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Naturally biosynthesized secondary plant products and its importance: An overview

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Abstract
Plant secondary metabolites (SMs) play vital roles for the survival of plants in the open environmental condition. Plants are also providing diverse group of valuable natural products in the form of secondary plant products. The major roles of secondary metabolites produced by plants are protection against pathogenic agents and environmental stresses. Indeed, accumulation of secondary metabolites in the plant organs depends on the climatic factors such as light, soil, temperature, salinity and fertility of the soil. However, metabolites naturally synthesized by plants are very crucial for the living beings on the earth; particularly for the human beings in the form of bioactive compounds for the treatment of various kinds of diseases and other health benefits. Secondary metabolites produced by plants are used as drug, flavors, fragrance, insecticide and dyes of high economic value. Some metabolites synthesized by fungus and bacteria are involved in the resistance mechanism against various kinds of abiotic and biotic stresses. Emerging technologies in the field of plant science enhance the usefulness of higher plants as renewal source of phytochemical, especially medicinal drugs. Continuous efforts and exploitation of natural plant resources is expected to lead in the production of valuable secondary metabolites with medicinal importance.

Keywords: secondary metabolites, alkaloids, terpenoids, phenolics, nitrogen-containing secondary metabolites, drugs, flavonoids

1. Introduction
Plants on the earth are wonderful gift of nature and play numerous vital roles for the living organism and also for the development of environmental balance. Plant produces several types of phytochemicals due to their metabolic activities. Generally plant metabolites are either primary or secondary in origin. The organic compounds like carbohydrates, proteins, lipids, nucleic acids plays central role to the metabolism of plants. Such types of compounds are considered as primary metabolites or primary plant products (Kumar and Mina, 2013) [57]. Apart of these compounds, certain plant genera and some plant species synthesized number of organic compounds but they are not involved in the primary stream of metabolism and have no any direct function of the growth and development of the plants (Bourgaud, *et al*., 2001) [14]. These compounds are chemically diverse in nature and are called as secondary plant products or plant secondary metabolites. Term secondary metabolite was coined by Albrecht Kossel in 1910, a novel laureate in the field of medicine and physiology (Jones, 1953) [51]. Secondary metabolites are frequently distributed throughout the plant kingdom and perform defense mechanism against pathogens and herbivores. Most of the plants are capable to produce and synthesized diverse group of organic compounds in the form of secondary plant products (Gokulan, *et al*., 2014) [38]. The secondary products synthesized by the plants are the metabolic intermediates and required to the plants for the survival in the environment and produced in response to number of stresses (Ruby and Rana, 2015) [81]. Some of the secondary plant products perform to attract the animals for seed dispersal and pollination agents as well as agents of plant to plant competition (Korkina, *et al*., 2018) [55]. Most of the secondary plant products perform non-volatile functions. Most of the plant secondary metabolites are used by humans as medicine, drugs, flavonoids and pigments (Navarova, *et al*., 2012) [70]. However, some of the plant secondary metabolites like chlorophyll, carotenoids, phytohormones and Phytochromes plays important role in the plant metabolism so they are considered as primary metabolites (Croteau, *et al*., 2012) [23].

Natural products such as alkaloids, terpenoids, tannins, rubber, gutta, phenolics etc are the major secondary plant products synthesized by the plants (Kroymann, 2011) [56]. Furthermore, some of the plant secondary metabolites are composed of isoprene units and have been identified in the form of terpenoids or terpenes. Few terpenoids like steroids are considered as primary plant products because of their distinguished characteristics (Berini, *et al*., 2018) [10]. Rather than isoprenoid, plants also produces compounds assemble with aromatic ring are commonly known as plant phenolics. These compounds are broad group of plant secondary products and are characterized on the basis of aromatic ring skeleton. Some secondary plant products having the diverse group of nitrogen atom attached to the basic carbon atom of the major compounds are also biosynthesized by the plant kingdom (Hall, *et al*., 2008) [42]. These compounds are either heterocyclic or non-heterocyclic in nature. Generally, secondary metabolites of the plants are diverse group of organic compound and naturally synthesized in very small quantity. They are mostly appearing in the plant organ in the form of phytochemicals (Ramakrishna and Ravishankar, 2011) [77]. Many plant secondary metabolites are used as aromatic compound, resins, gum, rubber, enhancers, insecticides and herbicides (Freeman and Beattie, 2008) [33].

Plant secondary metabolites produced by plants are also involved in the resilience mechanism for the number of abiotic stresses. The metabolic pathway initiated from primary carbon metabolism produces the ultimate precursor for the synthesis of various kinds of secondary plant products (Jamwal, *et al*., 2018) [49]. However, aromatic amino acid compound and their derivatives synthesized through shikimic acid pathway are actively involved in the stresses resilience mechanism with potential interference of tyrosine, tryptophan and phenylalanine (Parker, *et al*., 2009) [73]. Most of the secondary metabolites are accumulated in the various plant parts depending on the climatic situation and acute stress condition (Ahuja, *et al*., 2012) [1].

Research on the plant secondary metabolites and other natural products synthesized by the plants affects the diversity of plant species in the various capacity and certain species evolve to resistance secondary metabolites synthesized by the plants (Croteau, *et al*., 2012) [23]. In this review, we have describe in detail about the naturally synthesized secondary plant products in the form of plant secondary metabolites and its importance in the protection mechanism against herbivores, insects, pests diseases as well as their importance for human beings in the form of medicine and drug.

2. Common biosynthetic pathway of plant secondary metabolites

Plant secondary metabolites are extremely numerous and diverse group of natural products. The study of plant secondary metabolites and its biological function have great function because of the natural biosynthesis of large number of valuable molecules. Isoprenoid, terpenoids, phenolics and nitrogen-containing compounds are the major biosynthetic product of plant secondary metabolites in the nature (Thomas, *et al*., 2013) [93]. Most of the plant secondary metabolites are naturally biosynthesized through primary plant metabolism (Caputi, *et al*., 2011) [17]. Primary carbon metabolism are considerable responsible for the biosynthesis of the major group of plant secondary metabolites (Zillich, *et al*., 2015) [102].

Carbohydrate and their derivatives are the backbone of the plant secondary metabolite syntheses through various biosynthetic pathways. The complex carbohydrate breaks into simplest sugar and initiates the path of plant secondary metabolite biosynthesis (Vranova, *et al*., 2012) [99]. Major rout of carbohydrate metabolism like pentose phosphate pathway (PPP), glycolysis, pyruvate pathway provide the potent precursor for the biosynthesis of plant secondary metabolites (Paul and Dewick, 2009) [74]. The intermediate product of carbohydrates undergoes several enzymatic reactions through shikimic acid pathway, mevalonic acid pathway and malonic acid pathway to produce well known secondary plant products like terpenoids, phenolics and other nitrogen-containing secondary plant products (Azwanida, 2015) [6].

However, the aliphatic amino acid and their just derivatives of the TCA cycle are able to biosynthesize nitrogen-containing plant secondary metabolites. In addition to phenolic compound biosynthesis, the intermediate product between TCA cycle and acetyl-CoA of the pyruvate goes through malonic acid pathway (Ng and Or, 2015) [71]. The primary carbon metabolism of the carbohydrate inters through pentose phosphate pathway and gets converted into erythrose-4-phosphatey and immediately undergoes through shikimic acid pathway to yields well known compound of aromatic amino acid (Velderrain-Rodriguez, *et al*., 2014) [95]. Rather than pentose phosphate pathway, counterparts of primary carbon metabolism like phosphoenol pyruvate directly inter into shikimic acid pathway for the biosynthesis of nitrogen-containing secondary plant products (Berdy, 2005) [9].

3. Major classes of plant secondary metabolites and its importance

Several grouping criteria have been considered for the classification of plant-derived secondary products but classification based on the chemical property, chemical structure, appearance of aromatic ring system, sugars and basic carbon skeleton have been found as idea criteria. According to the chemical property and structure, plant secondary metabolites are broadly classified into three groups namely; Isoprenoids, phenolic compounds and nitrogen-containing secondary metabolites (Ilya, *et al*., 2002) [47].

3.1. Isoprenoid and its derivatives

Isoprenoids are the largest group of secondary plant products and are composed of basic carbon skeleton. Isoprene 5-C activated unit synthesized from acetyl-CoA through mevalonic acid pathway.

Table 1: Isoprene derived plant secondary metabolites

Isoprenoid class	Number of involved isoprene unit	Secondary metabolites	Plant source	Literature Source
Hemiterpene	One	Isovaleramide	*Valeriana povonii*	Sara, *et al*., (2010) [85]
Monoterpene	Two	Geraniol	*Palmorose oil*	Chen and Viljoen (2010) [20]; Dubey and Luthra (2001) [29]
Sequiterpene	Three	Farnesol	*Citrus auratium*	Azanchi, *et al*., (2014) [5]
Diterpenes	Four	Vitamin E	*Corylus avellana* L.	Amir and Gisou (2017) [3]
Triterpenes	Six	Squalene	*Olive oil*	Ghimire, *et al*., 2016 [35]
Tetraterpenes	Eight	Carotene	*Rhodotorula glutinis*	Cutzu, *et al*., (2013) [24]
Polyterpenes	More than nine	Rubber	*Palaquium gutta*	Singh and Sharma (2015) [90]

3.2. Nitrogen containing compounds

Most of the secondary plant products containing nitrogen atom in their structure are frequently distributed in the higher plants and generally synthesized from amino acid. Nitrogen-containing plant secondary metabolites are generally isolated from the vascular plants (Verma, *et al*., 2015) [97]. They are serving ad very important constituents of the plants from insects, pests, diseases and other environmental stresses. Some of the nitrogen-containing secondary plant products are complex in nature and can be separated thorough various extraction processes for the commercial exploitation of the naturally occurring pharmaceutical compounds and drugs (Griesser, *et al*., 2015) [39]. This group of plant secondary metabolite includes alkaloids, glucosinolates and cyanogenic glycosides (Roberts, *et al*., 1998) [79].

3.2.1. Alkaloids

Alkaloids naturally synthesized by plant species are alkaline in nature and containing one or more nitrogen atom in their heterocyclic ring. Alkaloids constitute the third largest group pg plant secondary metabolites. Alkaloids synthesized by the plants are diverse group of secondary metabolites and primarily isolated from the vascular plants (Wu, *et al*., 1977) [100]. More than 3000 alkaloids have been isolated from plant except algae. Alkaloids are known to be accumulated in young and growing plant parts of the epidermal and hypodermal cell as well as bundle sheath (David, 1998) [25]. Often, the alkaloids are synthesized in a particular plant organ but accumulated in the other plant organs viz. in tobacco, nicotine is synthesized in root and translocated and stored in the leaves (Fulton, *et al*., 1976) [34]. Most of the alkaloids naturally synthesized by plants are colourless, crystalline, non-volatile solids and some of them like coniine and nicotine are found in liquid form at ordinary temperature (Herbert, 2001) [44]. They are usually bitter in taste, insoluble in water but soluble in strong organic solvent like ether and benzene. Plant derived alkaloids are optically active and being laevorotatory (Gurley, *et al*., 1998) [41]. Some plant derived alkaloids like coniine are dextrorotatory while papaverines are optically inactive (Finkelstein, *et al*., 2010) [32]. Alkaloids synthesized in the plants have number of physiological roles like provide protection against predators, acts as nitrogen reservoir, acts as growth regulator particularly as seed germination inhibitor, they may help in to maintain ionic balance due to their chelating power (Farook, *et al*., 2009) [31]. Plant derived alkaloids are categorized into three classes on the basis of heterocyclic ring system and primary substrate of basic carbon skeleton. The major three category of plant alkaloids are protoalkaloids, true alkaloids and pseudo alkaloids (Cosci, *et al*., 2011) [22]. True alkaloids and protoalkaloids are directly derived from amino acid while pseudo alkaloids are not directly derived from amino acid. Protoalkaloids do not contain heterocyclic ring in their structure and most of them are amines (Chen, *et al*., 2009) [19]. Ephedrine and hordenine is the major representatives of the protoalkaloids. Some plant derived alkaloids contain heterocyclic ring in their structure are considered as true alkaloids (Diogo, *et al*., 2011) [27]. The true alkaloids are further classified into many groups on the basis of ring system present in their active molecules (Table-2). Pseudo alkaloids may be categorized in to three different groups' *viz.* terpenoids containing alkaloids (steroids), phenanthrene alkaloids and tropolone alkaloids (Bozic, *et al*., 2018) [15]. The terpenoids containing alkaloids are occurring in the form of glycosides that is the non-carbohydrate part of the glycoside.

Table 2: True alkaloids naturally synthesized by plant kingdom

True alkaloid groups	Source of synthesis	Natural plant products
Pyridine alkaloids	Contain piperidine skeleton and pyridine skeleton. Derived from aliphatic amino acid lysine through biogenic amine formation from nitronic acid	Nicotine
Pyrrolidine alkaloids	Contain pyrrolidine ring linked with pyridine ring. Derived from aliphatic amino acid ornithine as non-protenaceous amino acid	Strachydrine
Tropane alkaloids	They contain seven carbon basic skeleton formed by condensation of three or four carbon compound acetoacetate with pyrrolidine skeleton derived from ornithine	Atropine
Quinoline alkaloids	Contain quinoline skeleton. Derived from tryptophan and secologanin through from mevalonic acid through mevalonic acid pathway	Quinine
Isoquinoline alkaloids	They contain isoquinoline as basic skeleton attached with benzyl residue. Derived from aromatic amino acid tyrosine	Narcotine, Berberine and Papaverine
Quinolizidine alkaloids	Contain one or more quinolizine ring system. Derived from lysine through decarboxylation of biogenic amine and cadaverine	Lupinine
Piperidine alkaloids	Contain piperidine and pyridine skeleton. Derived from aliphatic amino acid lysine.	Atropine
Indole alkaloids	They contain indole skeleton and derived from aromatic amino acid tryptophan through biogenic amine tryptamine via mevalonic acid pathway	Ergatomine, Reserpine

Source: Hesse and Manfred (2002) [45].

3.2.2. Cyanogenic glycosides
These groups of nitrogen-containing plant secondary metabolites are volatile poison when plants are crushed. The toxins released are feeding deterrent to many insects and herbivores (Kartsev, 2004) [54]. They are basically originated from various amino acids like other alkaloids. They are frequently distributed in the species of legumes grasses and especially in the Rosaceae family (Shakhnoz, *et al*., 2013) [89]. After injury plants of such family release HCN gas in contact with enzyme *Glycosidase*, *hydroxynitrilelyase* and may poisonous in the nature (Kumar, 2014) [58]. Amygdalin is commonly known cyanogenic glycoside which occurs in the *Prunus* species (Tadeusz, 2007) [92].

3.2.3. Glucosinolates
Glucosinolates are basically synthesized in the mustard plant. They contain nitrogen atom along with sulphur atom in their basic skeleton (Pelletier, 1983) [75]. When plants are crushed and come into contact of enzyme *thioglucosidase* released from plant parts, release pungent and volatile toxin as isothiocyanates and nitriles which provide potent deterrent to feeding insects and other herbivores (Babbar, 2015) [7].

3.3. Phenolic compound
Plant produces diverse variety of secondary products of phenolic group with hydroxyl group as a functional group attached with aromatic ring. Lignins, tannins, coumarins and flavonoids are the well known compound of this group (Posmyk, *et al*., 2009) [76]. Plant derived phenolic compounds are diverse in chemical structure, some of them are soluble in water and rest are in the organic solvent (Metcalf, 1987) [68]. Most of the phenolic compound in the form of plant secondary metabolite perform functions like deterrent against herbivores and pathogens, provide mechanical strength to the plants and have significant protective function (Lattanzio, *et al*. 2006) [61]. Some phenolic compound play important role in the attraction of insects for pollination and seed dispersal. In some plant species, they are secreted by root system to check the growth of nearby competitor plants and such type of secretion may fatal to nearby plants (Randhir, *et al*., 2004) [78]. All plant phenolics (Except flavonoids) are biosynthesized in plants from common biosynthetic intermediates phenylalanine or its precursor shikimic acid through shikimic acid pathway (Sreevidya, *et al*., 2006) [91]. The starting metabolites in this pathway are erythrose-4-phosphate and phosphoenol pyruvate, which are intermediates of pentose phosphate pathway and glycolysis respectively. However, in the case of flavonoids, one aromatic ring and its side chain arises from phenyl alanine while other aromatic ring arises from acetyl-CoA through malonic acid pathway (Leustek, 2002) [62]. The first step in the biosynthesis of phenolic compounds from phenylalanine in plants is deamination of phenylalanine by enzyme phenylalanine ammonia lyase. The latter is most extensively studied enzyme if secondary metabolism in plant system (Kang and Kim, 2007) [53]. Plant phenolics may be classified on the basis of number of carbon atom and basic arrangement of the carbon skeleton in their structure (Grubb and Abel, 2006) [40]. Depending upon the complexity of side chain, phenolic compounds are classified as simple phenol, phenol carboxylic acid, phenyl propanes and flavan derivatives (Table–3).

Table 3: Major categories of naturally occurring plant phenolics

C-atoms	Basic skeleton system	Known categories
Six	C_6	Phenols
Seven	$C_6 – C_1$	Phenolic acid
Eight	$C_6 – C_2$	Phenyl propenes, Hydroxy cinnamic acid, Phenylacetic acid
Nine	$C_6 – C_3$	Chromones, Coumarins, Isocoumarins
Ten	$C_6 – C_4$	Naphthoquinones
Thirteen	$C_6 – C_1 – C_6$	Xanthones, Stibenes
Fourteen	$C_6 – C_2 – C_6$	Anthraquinones
Fifteen	$C_6 – C_3 – C_6$	Flavonoids
Eighteen	$[C_6 – C_3]_2$	Lignans, Neolignans
Thirty	$[C_6 – C_3 – C_6]_2$	Bioflavonoid
Poly "n"	$[C_6 – C_3]_n$ $[C_6]_n$ $[C_6 – C_3 – C_6]_n$	Lignins Melanins Condensed tannins

3.3.1. Simple Phenol
Simple phenolic compound are consists of aromatic ring skeleton with one or more hydroxyl groups. Ring is the simple phenolic compounds may bear additional methyl group and glycosides (Wuyts, *et al*., 2006) [101]. Hydroquinone, vanillin, and arbutin are the major representative of this group of phenolic compounds. Darkening of pear leaves in the autumn season is due to oxidation of hydroquinone into quinones are the major expression of simple phenolic compounds found in the plants (Savirnata, *et al*., 2010) [87]. Lignin is the complex and the branched polymer of simple phenolic compound with $C_6 – C_3$ basic carbon skeleton. Lignin is the second most abundant organic compound in plants after cellulose and comprises 15 to 25% of the dry weight of many woody plant species (Lipka, *et al*., 2010) [65]. They are chemically composed of three kinds of aromatic alcohol viz. coniferyl, coumaryl and sinapyl alcohol (Gebreyesus, *et al*., 1980) [37]. The proportion of these three alcohols are varies according to the age of plants and acute water deficit and high temperature condition. Plant-derived natural lignin are strengthening materials, found in the secondary wall of the supporting and conducting tissues like cell wall, tracheids and vessel elements of the plants (Saito, *et al*., 2004) [82]. It may also occur in the middle lamella and primary wall along with cellulose and other cell wall polysaccharides. Primary function of lignin to provide mechanical support to the plants and also protects cell wall from physical, chemical and biological attack (Del, *et al*., 2014) [26].

3.3.2. Phenol carboxylic acid
Phenol carboxylic acids are simple phenol, composed of carboxylic acid as a common substituent. Such types of phenolic compounds have one carbon atom in their side chain

skeleton (Ali, *et al*., 2008) [2]. Gallic acid and protocatechuric acid is the main representative of this group of phenolic compounds. Protocatechuric acid is obtained through beta-oxidation of caffeic acid as phenol propane (Beart, *et al*., 1985) [8]. Most of the coloured onion bulbs contain water soluble protocatechuric acid and catechol. These phenolic compounds protect onion bulbs from smudge disease (Mazid, *et al*., 2011) [67].

3.3.3. Phenyl propanes

They are basically consists of propane skeleton and characterized by side chain of three carbon atom attached to the basic aromatic ring system (Cesarino, *et al*., 2012) [18]. Cinnamic acid, cinnamic alcohol, isocoumarins and lignin are the major compound of flavan derivative phenolic compound. Such types of phenolic compounds are naturally synthesized in the plants of Apiaceae family after infection or acute stress condition (Evans, 2009) [30]. The coumarins of this category of phenolic compound are still not toxic until they are activated by hours of light. However, some furanocumarins activated to release high energy by UV irradiation of sun light (Iranshahi, *et al*., 2009) [48]. The activated furanocumarins can insert into plant DNA and bind with pyrimidine bases and suddenly block the transcription process. The active forms of coumarins are also able to inhibit the growth of micro-organism (Gan, *et al*., 2013) [36]. Coumarins itself and with scopoletin are able to inhibit the seed germination and cell elongation in most of the cases under water deficit and high temperature condition. Rather than seed germination inhibition and cell elongation, few classes of coumarins are able to stimulate the activity of IAA that leads to the degradation of phytochrome IAA (Venugopala, *et al*., 2013) [96]. In plants, coumarins are generally form after injury of plant organs and during the process of their formation O-coumaric acid beta-glycosidase come into contact with beta-glycosidase enzyme and O-coumarinic acid is formed which lactonisase to produce coumarins (Brooker, *et al*., 2008) [16].

3.3.4. Flavan derivatives

Flavonoids are 15 – C containing phenolic compound, naturally occurring in the plants and consist of $C_6 - C_3 - C_6$ basic carbon skeleton. Two aromatic ring at the left and right sides of the flavonoid molecules are designated as ring A and ring B respectively. The middle ring of the flavan derivatives are derived from shikimic acid pathway (Velderrain, *et al*., 2014) [95]. They are usually occurs as glycosides and are soluble in water. Most of the flavan derived phenolic compounds are appeared with particular colour *viz.* red, crimson, purple, blue and yellow. They are accumulating the vacuoles and synthesized outside of the vacuole (Wuyts, *et al*., 2006) [101]. Flavonoids perform number of function in plants including defense and pigmentation (Veronique, *et al*., 2013) [98]. Based on the oxidation and various position of the ring system, flavan derived secondary phenolic compounds are anthocyanin, flavones & flavonols, and isoflavones.

Anthocyanins are coloured flavonoids, appeared as plant pigments in various colours as blue, purple and red flowers (Sales, *et al*., 2012) [83]. Sometimes, they may occur in the other plant parts such as fruits, flowers, stems, roots and leaves. However, anthocyanin provide different colour to vast majority of flowers and fruits but sometimes the coloration of flowers and fruits may due to carotenoid pigments such as in yellow flowers and tomato fruits (Vattem, *et al*., 2005) [94]. Anthocyanin contain hydroxyl group at the third position of the central ring and fifth and seventh position of the A ring (Lin, *et al*., 2010) [64].

Flavones and flavonols are closely related to anthocyanin except that they differ in the central ring of their molecules (Jin, *et al*., 2010) [50]. They are usually yellowish and ivory colour and frequently distributed in the flower petals to contribute flower colour. Isoflavonoids are the other types of flavan derived phenolic compound found in most of the leguminous crops (Lake, *et al*., 2009) [59]. They perform various kinds of function and physiological activities such as insecticide, rodenticide etc. Isoflavonoids are well known phytoalexins, produced in the plants as fungal and bacterial infection (Seabra, *et al*., 2006) [88].

4. Secondary metabolites other than plant source

Plants are the natural source of secondary metabolites but least quantities of secondary metabolites are synthesized by some bacteria and fungi. Fungal and bacterial secondary products are actively involved in the development of tolerance/ resistance in the plant system for numerous biotic and abiotic stresses (Rokem, *et al*., 1984) [80]. Most of the bacterial and fungal secondary metabolites are considerably known to be biotic elicitors (Sarker and Oba, 2018) [86]. Therefore, biotic elicitors are characterized as substances that induce the biosynthesis of specific compound associated with the adaptation of plants under stressful condition. Elicitors are biotic or abiotic, biotic elicitors are organic substances that contain carbohydrates and develop their signal effect to minimal concentration (Hodaei, *et al*., 2018) [46].

4.1. Bacterial secondary metabolites and its importance

The bacterial productions of secondary metabolites are initiated in the stationary phase of the bacterial development without requirement of any kinds of nutrients (Gokulan, *et al*., 2014) [38]. The secondary metabolites synthesized by bacteria are not essential for the growth and development of bacterium (Jung, *et al*., 2003) [52]. The main synthetic pathways of the bacterial secondary metabolite production are shikimate, and non-ribosomal pathway. Most of the bacterial secondary metabolites are toxic to human and useful for the plant system for the development of resistance mechanism for the number of biotic and abiotic stresses (Lewis, *et al*., 1997) [63]. The secondary metabolites in bacterial origin are used in the hairy root culture of Scopolia parviflora, they activate the synthesis of scopolamine by inhibiting H6H (hyoscyamine 6_–hydoxylase) expression (Jung, *et al*., 2003) [52]. In addition, increased production of glycyrrhizic acid has been observed in the roots of *Taverniera cuneifolia* following treatment with *Rhizobium leguminosarum*, while significantly increased amounts of glycyrrhizic acid have been noted when Bacillus cereus, *Agrobacterium rhizogenes*, and *Bacillus aminovorans* are instead used for the elicitation (Awad, *et al*., 2014) [4]. In another study, Rhizobacterium induced the production of pseudohypericin and hypericin in the seedlings of H. perforatum (Manero, *et al*., 2012) [66].

4.2. Fungal secondary metabolites and its importance

Fungal secondary metabolite includes polyketides, non-ribosomal peptides and terpenes. These substances are not required for the growth and development of fungus but play vital role in the in the survival of fungi in their particular environment (Boruta, 2018) [13]. Penicillin is the well known fungal secondary metabolites on the earth and have broad spectrum of medicinal importance (Conniff, 2017) [21]. Some fungal secondary metabolites are being acts as fungal elicitors for the plant system (Parchmann, *et al*., 1997) [72]. They are also involved in the several kinds of defense system for the survival of plants (Lattanzio, *et al*., 2006) [60]. In contrast, biographic pathogens (e.g., *Fusarium* spp. or *Phoma* spp.) do not kill the host cells but rather alter the host's metabolic and secretory systems to take nutrients from the host cells (Boerema, *et al*., 2004) [12]. In related studies, the monolignol pathway is stimulated by fungal mycelial extracts in cell cultures of *Linum usitatissimum* (Hano, *et al*., 2006) [43]. In soybean and potato plants, microbial resistance can be induced by cultures of Phytophthora. Resistance to Phytophthora has been induced in Capsicum annuum using extracts obtained from microbial-rich composts (Sang, *et al*., 2010) [84]. The production of catharanthine, serpentine, and indole alkaloids (e.g., ajmalicine) in cell suspensions of C. roseus is induced by fungal cell-wall fragments (Namdeo, *et al*., 2002) [69].

5. Biotechnological approaches towards secondary metabolites

Specific plant breeding techniques and strategic biotechnological approaches may helpful in the exploitation of plant secondary metabolites for their improvement and potential utilization in drug and pharmaceutical industries (Drewnowski and Gomez-Carneros, 2000) [28]. Furthermore, selective breeding and biotechnological approaches may used to reduce harmful secondary metabolites in food. In most of the cases increased content of secondary metabolites cases several types of disorder because of their harness may also be improved using accelerated breeding approaches of crop improvement (Biosafety Unit, 2020) [11]. Plant tissue culture technique is another potential approach of the biotechnology for large scale propagation of the desired secondary metabolite producing plants.

6. Conclusion

Secondary metabolites naturally synthesized by plants are one of the marvelous gifts of nature on the earth. Secondary metabolites have important ecological importance for the plants. Most of the plant derived secondary metabolites are protective in nature and able to protect plants against herbivores, pathogens and microbes. May secondary metabolites directly inhibit the pest and pathogen infection and also confer the stress tolerance in the plants. They are also involved as plant-plant competition and plant-microbe symbioses. Furthermore, identification of desired plant source of secondary metabolites is one of the important practices to impart the drug discovery. This review article can provide a robust platform for additional experiment and exercise through employing biotechnological approaches to explore the importance of plant derived secondary products for the future research to enhance bioactive accumulation.

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