, attractant, signaling, and protective functions. Plants synthesize and accumulate phenolic acids and flavonoids in the vacuoles of mesophyll and epidermal cells in response to light stress conditions[124]. Falcone *et al.*[37] noted that after exposure to UV-B radiation the genes P1, B, and PL1 increaseexpression in maize which inducesthe

synthesis of transcription regulators that regulates the activity of protein ZmFLS1 for converting the dihydro-flavanols, dihydro-quercetin, and dihydro-kaempferol to flavonols, quercetin, and kaempferol respectively. Radyukina *et al.,*[103] observed the accumulation of flavonoids and anthocyanins in plants exposed to ultraviolet light and salinity stress. Their report suggested that flavonoids protect plants from UV-B radiation and anthocyanins protect them from salinity stress. Manukyan[83] reporteda high accumulation of total phenol in *Melissa officinalis*, *Nepeta cataria,* and *Salvia officinalis* after exposure to low UV-B radiation. In *Salvia miltiorrhiza*, Ma *et al.*[80] observed that UV radiation increases the concentration of rosmarinic acid and lithospermic acid. They suggested that methyl jasmonate induces biosynthesis of enzymes tyrosine aminotransferase, cinnamic acid 4-hydroxylase, 4-hydroxyphenylpyruvate reductase, and phenylalanine ammonia-lyase (PAL) that are responsible forthe biosynthesis of rosmarinic acid and lithospermic acid. Ghasemzadeh *et al.*[43] reported accumulation of specific phenolic compounds in sweet basil leaves was dependent on the intensity of UV-B radiation. They suggesteda direct correlation between synthesized phenolic compounds'reactive oxygen species (ROS) generation due to UV light damage. They observed that some phenolic acids like cinnamic acid, gallic acid, quercetin, ferulic acid, catechin, rutin, luteolin, and kaempferol are precursors for biosynthesis of different flavonoids through phenylpropanoid metabolism that utilizes PAL and chalcone synthase enzymes. when it is exposed to low UV-B light Csepregi *et al.*[34] reportedan increased accumulation of flavonols, quercetin, and kaempferol derivatives in leaves of *Arabidopsis thaliana*. Leon-Chan *et al.*[73] observed that the low temperature and UV-B radiation causes the degradation of chlorophyll and accumulation of carotenoids, chlorogenic acid, flavonoids apigenin-7-O-glucoside, and luteolin-7-O-glucoside in leaves of bell pepper. They specifically observed that UV-B radiation increases flavonoid concentration in leaves whereas the combination of low temperature and UV-B radiation increases chlorogenic acid in leaves. They also noted that the luteolin-7-O-glucoside is involved in quenching of the reactive oxygen species (ROS) produced due to low temperature and UV-B radiation stress. Lobiuc *et al.*[78] suggested that the phytochemical content of the basil green cultivar was high in red light whereas of the basil red cultivar was high in blue light when exposed to different proportions of blue and red light. In a comparative study, they observed an increased accumulation of rosmarinic acid, caffeic acid, and anthocyanin when exposed to blue light and white light. Similar reports were made by Taulavuori *et al.,*[125], Stagnari *et al.,*[122], and Nadeem *et al.,*[91]. Teerarat[126] reported an accumulation of phenolic compounds, especially chlorogenic acid and other flavonoids in leaves of *Coffea arabica* after exposure to UV light.

Role of plant phenolics in countering temperature stress and drought stress :

Extreme temperature conditions usually inhibit plant metabolism and stimulate the production of reactive oxygen species (ROS) which damage the cells[10,48]. To combat this damaging stress plants accumulate osmoprotective compounds such as soluble sugars, proline, glycine betaine antioxidant

enzymes, and other defensive substances which provide protection from oxidative damage[17,116]. The phenolics, terpenes, and alkaloids also accumulateduring temperature stress to develop stress resistance ability in plants[52,96]. During temperature stress activity of the enzyme phenylalanine ammonia-lyase (PAL) increases which results in the accumulation of phenolic compounds in plant cells. Rivero *et al.,*[108] suggested that during heat and cold stress, there is a remarkable accumulation of soluble phenolics in watermelon and tomato. Kasuga *et al.,*[60] indicated that cold-induced phenols accumulation in plant cells decreases the freezing point, maintains water potential, and protects cellsfrom disruption. Weidner *et al.*,[130] reported increased content of tannins and soluble phenols in the roots of grapevine after cold treatment. Amarowicz *et al.*[5] demonstrated that during cold stress there is increased accumulation of gallic acid, ferulic acid, and caffeic acid in plants. Isshiki *et al.*[55] observed an accumulation of farinose flavonoids in the aerial part of fairy primrosewhen it was exposed to freezing cold stress. Rana and Bhushan[105] suggested that biosynthesis and accumulation of phenolic compounds in plants provide tolerance against cold stress. In the same line, Commisso *et al.*[32] provided evidence that phenolic compounds protect the cytoskeleton of microfilaments from reactive oxygen species. Chalker-Scott and Fuchigami[28] reported that cellular injury and stress tolerance capacity in plants is increased by the accumulation of phenolic compounds like suberin or lignin.

When the plant is exposed to drought stress it usually produces reactive oxygen species (ROS) (hydrogen peroxide H_2O_2, singlet oxygen O, superoxide anion O_{2-}, and hydroxyl radical OH) which may cause protein degradation, membrane damage, lipid peroxidation, deoxyribose nucleic acid (DNA) damage andcell mortality[117,136]. To prevent this damage, plants have a special system of detoxification which is regulated either by enzymes (superoxide dismutase (SOD), ascorbate peroxidase (APX), catalase (CAT), peroxidase (POD)) or by antioxidant molecules (phenols, vitamin C, carotenoids, tocopherol, and glutathione)[12]. Kumar *et al.*[67] suggested that the overproduction of reactive oxygen species (ROS) during stress is balanced through the production of phenolic compounds and flavonoids using the phenylpropanoid pathway[67]. Akula and Ravishankar[1] observed an accumulation of flavonoids in the leaves of willow plantsduring drought stress. A similar observation was made by Nakabayashi *et al.,*[92] in leaves of *Arabidopsisthaliana*in response to drought conditions. An increase in phenylalanine ammonia-lyase (PAL) activity indicates the beginning of the plant's antioxidant defense mechanism and is regulated by the feedback inhibition process through the increase in the accumulation of its own product cinnamic acid[22]. It regulates the activity of the enzyme and in turn, specific phenolic compounds are synthesized in response to biotic or abiotic stress. Chalcone synthase is an enzyme that shows high activity during drought stress. It is a key enzyme in the flavonoid synthesis pathway that acts on the CoA-ester of cinnamic acid to form chalcone. The chalcone is converted to flavanone by the chalcone flavanone isomerase (CHI) enzyme through isomerization which is a precursor for the synthesis of numerous flavonoid compounds[67]. Hura *et al.,*[54] reported the accumulation of ferulic acid and high

activity of PAL enzyme in leaves of maize under water stress conditions. Phimchan *et al.*[101] also reported high PAL activity and ferulic acid accumulation in fruits of capsicum during drought stress. Nakabayashi *et al.*[92] observed the high activity of another enzyme chalcone synthase (CHS) in response to drought stress in *Arabidopsis*. Some workers have observeda high accumulation of phenolic compounds in vegetables, fruits, and cereals under drought stress[42,121]. Sarker and Oba[112] observed a high accumulation of flavonoids in the leaves of *Amaranthustricolor* during drought stress. Brunetti *et al.*[24] suggested that *Moringa oleifera*can serve in water deficit conditions by accumulating flavonoids in leaves. Moayedinezhad *et al.,*[90] indicated that drought stress had a marked influence on the content of various phenolic compounds such as total phenolic content, total as well as individual polyamines, and organic acids in grapevine cultivars. Severe heat stress increases the accumulation of phenolic acids *i.e.*, p-coumaric, syringic, and vanillic acids, and decreasesferulic acid, whereas severe drought had a higher impact on ferulic acid and the total sum of phenolic acids in durum wheat[69]. Park *et al.,*[99] also identified drought-responsive phenolic compounds in *Ligularia fischeri*and studied their biosynthesis and regulation.

Role of plant phenolics in countering salinity stress :

Usually, salinity stress induces the production of reactive oxygen species (ROS) in plants resultingin oxidative stress. To counter this oxidative damage plants produce antioxidative metabolites such as polyphenols, flavonoids, anthocyanins, pro-anthocyanidins, phenolic acids, and phenolic terpenes which quench the singlet oxygen, neutralize or absorb free radicals and decompose peroxides[96]. Yang *et al.,*[134] suggested the accumulation of specific phenolic compounds in plants during salinity stress. Parida *et al.,*[98] earlier reported that there was a significant increase in polyphenols content in plants of *Aegiceras corniculatum* after 250 mM NaCl treatment. Ksouri *et al.,*[66] suggested that there was a significant increase in polyphenols in jerboa plants after treatment with 100 mM and 400 mM NaCl. Hanen *et al.,*[45] suggested that the phenol content in a leaf of the plant *Cynara cardunculus* increases in response to 50 mM NaCl treatment. Lim *et al.,*[76] suggested that the accumulation of phenolic compounds in response to salinity stress in *Fagopyrum esculentum* is due to the increased content of compounds such as vitexin, iso-orientin, rutin, and orientin. Similar reports were presented by Petridis *et al.*,[100] and Borgognone *et al.,*[21].

Another mechanism acquired by plants to resist salinity stress is through salicylic acid which is an endogenous growth regulator and signaling molecule. It is a phenolic phytohormone that controls stress by decreasing H_2O_2 levels and reducing oxidative damage in plants[72]. It enhances growth, development, and productivity in plants during stress conditions[104]. Many research studies have suggested the function of salicylic acid in increasing salinity tolerance in plants. Jini and Joseph[58] and Khan *et al.,*[62] suggested that salicylic acid strengthens the salinity tolerance in plants such as *Medicago sativa, Vicia faba, Brassica juncea,* and *Vigna radiata.* Jayakannan *et al.,*[57] observed that exogenous salicylic treatment increased

water content and growth of shoots in Arabidopsis plants growing under saline conditions. Various studies of mutant plants have suggested the function of salicylic acid in providing salinity tolerance to plants[11,26,47,89]. Various studies on the exogenous application of salicylic acid to salinity-stressed plants have also confirmed that salicylic acid alleviates the toxic effect of salt and increases the resistance of plants against salinity[9,12,61,97]. Hanifah and Purvestri[46] reported that there is an increase in the accumulation of Phenolic compounds, total flavonoid, and antioxidant activity with the increase of saline concentration.Kiana *et al.* (2021) reported the vigorous antioxidant activity and robust accumulation of phenolic compounds in the leaves of *Triticum vulgare* and *Aegilops cylindrica*.

Role of plant phenolics in countering heavy metal stress :

The plants take up heavy metals through their roots which get accumulated inside the cell wall by the apoplastic system. These heavy metals may cause harm to plants by hindering biochemical metabolisms such as cell division,cell elongation, photosynthesis, nitrogen metabolism, respiration, mineral nutrient utilization, and water transportation[31,123]. It was noted that heavy metals inactivate essential enzymes by binding to their active sites, it alsoinducesthe biosynthesis of reactive oxygen species, and exchange metal ions from biomolecules[115]. Under heavy metal stress conditions, plants synthesize phenols and flavonoids to scavenge the harmful reactive oxygen species (ROS) which donates their electron to peroxidase enzymes to detoxify hydrogen peroxide produced by heavy metals[111]. Under cadmium stress, maize accumulates phenolic compounds in roots[118]. Ali *et al.,*[4] observed high activity of enzymes responsible for the biosynthesis of phenols and flavonoids in roots of Panax ginseng exposed to copper sulfate. Kovacik *et al.,*[65] reported that when *Matricaria chamomilla*was exposed to nickel,the activity of the polyphenol oxidase enzyme decreased and there was an increase in total phenolics content. There was a remarkable increase in the activity of phenylalanine ammonia-lyase (PAL) and shikimate dehydrogenase enzymes with an accumulation of chlorogenic acid, protocatechuic acid, and caffeic acid. Marquez-Garcia *et al.,*[84] observed that when*Erica andevalensis* are exposed to cadmium, the concentration of rutin, cinnamic acid derivatives, and epigallocatechin increases. They suggested that increased cadmium exposure decreases the concentration of phenolic compounds in plants to reduce the deleterious effect of produced phenoxyl radicals. Malcovska *et al.,*[81] suggested the production of phenolic compounds increases in plant cells when plants are under heavy metal stress as phenols are reactive oxygen species (ROS) scavengers and metal chelators. Kisa *et al.,*[63] observed that when Zey maize plants are exposed to cadmium and lead, the phenolic compounds (chlorogenic acid and rutin) increased in leaves whereas there was a decrease of caffeic acid and ferulic acid. Later in 2019, Kisa *et al.,*[64] reported the changes in phenolics compounds in tomatoes in relation to heavy metal stress. Janczak-Pieniążek*et al.,*[56] studied the pattern and correlated the metal stress with an accumulation of phenolic compounds in winter wheat varieties.

Role of plant phenolics in countering microbial pathogens :

Plant growth and development are directly influenced by a variety of abiotic and biotic stresses.The plants mechanize their defense in two stages, first there is a rapid accumulation of phenols at the infection site that slowdowns the growth of invading pathogens. In the second step,it biosynthesizes specific stress-related substances (simple phenols, phenolic phytoalexins, hydroxycinnamic acids, etc.). These compounds restrict the pathogen from invasion. The sequence of plant defense mechanisms includes the accumulation of phenolic compounds, necrosis, host cell death, modification of cell wall through phenolic compounds deposition or development of some kind of barriers, and at last synthesis of specific toxic compounds to eradicate the pathogens[95]. Pattern recognition receptors (PRRs) are the proteins present in the cell membrane of plants. They recognize conserved pathogen-associated molecular patterns (PAMPs) of microorganisms and givea signal to synthesize specific phenolic compounds, through a defense mechanism known as PAMPs-induced immunity[20,50,94,102,138].

In some cases, plants induce multi-component defense response after a pathogen attack which includes the reprogramming of genetic resources, expression of a large number of defense-related genes, and encoding of enzymes that catalyze the biosynthesis of defense metabolites (phytoalexins). The process is regulated by transcriptional factors responsible for the accumulation of specific phytoalexins in plants. Salicylic acid also plays a crucial role in resisting pathogen attacks in plants. During pathogenic infection, there is a remarkable accumulation of pathogenesis-related (PR) protein at the location distant from the infection site and to regulate systemic acquired resistance (SAR) in plants salicylic acid and H_2O_2 play a vital role[14,59].

Some plants possess innate immunity against pathogenic bacterial species. They have developed metabolic mechanisms to resist pathogenic bacteria through the accumulation of phenolic compounds. Postel and Kemmerling[102] reported that plants recognize bacterial pathogens through pathogen-associated molecular patterns (PAMPs). In walnut plantsinfected by *Xanthomonas arboricola* bacteria, Mikulic Petkovsek *et al.,*[88] observed an accumulation of hydroxycinnamic acid, gallic acid, quercetins and catechin. Cho and Lee[30] identifiedan accumulation of sakuranetin in rice plants infected by *Xanthomonas oryzae* and *Burkholderiaglumae*. Wang *et al.,*[129] suggested that polyphenols inhibit bacterial species such as *Escherichia coli, Klebsiella pneumoniae, Staphylococcus aureus, Salmonella cholera-esuis, Bacillus subtilis, Serratia marcescens,* and *Pseudomonas aeruginosa*.

Earlier studies suggested that phenolic compounds eliminate fungal pathogens by altering the permeability of cell membrane, the integrity of the cell wall, the formation of free radicals andsuppression of enzymes activity, damage of DNA, and suppression the expression of virulence genes[6,39,93,102]. Gallego-Giraldo *et al.,*[41] reported the suppression of lignin biosynthesis genes (HCT) leads to the accumulation of salicylic acid which in turn increases the transcription level of some pathogenesis-related (PR) genes to improve the immunity of plants. Widodo *et al.,*[131] suggested that

coumarins inhibit the growth of fungi by altering the thickness of the mitochondrial matrix, inducing apoptosis. Al-Barwani and Eltayeb[3] observed the antifungal activity of psoralen and furanocoumarin against fungi *Alternaria brassicicola, Sclerotinia sclerotiorum* and *Cercospora carotae*. Some other similar reports includes that of Al-Amiery *et. al*.,[2], Serpa *et al.*[116] and Zuzarte *et al.,*[139]. Belofsky *et. al*.,[18] suggested that the isoflavone sedonan A isolated from plant *Dalea formosa* prevents from infection caused by *Candida albicans* and *Candida glabrata* by inhibiting the activity of intracellular transcription targets and efflux pumps. Sherwood and Bonello[119] suggested that lignin has potent antifungal activity against the fungi *Diplodia pinea* under in vitro conditions. Anttila *et al.,*[7] suggested that the tannin extract isolated from the cone and bark of conifer plants has a toxic effect on four soft rot fungi, three white rot fungi, and eight brown rot fungi. Rashed *et al.,*[106] observed the toxic effect of *Ammivisnaga* seed extract against the fungi *Rhizoctonia solani* was due to the presence of coumarins. In sugarcane, Marques *et. al*.,[85] observed the accumulation of phenolic compounds at the infected site during the early stage that might be helpful to prevent the penetration and spread of *Sporisorium scitamineum* fungi in other parts of the plant.

Kumar and Pandey[68] suggested that phenolic compounds suppress viral infection in plants by inhibiting viral replication through simultaneous damageof protein,and nucleic acids and inhibition of viral enzyme activities. Hu *et al.*[53] observed the antiviral activity of different phenolic compounds isolated from *Arundina graminifolia* against the tobacco mosaic virus. Zhao *et al.,*[137] suggested that the two flavonoids (fistula flavonoid B and C) isolated from the bark and stem of the plant *Cassia fistula* has antiviral activity against the tobacco mosaic virus. Shokoohinia *et al.*[120] suggested that coumarins inhibit viral replication in cells by inhibiting enzymes such as protease, integrase and reverse transcriptase. Li *et al.,*[75] identified the phenolic compound gramniphenol which exhibited antiviral activity against the tobacco mosaic virus. Later in 2016, Liu *et al*. reportedthe antiviral potential of two coumarins isolated from leaves of *Nicotiana tabacum* against tobacco mosaic virus. Zakaryan *et al.,*[135] suggested that flavonoids suppress viral infection by distracting of viral RNA translation, inhibiting viral DNA replication, inhibiting viral protein synthesis, inhibiting transcription factors responsible for viral enzymes and genome synthesis, and interfering with viral structural protein.

Role of plant phenolics in countering insects, nematodes, and herbivorous organisms :

Plants have to face various pathogenic attacks in the natural environment. To resist these pathogens plants have adjusted their physiological metabolism and developed metabolic pathways which synthesize a wide range of phenolic compounds. These phenolic compounds are used either to attract or repel different organisms as per plants' benefit. Through their toxicant effect and inhibition, they protect plants from various insects, nematodes, and herbivorous animals which feed on them[19]. Feeny[38] suggested that tannins have an inhibitory effect on the growth of

Opheropthera brumata larvae. Levin[74] suggested that the phenolic quinone hypericin secreted by glands on leaves, sepals, or petals of *Hypericum* spp. is toxic to insects and mammals. He also suggested that the presence of gossypol in the leaves and flowers of plants can inhibit grazing by mammals and infection by tobacco budworms or bollworms. Hedin *et al.,*[49] suggested that some flavonoids present in cotton plants are feeding inhibitors for the boll weevil, Anthonomus grandis. Luczynski *et al.,*[79] suggested that the concentration of catechol increases in the leaves of strawberries when infected by spotted spider mites. Byers[25] suggested that the bark beetle *Scolytus multistriatus* does not consume *Carya ovata* due to the presence of the phenolic compound juglone which is not palatable to them Accumulation of anthocyanins provides red, blue, or purple color to leaves, and flowers or fruits which protects the plant from the herbivorous animals and insect pathogens. These pigments developed in leaves are either not palatable for animals to eat or are not visible to animals due to a lack of red visualization receptors. Usually, insect pathogens are found to avoid red leaves and are noted to colonize mostly on green leaves. Because red leaves have better chemical defense, coupled with the worst nutritional value,whichinduces adverse effects in insects. Hence autumn colors of leaves is an adaptive mechanism of plants to reduce pathogen attacks[8,44,71]. Further, Rehman *et al.,*[107] suggested that catechol, a phenolic compound binds to the digestive system of mites and inactivates digestive enzymes mites. Furstenberg-Hagg *et al.*[40] opined that most wheat cultivars arevery rich in phenolic content,therefore, not consumed by cereal aphids *Rhopalosiphum padi*.

Plants constantly interact with the environment, and climate change has already impacted their diversity, growth, and survival. In order to minimize the impact of various climate change-related stresses, plants produce diverse defense secondary metabolites, mainly phenolic compounds. Phenolic compounds regulate crucial steps in plant metabolism to provide resistance against various biotic and abiotic stresses. To protect against UV radiation plants synthesize phenolic acids and flavonoids to scavenge the reactive oxygen species (ROS) generated. During temperature stress activity of the phenylalanine ammonia-lyase(PAL) enzyme increases which results in the accumulation of phenols in plant tissues. The accumulation of phenols during drought stress is regulated by the activity of either phenylalanine ammonia-lyase (PAL) or chalcone synthase (CS). Phenylalanine ammonia-lyase (PAL) acts as a precursor for the biosynthesis of various phenolic compounds. Chalcone (CS) synthase helps to accumulate numerous flavonoid compounds in plants during water deficiency. During salinity stress plants accumulate polyphenols, flavonoids, anthocyanins, phenolic acids, and terpenes to resist oxidative stress. Plants also accumulate salicylic acid during salinity stress to decrease the level of H_2O_2 and reduce oxidative damage. Plants synthesize phenols and flavonoids to scavenge the reactive oxygen species (ROS) produced during heavy metal stress. Plants accumulate phenolic compounds at the infection site to inhibitthe growth and penetration of microbial pathogens in other tissues and organs. It recognizes microbial pathogens and induces a defense response at the genetic level to biosynthesize defense metabolites. Plants also accumulate salicylic

acid and H_2O_2 at the infection site to regulate systemic acquired resistance (SAR). Phenolic compounds also play a vital role as inhibitors or toxicants for nematodes, insects, and herbivores.

Future prospective :

The biosynthesis of phenolic compounds in plants during abiotic and biotic stress increases the adaptation of plants in extreme environmental conditions. Therefore, it is necessary to understand the molecular mechanism regulating biosynthesis and accumulation of specific phenolic compounds during particular stress conditions. There should be molecular and genetic level studies on the regulation of transcription factors responsible for the biosynthesis of specific phenolic compounds during each type of stress. A line of progressive study on interactive biology between phenolic compounds and salicylic acid is possible to understand the crosstalk between them while respondingto salinity stress, oxidative damage, and microbial pathogen attack. This will help to develop effective strategies to develop crop varieties that could overcome stress conditions.

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