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The Nutraceutical value of Horticultural Crops

Review Article

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Abstract

Nutraceuticals are one of the secondary metabolites that are being produced by diverse group of plants including the horticultural crops. The secondary metabolites in diverse horticultural crops are produced in significant amounts when encountered with different stresses such as wounding stress, abiotic stress, biotic stress, exposure to ultraviolet radiation etc. The secondary metabolite production in the plants enhances their response towards different stresses and help the plants to fight against the stresses in addition to their growth and development. The secondary metabolites expressed in horticultural crops such as phenolic compounds, flavonoids, alkaloids, polyphenols, terpenoids have proven to exhibit number of health benefits such as anti-inflammatory, anti-diabetic, anticancer response. The indepth knowledge of the biosynthetic pathways could lead to the enhancement of the secondary metabolites. Also, the stress responses can be modulated in a ways that could lead to the optimal expression of the genes involved in the production of these secondary metabolites. In the present review article, various horticultural crops including two vegetable and four fruit crops were assessed for the production of secondary metabolites under stress conditions, the biosynthetic pathways leading to the specific secondary metabolite production along with their health benefits have been discussed in detail.

Keywords: Nutraceuticals, Health benefits, Secondary metabolites, Abiotic stress, Alkaloids, Terpenoids, Flavonoids.

Introduction

Rapid industrialization and modernization in the last 20th century have drastically shifted the human community' s interest from naturally derived food products to fast foods, which in turn has resulted in various lifestyle related diseases like high blood pressure, diabetes, cardiovascular diseases etc. However, with the increasing awareness about the ill-effects and health complications associated with such type of diet and lifestyle people now-a-days are turning towards fruits, vegetables and other plant products not only for their nutritional values but also for their health benefits. Currently, the human society is very much inclined towards remedial approaches such as nutraceuticals, nutrition therapy, and phototherapy, compared to chemical pharmaceuticals or radiotherapy for improving their health status (1). The growth of nutraceutical and herbal products market as a multi-billion dollar industry is a clear evidence of this trend.

Plants produce a wide variety of phytochemicals called secondary metabolites, which are a valuable and rich source of pharmaceuticals and nutraceuticals (1). The term "nutraceutical" refers to a group of substances that are either food or components of food that provide medical or health benefits (2).The emergence of nutrients as medicines in the pharmaceutical world is of great importance and has drawn the attention of scientists and researchers towards the substantial benefits of nutraceuticals (3). This review paper will discuss the role of secondary metabolites as nutraceuticals.

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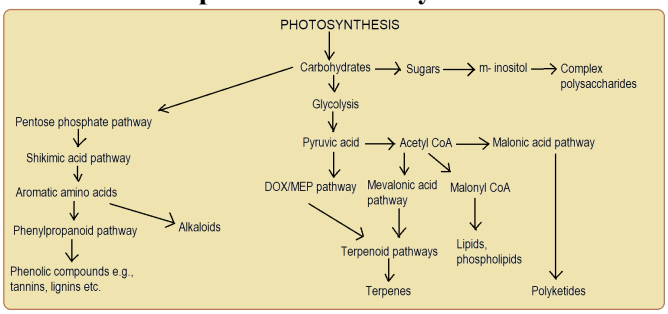
Primary and Secondary metabolites

The small compounds or intermediates produced during metabolism, playing a myriad of functions, including those of fuel, structure, signaling, catalysis, inhibition and stimulation of enzyme activity, defense, and interactions with other species are referred to as metabolites (4).

While primary metabolites provide the raw materials for processes like photosynthesis, respiration, and movement; secondary metabolites are necessary for normal growth and development (5). The intricate molecular make up of secondary metabolites typically result from modification of primary metabolites during biosynthesis, such as glycosylation, methylation, and hydroxylation (6). Secondary bioactive compounds serve crucial functions in plants such as playing an essential role in protecting them against various microorganisms, such as viruses, bacteria, and fungi, as well as herbivores like arthropods and vertebrates (7,8). Secondary metabolites are classified into three main groups: terpenes, phenolics, and nitrogen-containing

compounds. Terpenes, the largest class of secondary metabolites, are synthesized from acetyl-coenzyme-A molecules or glycolytic intermediates by mevalonic pathway. Their basic structure is isoprene units and they are classified based on the number of 5 carbon units (7). Phenolic compounds are diverse biomolecules that include flavonoids, tannins, antioxidants, and lignin. The basic structure of flavonoids is two aromatic rings linked by three carbon units (9). Most phenolics are water-soluble, some are soluble in organic solvents, and others are large insoluble polymers (10). Alkaloids are compounds that contain nitrogen and are usually part of a heterocyclic ring. Some alkaloids have pharmacological effects on animals and most are water-soluble (11). Biosynthesis of secondary metabolites from primary metabolites is presented in fig-1.

Fig.1 Figure representing the Metabolic Pathway of certain important Secondary Metabolites.



Secondary metabolites as nutraceuticals

Humans have been utilizing plant metabolites for various purposes since 2600 BC (6). Among which many secondary metabolites have been found to have beneficial effects on human health and are thus considered as nutraceuticals. Nutraceuticals are defined as functional foods or dietary supplements that provide health benefits beyond basic nutrition. They have gained popularity in recent years as an alternative to traditional pharmaceutical drugs due to their natural origin, lower risk of side effects, and perceived health benefits (2). Secondary metabolites have been identified as potential nutraceuticals because of their bioactive properties. For example, flavonoids and phenolic compounds have antioxidant properties, which can help to reduce oxidative stress and inflammation in the body. They also have anti-cancer and anti-diabetic properties (12). Alkaloids have been found to have antimicrobial, analgesic, and anti-inflammatory properties, and terpenoids have also been shown to have anti-cancer, anti-inflammatory, and anti-microbial properties (7, 6).

Importance of horticultural crops with respect to their nutraceutical values

With the increasing health awareness among people, nutraceuticals have gained substantial importance. There has been an increase in consumption of horticultural crops loaded with nutraceuticals, as they play a significant preventive and therapeutic role in various chronic diseases (13). Their plausible essential significance in promoting human and animal health and well-being cannot be overstated, especially for a developing undernourished nation like India. They are recognized as a millennium food of the century because of their numerous health advantages. The current knowledge is only the beginning; there is still a sizable body of indigenous folklore and unexplored ideals to be paved through. Therefore, there is a pressing need to research the healthful and therapeutic qualities of horticultural crops (14). The choice of plants for this review was made based on their ubiquity, accessibility, and range of advantageous metabolites. The goal of this research is to give readers a thorough grasp of how crucial plant components are and how they might be advantageous to our health. This information can make it easier for us to understand the benefits of including these plant chemicals in our diets.

However, the main objective of this study is to uncover and examine the nutritional advantages of horticulture crops via these secondary metabolites .The study investigates methods for increasing the production of these metabolites by putting plants under various, suitable stress situations. By doing this, we may be able to increase the nutritional worth of these crops and make them even better for our health.

Some popular horticultural crops and their nutraceutical value

Carrot

Carrot (*Daucus carota* L.) is a multi-nutritional plant as it pertains to highly rich natural bioactive compounds. According to Ayurveda, carrots, if consumed or applied, can help treat skin diseases or diseases related to the liver, excessive blood pressure, nourish weakened cardiac muscles, enhancing overall body immunity, and digestion. Carrot is a rich source of secondary metabolites such as carotenoids, polyacetylenes, anthocyanins, coumarins, flavonoids, and phenolics known to be beneficial for human health (15).

Application of wounding stress along with additional stresses such as ultraviolet (UV) radiation, hyperoxia, and phytohormones have been reported to promote wound-induced phenolic compound accumulation in carrots (16, 17, 18, 19) among which 3,5-dicaffeoylquinic acid (3,5-diCQA), 4,5-dicaffeoyl quinic acid (4,5-diCQA), and hydroxycinnamic acids are the key phenolic metabolites (20). The phenolic compounds prevent water loss with the help of process called lignification (20).

Fig. 2 Diagrammatic Representation of the production of Phenolic Compounds due to Wounding Stress

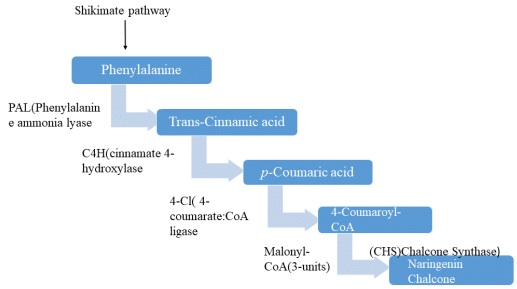
Health benefits of phenolic compounds in humans:

Phenolics in general can have a lot of health benefits for example hydroxycinnamic acid (phenolic compound) and its derivatives can potentially be used for cosmeceutical function as they interact with biochemical processes such as inhibition of melanin production, reduction of cytokine levels, photoprotection, and anti-elastase action, UV filtering and collagen synthesis(21) .Hydroxycinnamic acid has also been reported to possess anti-microbial, anti-inflammatory, anti-oxidant and, anti-aging properties(21,22). Furthermore, *diCQAs* (*dicaffeoylquinic acid*) specifically *4,5-diCQA* seems to have chondroprotective effect in osteoarthritis along with other health promoting benefits such as anti-inflammatory and antioxidant nature and therefore can be used as food supplement (23, 24).

Tomatoes

Solanum lycopersicum L. commonly referred to as tomatoes are considered to be therapeutic plants since they reduce the risk of diseases including cancer (25), osteoporosis, and many heart diseases(26). Many secondary metabolites, including polyphenols, carotenoids, flavonoids, phenolics, glycoalkaloids, and alkaloids, are produced by tomatoes when encountered with stress. The main tomato polyphenols are hydroxycinnamic acids, flavanones, and anthocyanins. Additionally, tomato fruits contain flavonol glycosides like rutin and kaempferol-3-rutinoside (27). Naringenin chalcone, one of the vital polyphenols in has been reported to have a good deal of health benefits. It is anti-allergic in nature as it inhibits the release of histamine, besides this, it also enhances the metabolic processes of adipocytes and have insulin-sensitizing effects (28, 29). Figure 3 illustrates the diagrammatic representation of synthesis of Naringenin chalcone in tomato (27).

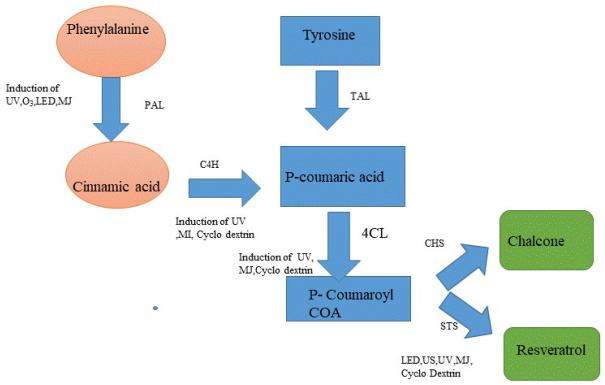
Fig 3: Diagrammatic Representation of Biosynthetic Pathway of Naringenin (Polyphenol) in Tomato



Grapes

Grapes (*Vitis vinifera* L.) are well-known for their multiple health advantages and are one of the most thoroughly examined medicinal plants. Traditionally, grapes are used for disinfecting skin wounds or treating diarrhea and digestive infections. It is well known to have properties that promote cardiovascular health and delay the aging process (30). Grapes contain several secondary metabolites such as phenols, polyphenols, organic acids, tannins and terpenoids etc. Grapes are rich in nutrients, specifically phenolic compounds such as stilbene, flavonols, proanthocyanidins, and anthocyanins, which are known to have health benefits particularly beneficial in preventing cardiovascular illnesses (31). Among them, Resveratrol which is a polyphenol specifically present in grapes has significant importance. It is considered as a rare polyphenol which is known to be present in grape skin, seed, stem, shoot, bud, root, and leaves but i least amounts (32, 33). It had been shown that the concentration of resveratrol was dramatically raised by more than 2000-fold in grape skin under UV and LED exposure (34, 35). Figure 4 depicts the biosynthetic pathway for the production of resveratol.

Figure 4: The Diagrammatic View of the Biosynthetic Pathway of Resveratrol



PAL - Phenylalanine ammonia lyase; C4H - Cinnamate-4-hydroxylase; 4CL - Coumaroyl-CoA ligase; TAL - Tyrosine ammonia-lyase; CHS - Chalcone synthase; STS - Stilbene synthase; UV - Ultra violet; US - Ultrasonication; LED - Light-emitting diode; O_3 - Ozone; MJ - Methyl jasmonate.

Health benefits of Resveratrol

Besides having anti- cancerous properties, Resveratrol is helpful in maintaining cardiovascular health as it lowers the LDL “bad cholesterol”. Similarly, it improves insulin sensitivity which facilitates the regulation of blood sugar levels in the body (36). Besides, resveratrol shows anti-microbial properties in plants, thus playing an important role in plant defence.

Pre-clinical evidence has suggested the role of, resveratrol in improving brain function or cognitive skills by enhancing the capacity of cerebral vasculature to enlarge in response to cognitive demands (37,38, 39).

Banana (*Musa acuminata* Colla)

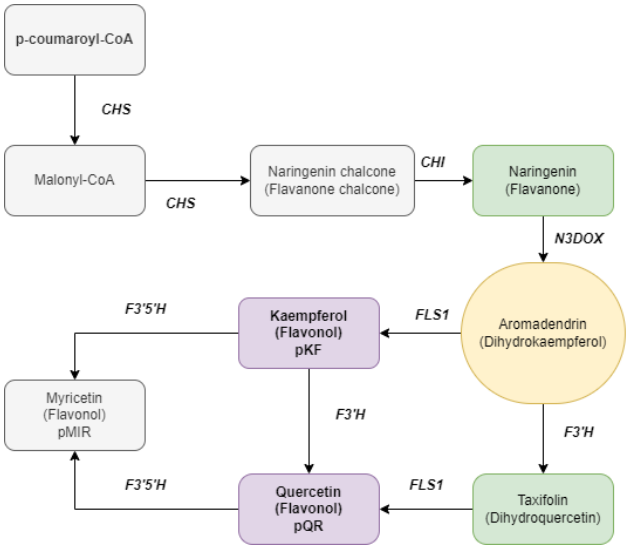
***Musa acuminata* Colla** produces different types of secondary metabolites such as terpenoids, carotenoids, alkaloids, phenolic compounds, and flavonoids (40). The production and level of different secondary metabolites vary depending upon the several factors such as the variety of banana, growing conditions, the stage of ripeness and different biotic and

abiotic stresses (41). A class of roughly 6000 nutraceuticals known as flavonoids, many of which can be found in ***Musa acuminata*** **Colla**, is broadly dispersed throughout plant cells. Flavonoids are extensively dispersed secondary metabolites with a variety of metabolic roles (42). The generic chemical structure of all flavonoids is composed of 15 carbon atoms (C6- C3-C6), with two aromatic rings (rings A and B) joined by a heterocyclic pyran C that contains one oxygen (ring C) (43). Its fundamental structure is adaptable to many substituents, including sugars and hydroxyl or methyl groups; in fact, ring C's chemical alterations result in the development of more than 9,000 flavonoid derivatives (44). The flavonoid subfamily flavonols (such as quercetin and kaempferol) is abundantly present in ***Musa acuminata*** **Colla** and contains several compounds of significant dietary significance for both humans and animals (45). These polyphenolic supplements have strong antibacterial (membrane potential disruptors), antioxidant (free radical scavengers), pharmacokinetic (CYP450 modulators), anti-inflammatory (lipoxygenase inhibitors), antiangiogenic (VEGF inhibitors), and antitumor (cyclin inhibitors) properties (46). Because these polyphenols typically appear in ***Musa acuminata*** **Colla** as inactive glycosylated derivatives, in low concentrations, or as a component of intricate mixtures with other polyphenolic compounds, biotechnological production of these nutraceuticals is preferred. One method for doing this is via heterologous biosynthesis in industrial actinomycetes (47).

Therefore, Flavonoids are one of the most important classes of secondary metabolites in banana. The regulation of flavonoid biosynthesis pathway, which aids in protection against UV-B radiation and pathogen infection, nodulation, and pollen fertility, is discussed in the current review (48). Flavonols are the byproducts of hydroxylation of the flavonoid ring C-3. They frequently occur in glycosidated forms in plant cells because of their C-3 position's great susceptibility to glycosidation (49). Figure 5 depicts the biosynthetic pathway for the production of flavonoids in banana.

Phenylalanine is formed via the shikimate pathway, while flavonoids (quercetin and kaempferol) are produced from phenylalanine via the phenylpropanoid pathway. By the actions of the enzymes phenylalanine ammonia lyase (PAL), cinnamic acid 4-hydroxylase (C4H), and 4-coumarate: CoA ligase, the aromatic amino acid phenylalanine is transformed into p-coumaroyl-CoA (4CL) (50). Furthermore, PAL is essential for mediating the transfer of carbon from primary to secondary metabolism in plants. In the second phase of the general phenylpropanoid route, the cytochrome P450 monooxygenase C4H, which is present in ***Musa acuminata*** **Colla**, catalyzes the hydroxylation of trans-cinnamic acid to produce p-coumaric acid as it is the first oxidation process (51). In the third stage, addition of a coenzyme A (CoA) unit to p-coumaric acid takes place in which 4CL catalyzes the synthesis of p-coumaroyl-CoA. The 4CL gene often appears in ***Musa acuminata*** **Colla** as a family, the majority of which

Figure 5: The Diagrammatic View of the Biosynthetic Pathway of Flavonoids



Enzyme Abbreviations: *CHS – Chalcone Syntase; CHI – Chalcone Isomerase; N3DOX – naringenin 3-dioxydenase; FLS1 – Fl avonol Synthase 1; F3' H – Flavonoid 3'-hydroxylase; F3'5'H – Flavonoid 3', 5'-hydroxylase*

exhibit substrate specificity (52). Chalcone synthase converts p-coumaroyl-CoA to malonyl-CoA and then malonyl-CoA to naringenin chalcone (a flavanol chalcone), respectively. Chalcone isomerase catalyzes the stereospecific cyclization of the naringenin chalcones to naringenin (53). Enzymes, naringenin 3-dioxydenase and Flavonoid 3'-hydroxylase are important because naringenin 3-dioxydenase catalyzes naringenin to dihydrokaempferol and Flavonoid 3'-hydroxylase catalyzes dihydrokaempferol to dihydroquercetin. Flavanol synthase transforms the dihydroflavonols such as dihydrokaempferol and dihydroquercetin into the kaempferol and quercetin, respectively (FLS) (44). Although F3′ 5′ H activity produces myricetin from kaempferol or quercetin, F3′ H can also catalyze the conversion of kaempferol to quercetin (54). The essential and rate-limiting enzyme in the flavonol biosynthesis pathway is FLS, a FeII/2-oxoglutarate-dependent dioxygenase, which catalyzes the desaturation of dihydroquercetin to produce a C-2 and C-3 double bond in ring C. (46). With the actions of enzymes including methyl transferases, GTs, and acyltransferase (AT), among others, kaempferol, quercetin, and myricetin are further changed to different flavonol derivatives (44).

Benefits of flavonoids in humans

Flavonoids are a group of natural compounds found banana (***Musa acuminata*** **Colla*)*** which have diverse health benefits and have been shown to have anti-inflammatory, antioxidant, anti-cancer, anti-diabetic, and anti-viral properties (55). Flavonoids have been found to play a crucial role in the prevention and treatment of various human diseases, for example in cardiovascular health by reducing inflammation, improving blood flow which reduce the risk of heart

disease, and prevent stroke (56). Flavonoids may also help to lower blood pressure and have also been found to have anti-cancer properties that may help to prevent the growth and spread of cancer cells. Studies have shown that flavonoids can inhibit the growth of certain cancers, such as breast, colon, and lung cancer (40). Additionally, flavonoids may help to reduce the risk of chronic diseases such as diabetes, by improving insulin sensitivity and improve brain function to reduce the risk of age-related cognitive decline. Flavonoids are also known for their anti-inflammatory properties, which can be beneficial in the treatment of various inflammatory disorders such as arthritis, asthma, and allergies (57).

Overall, flavonoids have shown promising results in the prevention and treatment of various human diseases. However, further research is needed to fully understand the mechanisms of action and potential benefits of these compounds. The first documented use of a flavonoid enzyme to boost the nutritional value of a vegetable crop by raising the content of flavonols, which have shown health-promoting properties in animals, occurred this past year. (58).

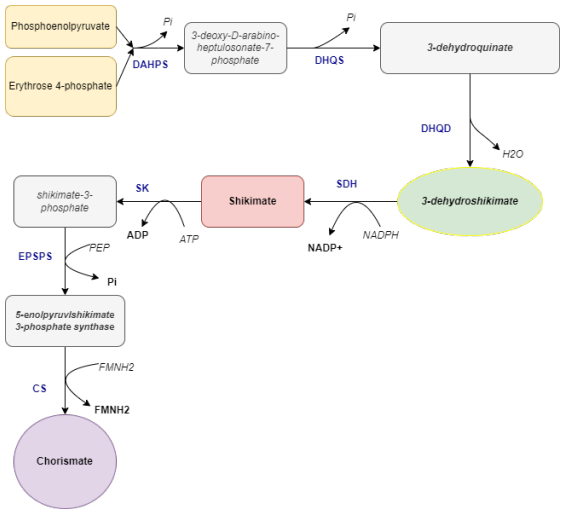
Jamun

Jamun (***Syzygium cumini* (L.) Skells**), also known as Indian blackberry or jambolan, is a fruit-bearing plant that is native to South Asia (59). ***Syzygium cumini* (L.) Skells** produces number of the secondary metabolites when encountered with different stressful conditions such as tannins, Ellagic acid which are polyphenolic compounds having potential health benefits, such as they exhibit antioxidant and anti-inflammatory properties and flavonoids such as quercetin and kaempferol (60). Tannins are one of the secondary metabolites that are produced in abundance when the ***Syzygium cumini* (L.) Skells** encounters various abiotic stresses such as heat, drought etc. and are produced by the shikimate-phenylpropanoid pathways, the majority of which are structurally and biosynthetically related. (61). Figure 6 illustrates the biosynthetic pathway for the synthesis of tannins via shikimate pathway reactions.

Benefits of Tannins in humans

Tannins have several potential health benefits, including anti-inflammatory, antioxidant, anti-cancer, anti-diabetic, and anti-viral properties (63). One of the key health benefits of tannins is their ability to prevent and treat various human diseases. For instance, tannins have been shown to have antiviral properties and can inhibit the replication of viruses such as the flu virus, HIV, and herpes (64). They may also help in the prevention and treatment of certain cancers, such as colon cancer, by inhibiting the growth and spread of cancer cells. Tannins are also known for their anti-inflammatory properties, which can help to reduce inflammation and swelling in the body (65). This can be particularly beneficial in the treatment of conditions such as arthritis, asthma, and other inflammatory disorders (66). Additionally, tannins may help to lower blood pressure and reduce the risk of heart disease by improving circulation and reducing oxidative stress in the body (67). They can also have a positive effect on digestive health, by promoting the growth of beneficial gut bacteria and reducing inflammation in the gut (62).

Fig. 6- Schematic Representation of Biosynthetic Pathway of Tannins in *Syzygium cumini*



Enzyme Abbreviations

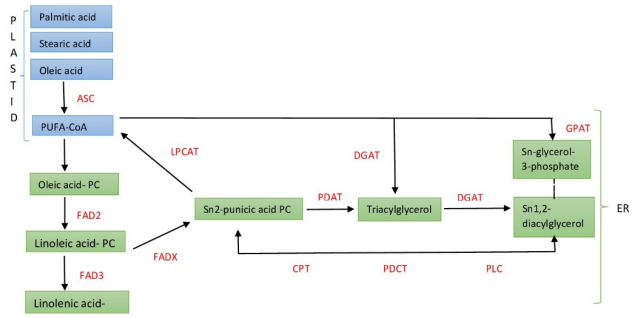
DAHPS – 3-deoxy-D-arabino-heptulosonate-7-phosphate synthase; DHQS – dehydroquinate synthase; DHQD – 3-dehydroquinate dehydratase; SDH – shikimate dehydrogenase; SK – shikimate kinase; EPSPS – 5-enolpyruvlshikimate 3-phosphate synthase; CS – Chorismate synthase (62).

Pomegranate

The pomegranate (*Punica grantum* L.) is a perennial fruit crop belonging to the Lythraceae family and is widely grown across the tropics. The Pomegranate plant's leaves, stem, fruits, bark, and roots all contain numerous bioactive compounds, including phenolic compounds such as flavonoids (such as catechins, anthocyanins, and other complex flavonoids), complex polysaccharides, and hydrolyzable tannins (like pedunculagin, punicalin, punicalagin, ellagic, and gallic acids). Also known as "seeded apple" or "granular apple", pomegranate is renowned for its delicious flavour, nutritional benefits, and therapeutic characteristics (68). Since the beginning of time, the pomegranate has been used in natural and holistic medical remedies to treat a variety of ailments, including sore throats, urinary infections, skin conditions, arthritis, coughs, digestive problems, and tapeworms (69). Pomegranate juice derived from the arils raises glutathione levels (22.6%) in erythrocytes while lowering lipid peroxidation (24.4% malondialdehyde) and protein oxidation (19.6% carbonyl), enhancing the antioxidant status in humans. It also has antitumoral and antihepatotoxic properties (68). Alike the pomegranate juice, the bioactives present in the seeds, testa and pericarp of pomegranate fruit also have numerous medicinal, nutritional and pharmacological properties. These compounds improve the cardiovascular, nervous, renal, and immune systems, aiding in the prevention of various diseases and

providing health benefits. Pomegranate peel and seed constituents possess anticancer properties, making them effective in treating various chronic illnesses like stomach ulcers, colon and prostate cancer, melanogenesis (skin cancer), and breast cancer (70). In recent years, Pomegranate seed oil (PSO) has been a subject of great dietary attention due to its supposed health benefits. The major bioactive constituent of this oil is a type of fatty acid called punicic acid with concentrations ranging from 60% to 80% is a conjugated linolenic acid. It has anti-inflammatory, anti-diabetic, anti-carcinogenic properties due to which it has vital health implications (71).Studies have suggested that punicic acid may help to reduce inflammation in the body, which can help to protect against chronic diseases such as heart disease, diabetes, and cancer. It may also help to reduce oxidative stress, which is a key factor in aging and the development of chronic diseases (72). Figure 7 shows the biosynthestic pathway for the formation of punicic acid (71).

Figure 7: Diagrammatic representation of the Biosynthetic Pathway of Punicic Acid



Enzyme Abbreviations

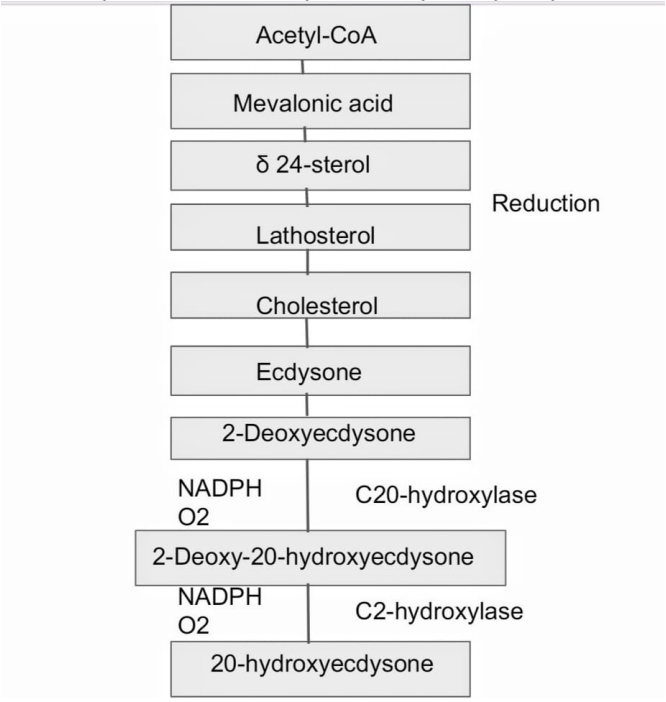
PC=Phosphatidylcholine; ACS= Acyl-CoA synthetase; FAD2,FAD3,FADX=Fatty Acid Desaturase; LPCAT=Lysophosphatidylcholine Acyltransferase; PDAT= Phospholipid-diacylglycerol Acyltransferase; DGAT=diacylglycerol acyltransferase; GPAT= n-glycerol-3-phosphate acyltransferase; CPT= CDP-choline:1,2-diacyl-sn-glycerol cholinephosphotransferase; PDCT=phosphatidylcholine: diacylglycerol cholinephosphotransferase; PLC= phospholipase C

Spinach

Spinach (*Spinacia oleracea* L.) is a leafy vegetable crop belonging to the Chenopodiaceae family and is widely consumed all over the world. It is a globally cultivated vegetable that is typically eaten after boiling fresh or frozen leaves or raw in a salad (73, 74,75). It is a native of Southwest Asia and is believed to have originated from Iran. It has been cultivated in China since the 7th century and utilized in Europe since the 13th century (76,77). Spinach breeding helps to produce varieties with traits like improved yield and quality, increased disease resistance and abiotic stress tolerance such as heat stress (78), salinity and water stress (79).

Spinacia oleracea is rich in 20-hydroxyecdysone (20E) (80), a secondary metabolite that has therapeutic uses in wound healing, performance-enhancing, and anti-osteoporotic effects. Salt stress in spinach induces the accumulation of 20E, and research studies have shown that shoot cultures exposed to 200 mM salt accumulated 2.9 times more 20E than the untreated shoot cultures. 20E plays a crucial function in the moulting, metamorphosis, embryonic, and larval development of insects (81). The 20E and its derivatives are helpful in improving human health, boosting protein synthesis, and treating various illnesses brought on by the human immunodeficiency virus (HIV). Additionally, it is said to have tonic and antioxidant qualities (82).

Figure 8: Diagrammatic Representation of the Biosynthetic Pathway of 20-Hydroxycedysone



Health benefits of 20-Hydroxyecdysone (20E)

20E possesses chondro- and osteoprotective properties that stop fat from building up in the joints, bone marrow, and abdomen. Therefore, 20E can help prevent metabolic syndrome and its associated conditions, such as osteoporosis and osteoarthritis (83, 84). 20E can prevent the deterioration of muscle, bone, and cartilage in the joints by lowering body fat levels (83). BIO101, a 97% pharmaceutical grade 20E, provides an intriguing therapeutic alternative for COVID-19 patients who acquire severe variants of this fatal disease by enhancing respiratory function and eventually promoting survival (85).

Conclusion

In the present review article the nutraceutical value of the horticultural crops is discussed taking two vegetable (Carrot and Spinach) and four fruit crops (Banana, Grapes, Jamun, Pomegranate) as an example. The biosynthetic pathways involved in the production of specific secondary metabolites is discussed in detail

along with the potential health benefits of the secondary metabolites. From the present study conducted it is concluded that the horticultural crops produce tremendous number of secondary metabolites that holds the nutraceutical value and very much beneficial for our health systems. There are several biosynthetic pathways involved in the production of these secondary metabolites which can be manipulated via state of the art metabolic engineering tools.

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