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Review

Phytoextracts as Crop Biostimulants and Natural Protective Agents—A Critical Review

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Abstract: Excessive application of synthetic chemicals to crops is a serious environmental concern. This review suggests that some potential natural compounds can be used as alternatives and could be applied directly to plants to improve crop growth and productivity. These phytoextracts can serve as biostimulants to induce abiotic and biotic stress tolerance in different crops growing under diverse environmental conditions. The biosynthesis and accumulation of a variety of chemical compounds such as glycinebetaine, vitamins, nutrients, and secondary metabolites in some plants are of great value and an environmentally friendly cheaper source than several synthetic substances of a similar nature. The review summarizes the information regarding the potential role of different plant phytoextracts and suggests subsequent applications to modulate crop stress tolerance. Future studies should focus on the relative effectiveness of these plant-based extracts compared with their synthetic counterparts and focus on practical applications to signify sustainable practices linked with the use of natural products.

Keywords: abiotic stress; biotic stress; biostimulants; phytoextracts; sustainability

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1. Introduction

The concept of sustainable agricultural practices is still a dream, although the idea was presented a long time ago [1,2]. Farmers and researchers of this modern era utilize synthetic chemicals as growth stimulants, herbicides, insecticides, and repellants at mass scale, as well as several synthetic amendments to enhance soil fertility [3]. A comparatively recent approach is to use synthetic nanomaterials for various agricultural practices (fertilizers, pesticides, nano-nutrient and pesticide carriers) and its associated risks remain questionable [4,5]. Biostimulants are natural or synthetic substances that can be applied to seeds, plants, and soil. These substances cause changes in vital and structural processes in order to influence plant growth through improved tolerance to abiotic stresses and increase seed and/or grain yield and quality [6]. Soil content is regulated by a number of aspects, such as organic carbon content, moisture, nitrogen, phosphorous, potassium contents, and biotic/abiotic factors. However, indiscriminate use of fertilizers, particularly nitrogen and phosphorus, has led to substantial pollution of soil by reducing pH and exchangeable bases; thus, these nutrients become unavailable to crops, leading to loss of productivity [7–9]. The pace at which modern farmers have shifted towards the use of synthetic compounds are alarming and the contamination of terrestrial and aquatic environment, entry into food chain and associated hearth risks has become a concern [10,11]. Such intensive use of synthetic compounds should be revisited before it is too late.

In the present review, an alternative approach is presented to encourage the use of plant extracts to enhance plant growth, productivity and agents for crop protection, and to improve the ecosystem services therein. Plants are typically exposed to myriad biotic and abiotic stresses, including feeding from wild animals and insects, weed infestation, hail, mechanical injury, diseases, low soil fertility, drought, salinity and others that can diminish the plant photosynthetic area, thus attaining total plant biomass or grain yield [12–14]. Research has been continuing to develop effective methods for crops under stress and non-stress conditions. Exogenous application of plant growth regulators, essential/beneficial nutrients, antioxidants and osmoprotectants has been reported to be effective in improving stress tolerance among plants [15,16]. Regarding the use of synthetic compounds, not only cost, but also duration of effectiveness, availability at commercial level, general acceptance, applicability to heavy metals and organic wastes, mobility, and volume reduction, are also important. Plants can serve as a cheap natural source of bioactive compounds and secondary metabolites enriched with beneficial compounds [17,18]. The present review summarizes how different phytoextracts can be used to improve plant growth under diverse environmental conditions.

2. Phytoextrants

Plants are the basic source of food, energy and dietary fibers for mankind [19]. However, the production of cereal crops affected due to various biotic and abiotic factors due to anthropogenic activities [20–22]. Fungal pathogens are responsible for plant diseases and cause high economic losses [23,24]. Synthetic fungicides, which are toxic and harmful to the environment, are used to control plant diseases caused by fungal pathogens; nowadays, the trend is shifting towards healthy, safe and sound ecofriendly control of fungal pathogens [25]. Phytoextracts of *Beta vulgaris*, *Moringa oleifera*, *Citrus sinensis*, *Melia azedarach* and *Azadirachta indica* significantly inhibited the fungal growth and spore germination [26,27]. The details of these phytoextracts studied under the abiotic stresses in plants are as follows:

2.1. *Beta vulgaris—Source of Glycinebetaine*

Economically important cultivated beets such as fodder beets, sugar beets, garden beets (e.g., red beet) and leaf beets (e.g., Swiss chard) belong to the sub-species *Beta vulgaris* [28]. All beets originate from a halophytic plant, *Beta vulgaris* (sea beet or wild beet). Glycinebetaine (GB) is a quaternary ammonium compound naturally synthesized by various plant species. Involvement of GB in the protection of native protein from denaturation, cell membranes from oxidative damage and its contribution to cellular osmotic adjustments under water-limited environment make it a vital plant-osmolyte [29]. It is also involved in the regulation of various biochemical processes via systematic signaling pathways and studies also suggested its positive contribution to carbon, nitrogen reserves and reactive oxygen species neutralization [30]. Although several studies report different responses of *Beta vulgaris* to environmental stresses, research articles and reviews mostly focus on salt and drought response mechanisms in beets [31,32]. Therefore, we need breeding techniques and agronomic practices for better tolerance to biotic and abiotic stresses in *B. vulgaris* [33]. Thus, cultivated beets and their wild ancestor are important genetic sources for crop breeding programs and studying abiotic stress tolerance [32]. Sugar beet belongs to the family Chenopodiaceae, and beetroot also contains a significant fraction of antioxidants and other bioactive compounds such as betaine, betalain and ferulic acid [31]. Glycinebetaine was primarily discovered from sugar beet (*Beta vulgaris*), which accumulates GB up to 100 mM concentration [34]. These compounds can improve agricultural productivity through mitigation of adverse effects of environmental stresses on cultivated crops.

The exogenous application of GB improved plant growth and productivity under different stress conditions (Table 1). Nowadays, a number of compounds including osmoprotectants such as proline and GB are used with exogenous application to plants to reduce the harmful effects of abiotic stresses including drought stress. GB, a quaternary ammonium substance, is an osmoprotectants that can effectively scavenge ROS in plant tissues [35,36], and improves the photosynthetic rate by maintaining the Rubisco ultrastructure [17]. It is present in different amounts in plant parts including seed, stem, root and flowers [37]. During the early juvenile stage of plant, it is present in small amounts in the roots but later increases in leaves [38]. Different levels of GB can be observed in different plant species under different abiotic stresses depending on plant species, genotype, development stage, application modes and different stress conditions [39]. GB plays an essential role to provide protection from high accumulation of ROS species in plants under water shortage [40] and increases the photosynthetic defensive mechanism [29]. Rapid change in cellular metabolism, inferior level of water potential and ABA recognition sites give rise to accumulation of GB under water stress [17]. Furthermore, exogenously applied GB enhances yield and tolerance level by increasing chlorophyll contents, stimulating antioxidant defensive system, decreasing ROS and stabilizing the photosynthesis ability of photosystem II under drought stress [36]. The application of sugar beet extract also resulted in improvement in drought stress tolerance in okra plants through maintenance of ionic homeostasis which contributed to the better photosynthetic activity and yield attributes [32]. Similarly, improvement in growth and biochemical parameters of drought-stressed pea plants was recorded in response to sugar beet extract application [33]. Interestingly, economically important cereal crops such as wheat, rice, barley and maize do not synthesize or retain GB naturally. As a way forward, exogenous application of sugar beet extract can be tested on major cereal crops to study its effects in abiotic stress tolerance particularly osmotic stress [32]. Moreover, various transgenic plants over-expressing GB biosynthetic genes and enhanced retention also exhibited drought and salinity tolerance (Table 2).

Table 1. Role of exogenously applied glycinebetaine (GB) in modulation of growth and physio-biochemical attributes in plants under stress conditions.

Type of Stress	Mode of Application	Concentration	Plant/Species	Effects	Reference
Salt	Foliar spray	50 mM	Okra	Enhanced growth, gaseous exchange and mineral nutrients uptake under saline stress conditions	[41]
Salt	Foliar spray	50 and 100 mM	Wheat	Accumulation of GB, in or outflux of nutrients, activities of SOD, POD and CAT enzymes	[42]
Drought	Foliar and pre-sowing	50 and 100 mM	Sunflower	Improvement in water status and turgor potential of cells/tissues under water stress conditions	[43]
Drought	Foliar spray	30 mM	Maize	Enhanced sugars, oil proteins, fiber, Ash, moisture, GB, micro and macro nutrients in seeds of maize	[44]
Drought	Foliar spray	50 and 100 mM	Wheat	High biomass production, shoot length, transpiration rate, root P, N and shoot K^+ under varying water regimes	[45]
Salt	Foliar spray	5 and 10 mM	Cowpea	Improved plant growth, yield production and biochemical constituents under saline conditions	[46]
Drought	Foliar spray	100 mM	Rice	Improved growth, yield, chlorophyll pigments and leaf fluorescence	[47]
Drought	Foliar spray	100 mM	Rice	Improved chlorophyll, carotenoids, leaf fluorescence and yield attributes	[48]
Drought	Foliar spray	100 mM	Rice	Increased proline, soluble sugar, starch, paddy yield and yield/plant under water stress conditions	[49]
Drought	Foliar spray	25 and 50 mM	*Carapa guianensis*	Improved GB accumulation, and activities of CAT and APX enzymes	[50]
Drought	Foliar spray	100 mM	Wheat	Improvement in proline and GB accumulaton	[51]
Drought	Foliar spray	4 mM	Pea	Increased soluble proteins, yield as well as activities of SOD, APX and CAT enzymes	[52]

Table 2. Role of GB in genetically engineered plants subjected to stress conditions.

Stress	Plant in Which Transferred	Gene	Effects	Reference
Freezing stress	*Arabidopsis thaliana*	*CodA*	Enhanced tolerance against stress	[53]
Salt stress	*Arabidopsis thaliana*	*CodA*	Increase in accumulation of GB under stress condition	[54]
Drought and salt stress	Tobacco	*AhCMO*	Tolerance against stress	[55]
Chilling stress	Tomato	*Cod A*	Increase in accumulation of GB	[56]
Salt and water stress	Tomato	*CodA*	Improved RWC, chlorophyll, proline and GB	[57]
Chilling stress	Maize	*CodA*	Increased germination, GB, photosynthesis, soluble sugars and aminoacids	[58]
Salt stress	Rice	*COX*	Increased endogenous GB accumulation	[59]
Oxidative, salt and drought stress	Potato	*CodA*	Reduced membrane damage, high biomass production and RWC	[60]
Water stress	Rice	*CodA*	Protected photosynthetic machinery	[61]
Low phosphate	Tomato	*CodA*	Enhanced enzymes activity and phosphate uptake	[62]
Salt stress	Tomato	*CodA*	Regulation of transporters and ions channels	[63]
Salt stress	Tobacco	*BADH*	Protected enzymes and improved photosynthesis	[64]

2.2. *Moringa oleifera*—Source of Vitamins and Nutrients

Moringa, belonging to Moringaceae, is known as the "miracle tree" that has versatile uses in both animals and plants. The extract from *Moringa oliefera* serves as a cheap, eco-friendly, novel biostimulator, and bioenhancer that increases sustainable agriculture and crop production [65]. *Moringa* contains several essential components such as mineral nutrients, phytohormones (e.g., auxins, gibberellins, and cytokinins), vitamins, flavanols, phenols, sterols, and tannins, as well as several phytochemicals that make it highly beneficial for plants. It induces seed germination, plant growth, photosynthesis, and yields traits at a low cost. It also increases flowering, improves floral traits, fruiting, post-harvesting, and product quality of the fruit, and decreases senescence [66]. Plants are a rich source of different vitamins (carotenoids, B vitamins, ascorbic acid, tocopherols and quinines) that regulate biochemical and physiological processes and contribute to plant development and determine productivity. The effect of exogenously applied vitamins and nutrients in the induction of abiotic stress tolerance in plants is presented in Table 3. The *M. oleifera* Lam. is a tree found worldwide and is considered as bioregulator as it is a rich source of ascorbic acid, K^+, Ca^{2+}, Fe^{2+}, riboflavin, carotenoids, phenolics and hormones including zeatin [67].

Table 3. Modulations in plant growth and plant biochemical characteristics by exogenous application of different vitamins and nutrients under stress conditions.

Vitamins	Levels	Stress	Crops/Species	Effects	References
Thiamine	25, 50, 75, 100, 125 and 150 mg/L	Salt	Maize	Reduced Na^+ concentration, MDA, H_2O_2, RMP while improving N, P, Ca^{2+}, and K^+, growth, chlorophyll and the activities of CAT, SOD and POD	[68]
Ascorbic acid	0.1 and 0.5 1 mM	Salt	*Saccharum* spp.	Improved growth, activity of POD and SOD as well as proline contents	[69]
AsA	0.5 and 1 mM	Drought	Wheat	Enhanced net photosynthesis rate, chlorophyll and growth	[70]
AsA	150 mg/L	Drought	Quinoa	Improved growth, RMP, Proline, GB, AsA, TSP, amino acids, total soluble sugars, reducing and non-reducing sugars activities of SOD and POD enzymes	[71]
Thiamine	5 and 10 mg/L	Salt	Sunflower	Reduced leaf water potential, improved RWC, chlorophyll, total amino acids, dry mass and concentration of K^+	[72]
Thiamine	50 and 100 mM	Drought	White clover	Improved biomass, shoot root length and chlorophyll pigments	[73]
Tocopherol	0.25, 0.5 and 1 mM	Salt	*Vicia faba*	Increased growth, leaf area, yield, RWC and nutrients uptake	[74]
Tocopherol	100, 200 and 300 mg/L	Drought	*Mung bean*	Improved plant height, total soluble proteins, ascorbic acid, amino acids, activities of POD and CAT enzymes while reducing MDA contents	[75]
AsA and Tocopherol	400 mg/L	Salt	Flax	Reduced peroxidation and polyphenol oxidase while accumulating proline, antioxidants and carbohydrates	[76]

Exogenous application of *M. oleifera* extract improved seed germination and seedling establishment under normal and stress conditions [77]. Improvement in chlorophyll, activities of antioxidant enzymes and recovery in yield attributes of salinity stressed wheat are reported in response to *M. oleifera* extract application. Salinity tolerance in bean plants was also improved in response to foliar-applied extract of *M. oleifera* [65]. Another study reported that seed priming with *M. oleifera* extract mediated improvement in the germination and growth attributes of rangeland grasses such as *Cenchrus ciliaris*, *Echinochloacrus-galli* and *Panicum antidotale* [78]. The foliar application of *M. oleifera* extract mitigated cadmium toxicity in bean plants [79] and *Saccharomyces cerevisiae* [80]. Field trials are lacking which should be focus on future studies as *M. oleifera* extract could serve as a natural, cheap and green source of nutrients and vitamins that can be exploited to modulate crop growth and stress responses. *M. oleifera* roots, leaves, flowers, fruit, pods, and seeds have high nutrient values because it is rich in essential phytochemicals, e.g., minerals, vitamins, nicotinic acid, riboflavin, pyridoxine, β-carotene, flavonoids, glycosylates, phenolic acids, terpenoids, sterols, alkaloids, and fatty acids [79]. Therefore, it is used as herbal medicine and is known as a panacea. *Moringa* leaf extract has high nutrient and antioxidant value and is used as a therapeutic agent [80]. It serves as a potent antioxidant, as well as anti-inflammatory, anticancer, antimicrobial, antitumor, antitrypanosomal (control sleeping sickness), antiviral, antileishmanial, antidiabetic, antihypertension, and antispasmodic bioactive compounds [78]. Recently, *Moringa* seeds have been significantly characterized as having seed oil potential. *Moringa* seed extract is used against dyspepsia, heart disease, and eye diseases. *Moringa* seeds have strong antifungal activity against a zoophilic dermatophyte [81]. *M. oleifera* seeds contained active coagulant and antimicrobial agents, and this could be utilized for water purification as a viable replacement of proprietary chemicals such as alum sulfate [66]. Only in a few cases has an in vitro culture technique been used to promote the production of antioxidant compounds in moringa cells. Indeed, in recent decades, in vitro growth has been widely proposed as a means for inducing plant secondary metabolism, especially under stimulation by elicitors and stress conditions [65,66].

2.3. *Citrus sinensis—Source of Ascorbic Acid*

Ascorbic acid (AsA), also referred to as vitamin C, is a major nonenzymatic antioxidant in plants and plays an important role in alleviating certain oxidative stresses caused by biotic and abiotic stress [82,83]. AsA can enhance the growth of a plant and boost its capacity to withstand stress [84–86]. Moreover, AsA is the first line of plant defense against oxidative stress by removing a number of free radicals, such as $O_2^{\bullet-}$, $HO^{\bullet}$, and H_2O_2, mostly as a substrate of APX, an essential enzyme of the ascorbate–glutathione pathway [17,54,55]. Ascorbate is a cofactor for several cellular enzymes, such as violaxanthin de-epoxidase, which is essential for photoprotection by xanthophyll cycle and other enzymes and is directly involved in the removal of ROS, and the addition of exogenous AsA will inhibit lipid peroxidation and decrease malondialdehyde (MDA) content in plant tissues, thus improving the antioxidant ability of plant tissues [71,83,87,88]. The effect of ascorbic acid on improving the salinity tolerance of potatoes was studied by Sajid and Aftab [89]. They noted that activity of most antioxidant enzymes, such as SOD, POD, CAT and APX, increased significantly under NaCl stress conditions after exogenous application of ascorbic acid, thereby improving plant survival under environmental stresses. Younis et al. [90] also stated that a marked and statistically significant increase in the percentage resistance to salt stress and growth of *Vicia faba* seedlings was caused by the exogenous addition of 4 mM ascorbic acid with NaCl to the stressful media during experimentation (12 days). Aly et al. [91] observed that addition of 1 mM of ascorbic acid to Egyptian clover (*Trifolium alexandrinum* L.) seedlings grown in NaCl medium significantly increased seeds germination, carotenoids and chlorophyll and the dry mass of seedlings grown in NaCl medium.

Being a cofactor of various enzymes involved in phytohormone-dependent signaling cascades [92,93], it acts as a signaling molecule in various cellular and sub-cellular processes [94]. It can efficiently quench reactive oxygen species and thereby protect membrane structures and vital bio-molecules from oxidative stress [95]. The diverse involvement of ascorbic acid in the regulation of plant growth, physio-biochemical responses, flowering and most importantly stress sensing, signalling and regulation of ascorbate-glutathione cycle is well documented [96]. Sweet oranges are cultivated as the largest citrus fruit, and its global cultivation produces about 70% of total annual citrus yield [97]. The cultivation and production of oranges in Pakistan is ranked amongst the top suppliers. Sweet oranges are borne on a small flowering evergreen tree (7.5 to 15 m height) from the Rutaceae or citrus family and are rich source of vitamin C, and contain trace quantities of other vitamins and minerals including Ca, K, Mg, folate, thiamin and niacin [98]. Its juice is a good source of vitamin C, folate and polyphenols. The exogenous application of vitamin C improves stress tolerance among plants via regulation of cell expansion, ion transport, phytohormone signaling and reactive free radicals [71,99]. The use of *Citrus sinensis* extracts could potentially be an eco-friendly approach to induce multi-stress tolerance in plants and future studies should investigate its involvement and efficacy to regulate crop responses.

2.4. Melia azedarach—Source of Terpenoids

Melia azedarach is a deciduous tree of the Melia genus, which also commonly known as the purple flower tree, forest tree, and golden Lingzi. It is a fast-growing and high-quality timber tree; it is also a good nectar plant and a vital plant pesticide [100]. The timber, which resembles mahogany, is used to manufacture agricultural implements, furniture, plywood, etc. *Melia azedarach* is also of value for the health care and pharmaceutical industries, an effective composition due to its analgesic, anticancer, antiviral, antimalarial, antibacterial, antifeedant, and antifertility activity [101]. Furthermore, it is an important afforestation tree species, as are the surrounding greening tree species. *Melia azedarach* is widely distributed. It is native to tropical Asia and has been introduced to the Philippines, United States of America, Brazil, Argentina, African and Arab countries [100]. In China, it is concentrated in the south and southwest, with a relatively concentrated distribution in the east and central regions, and a marginal distribution area in the north, southwest, and southern Shanxi and Gansu [102]. For this reason, *Melia azedarach*, as a tree native to China, has diverse provenances [103].

Various naturally occurring secondary metabolites including terpenoids play developmental and regulatory roles among plants. Terpenoids are derived from isoprene units and such compounds serve as pigment molecules, vitamins, hormones and non-enzymatic antioxidants [104]. The diverse involvement of terpenoids in plant physio-biochemical functioning and regulation of stress tolerance is documented (Table 4). The *M. azedarach* (Persian lilac or Chinaberry) is a deciduous tree from Meliaceae family is rich in terpenoids [100]. Different plant parts including fruit, root, bark, stem and leaf contain diverse chemical compounds such as azedarachins, trichillins, limonoids and meliacarpns. It is widely distributed in sub-continent countries including Pakistan, Nepal, Bangladesh, Sri Lanka and exhibit excellent medicinal properties [103]. Certain phenolic compounds also contribute to higher antioxidant activity of *Melia* [105]. Extracts of *M. azedarach* fruit were effective in controlling chickpea blight. Similarly, a pathogenic fungus, *Sclerotium rolfsii* was found to be controlled by the application of *Melia* extract [106]. Antifungal and antibacterial properties of the *M. azedarach* extract on pathogenic fungal species including *Fusarium oxysporum*, *Fusarium solani*, *Fusarium sambucinum*, *Fusarium oxysporum*, *Alternaria alternate*, *Botrytis cinerea* and bacteria including *Enterococcus faecalis*, *Escherichia coli* and *Bacillus subtilis* were prominent [107]. The application of *M. azedarach* leaf extract was reported to enhance salinity tolerance of pea plants [108]. The inhibitory effects of *M. azedarach* extracts were also recorded on germination and biochemical traits of radish [107] and future studies should investigate the crop-specific effect of *M. azedarach* extracts to potentiate its applications at larger agricultural scale.

Table 4. Role of phenolics compounds in improvement of plant growth and biochemical attributes under stress conditions.

Phenolic Compounds	Levels	Stress	Crops/Species	Effects	Reference
Caffeic acid	100 µM	Salt	Soybean	Decreased superoxide radical, improved cell viability, SOD, growth, manganese SOD isoforms and Cu/Zn SOD isoforms	[109]
Caffeic acid	10 and 20 mg/L	Heat	Cotton	Decreased electrolyte leakage and amino acids, increased alpha and beta amylase activity	[110]
Ellagic acid	50 ppm	Osmotic	Chickpea	Enhanced germination growth, Proline, GB, flavonoids, GSH, CAT, POX, SOD and GR while lowering MDA, H_2O_2, and electrolyte leakage	[111]
Coumarin	50 ppm	Salt	Wheat	Improved osmolytes, soluble sugars, K^+/Na^+ and antioxidants	[112]
Benzoic acid	0.25, 0.50, 0.75 and 1 mM	Heat	Cotton	Improved N, P, K and Z uptake	[113]
Salicylic acid	100, 200 and 300 mg/L	Salt	Sunflower	Improved biomass, growth and photosynthetic rate	[114]
Salicylic acid	0.1, 0.5 and 1 mM	Salt	Maize	Increased growth and uptake of N, mg, Fe, Mn and Cu while inhibiting Na^+ and Cl^-	[115]
Salicylic acid	100, 150 and 200 ppm	Drought	Maize	Improved chlorophyll, RWC, K content and leaf membrane stability	[116]
Salicylic acid	600 µMS	Cd toxicity	Potato	Increased RWC, chlorophyll, proline, CAT, SOD, APX, GR decreased MDA, H_2O_2, O^{2-}	[117]
Salicylic acid	100 µM	Cu toxicity	Rice	Improved RWC, chlorophyll, AsA and redox ratio	[118]
Salicylic acid	1 mM	Salt	Maize	Increased sugar, proline, while decreasing K^+ and phenolic contents	[119]
Salicylic acid	0.01%	Salt	Tomato	Increased AsA while decreasing phenolic compounds and amino acids	[120]
Salicylic acid	0.5 mM	Salt	Mustard	Modulated cell redox balance and increased the activities of enzymes	[121]
Salicylic acid	0.5 and 1 mM	Drought	Fennel	Increased water potential, RWC, osmolytes, chlorophyll, carotenoids and seed essential contents	[122]
Ferulic acid	0.6 mM	Heat	Blueberry	Increased proline, soluble sugars, RWC, transcription of genes encoding cu/zn SOD, CAT, GR, while decreasing H_2O_2, MDA, SO^{2-}	[123]
Cinnamic acid	0.5, 1 and 1.5 mM	Drought	Wheat	Improved proline, SOD, APX, guiacol peroxidase	[124]
Vannilic acid and p-hydroxybenzoic acids	25 and 50 µM	Drought	Rice	Improved flavonoids, phenolics, activities of antioxidants	[125]

2.5. *Azadirachta indica*—Source of Secondary Metabolites

About 135 compounds have been isolated from different parts of the *Azadirachta indica* (neem tree), and several reviews are available on the chemistry and structural diversity of these compounds [106]. As an ecologically friendly option, the formulation of biopesticides derived from the *A. indica* has been gaining interest. The main secondary metabolites responsible for the pesticide or antifeedant effecting *A. indica* are limonoids, or tetranor-triterpenoids, azadirachtin being the most active compound [126]. *A. indica* cell culture is seen as an interesting alternate for the production of these secondary metabolites. In particular, stirred-tank bioreactors have been used for this purpose, although other reactor systems have been employed [127]. Additionally, shake flasks play an important role in the preparation of inoculum. However, the hydrodynamic environment resulting from the agitation speed and the bioreactor configuration affects the plant cell growth and the metabolite yield in stirred-tank bioreactors [106]. Therefore, it is important to establish the relationship between the operating conditions of the bioreactor and culture response under hydrodynamic stress. The compounds have been categorized into two major classes such as isoprenoids and non-isoprenoids and exhibit incredible antifungal [128], antiviral [129], anticancer [130], antibacterial [131] and antioxidant properties [132]. Due to the presence of diverse secondary metabolites, neem extract application could induce biotic stress tolerance among plants against multiple pathogenic species.

Control of black scurf fungal disease in potato thorough exogenous neem extract is reported [133]. Neem extract mediated induction of biotic stress tolerance in pea plants against powdery mildew was linked with increased phenylalanine ammonia-lyase activity [127]. A recent study linked application of neem fruit extracts induced systemic acquired resistance in tomato plants against *Pseudomonas syringae* through increased activity of polyphenol oxidase enzyme [134]. Consistent with earlier reports, the application of neem and tulsi extracts reduced the severity of early blight of tomato through improvement in chlorophyll contents and increased antioxidant enzyme activities [135]. The use of neem extract suggested for management aphid attack on wheat [136] and corm-rot disease of *Gladiolus* [137] to prevent crop loss in Pakistan. Other than biotic stress, application of neem aqueous extracts improved growth and pigments which contributed improved photosynthesis in algae, *Nostoc muscorum* [138]. It is reported that neem extract reduced MDA contents and mitigated oxidative stress [138,139]. Based on the available literature, the application of neem extracts to crops can promote stress tolerance especially in response to pathogenic attack.

3. Conclusions

Phytoextracts containing biostimulants can be used as fertilizers to maintain the quality of crops by providing them with the essential metabolites and nutrients. Most importantly, these are cheaper, affordable and easily available for smallholder farmers compared to the synthetic products. The plant-extracts from *C. sinensis*, *M. oleifera* and *B. vulgaris* can be used to induce biotic and abiotic stress tolerance in plants as a cost-effective and environmentally friendly strategy to improve crop productivity. Still there are gaps and efforts regarding the direct application of plant-extracts on different crops as nutrients and/or biostimulants are limited and required more investigations. Plants such as *A. indica* and *M. azedarach* are naturally enriched with several terpenes and iso-terpenes (which can be obtained in extracts) that show significant insecticidal and pesticidal activity making them potentially eco-friendly alternatives over synthetic pesticides. As a future research prospect, field trials should investigate its efficacy against different insects, pests and microbial crop pathogens. In short, the undue use of synthetic compounds on our food and forage crops must be discouraged, and modern farmers and growers should follow sustainable practices.

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Abbreviations

Glycinebetaine (GB), reactive oxygen species (ROS), ascorbic acid (AsA), ascorbate peroxidase (APX), hydroxyl radical (HO), hydrogen peroxide (H2O2), malondialdehyde (MDA), superoxide dismutase (SOD), peroxidase (POD), catalase (CAT), sodium chloride (NaCl), calcium (Ca), potassium (K), magnesium (Mg).

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