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Bioactive Compounds from Horticulture Crops and their Utilization: A Comprehensive Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

This comprehensive review explores the rich reservoir of bioactive compounds present in horticulture crops and their diverse applications. Horticulture crops, including fruits, vegetables, and herbs, are recognized for their nutritional value and health-promoting attributes. The study focuses on elucidating the various bioactive compounds found in these crops, such as polyphenols, flavonoids, carotenoids, vitamins, and minerals, which contribute to their medicinal and therapeutic properties. The review delves into the extraction methods and identification techniques employed to isolate and characterize these bioactive compounds. Furthermore, it discusses the potential health benefits associated with the consumption of horticulture crops, including antioxidant, anti-inflammatory, and anticancer properties. The multifaceted roles of these compounds in promoting human health and preventing chronic diseases are emphasized. In addition to their nutritional significance, the review explores innovative utilization avenues for bioactive compounds, such as functional foods, nutraceuticals, and pharmaceutical applications. The integration of horticulture crop-derived bioactive compounds in various industries underscores their economic and societal importance. The findings presented in this review underscore the need for further research to unlock the full potential of bioactive compounds from horticulture crops, paving the way for the development of novel products that contribute to both human health and sustainable agriculture. Utilization of the bioactive compounds derived from horticultural crops has gained popular attention due to their outstanding health benefits and functional properties. This review article explores the diverse array of bioactive compounds present in horticultural crops and their versatile applications. These compounds, encompassing phytochemicals such as flavonoids, phenolic acids, carotenoids, or vitamins, have been linked to various health-promoting effects. By synthesizing current research, this review aims to provide insights into harnessing the potential of bioactive compounds from horticultural crops, fostering innovation, and contributing to the development of functional and successful products with enhanced health attributes.

Keywords: Bioactive; horticultural; phytochemicals; flavonoids; health.

1. INTRODUCTION

Bioactive substances are biochemicals that are found in living things and that stimulate or have power to induce biological activity in the same or other species of organism. Any substance found in the diet of people, animals, or plants that has power to affects the body after ingestion is referred to as a bioactive compound [1]. Extra nutritional components known as bioactive chemicals generally appear in meals in little or trace amounts. In-depth research is being done on them to see how they could affect health and how benefits could be gained [2].

2. BIOACIVE COMPOUNDS IN FRUIT AND VEGETABLE

In our diet, fruits and vegetables have a vibrant, savory, and nourishing role to play. As a result of the possibility of health advantages, bioactive substances found in fruits and vegetables, such as pigment (carotenoids, anthocyanins), polyphenols, vitamins, phytoestrogens, and glucosinolates, are gaining more attention worldwide [3].

3. CAROTENOIDS

The chloroplast and chromoplast found in plants and photosynthesis bacteria include organic pigments called carotenoids, that have red, yellow, and orange in color. Strong antioxidants known as carotenoids aid in the prevention of heart disease and cancer [4]. Fats along with other organic metabolic building components present in plants and microorganisms that photosynthesis are used to make carotenoids. Animals cannot produce carotenoids; thus, they must get them through their food [5].

3.1 Beta Carotene

Another of the main carotenoids that exist in orange, yellow, and green fruits and vegetables is beta-carotene ($C_{40}H_{56}$), which is found in greens (collard, turnip, spinach, lettuce), mangoes, cantaloupe melons, peppers, pumpkins, carrots, and sweet potatoes. It promotes the safeguarding of normal immune system, epithelial, and reproductive system development [6].

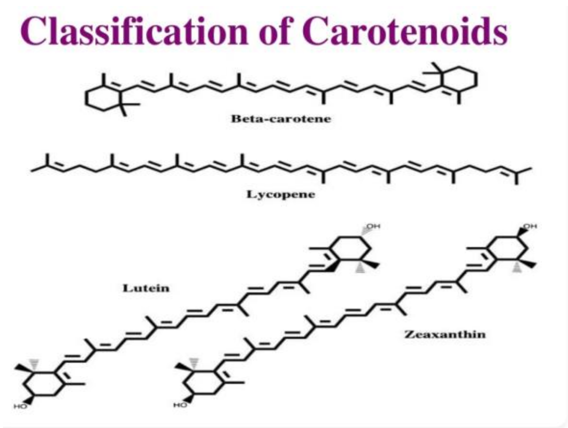

Fig 1. Classification of carotenoids

3.2 Lycopene

Some of the main carotenoids that exist in orange, yellow, and green fruits and vegetables is beta-carotene (C40H56), which is found in greens (collard, turnip, spinach, lettuce), mangoes, cantaloupe melons, peppers, pumpkins, carrots, and sweet potatoes. It supports the maintenance of regular immune system, epithelial, and reproductive system development [7].

3.3 Lutein and Zeaxanthin

The xanthophyll group of carotenoids, which includes lutein and zeaxanthin ($C_{40}H_{56}O_2$), are oxygenated carotenoids. They are frequently discovered in broccoli, maize, persimmons, spinach, collard greens, and other yellow leafy greens. Supporting eye health, lowering risk factors for coronary heart disease and stroke, and enhancing skin health are their main health advantages [8].

3.4 Anthocyanins

Most species of plants in the plant kingdom include anthocyanins, one of the biggest and most significant groups of water-soluble pigments. Anthocyanins are collected in cell vacuoles and are the pigments that give orange, red, purple, and blue flowers, fruits, and vegetables their distinctive color [9]. Blackberries, red and black raspberries, blueberries, cherries, blood oranges, grapes, and vegetables including red onion, radish, red cabbage, fennel, red lettuce, eggplant, and purple sweet potato are examples of foods with this coloring. Although they accumulate mostly in flowers and fruits, anthocyanins may be found in many sections of plants, including the leaves, stems, and storage organs [10].

3.5 Classification of Anthocyanins

Cyanidin: This is one of the most common anthocyanins and is responsible for red to purple colors. It is found in various fruits like berries (e.g., strawberries, blackberries, blueberries), red grapes, and red apples [11].

Delphinidin: Delphinidin produces a blue to violet color and is found in fruits like blueberries, blackberries, and grapes. It is also present in some flowers [12].

Pelargonidin: Pelargonidin is responsible for orange to red colors. It is found in fruits like strawberries, raspberries, and oranges [13].

Peonidin: Peonidin contributes to red to purple hues and is found in fruits like cherries, blackberries, and cranberries [14].

Petunidin: This anthocyanin produces red to purple colors and can be found in fruits like blackberries and blueberries [15].

Malvidin: Malvidin contributes to red to blue colors and is present in fruits like red grapes, blueberries, and blackberries [16].

3.6 Polyphenols

More than 500 phytochemicals are identified as polyphenols are a class of naturally generated micronutrients in plants. The compounds in question give a plant its color and can aid in defending it against numerous threats. You gain numerous health advantages from consuming foods which include polyphenols as well [17].

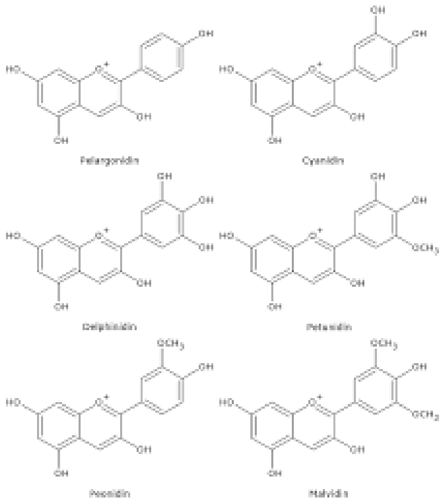

Fig. 2. Classification of anthocyanins

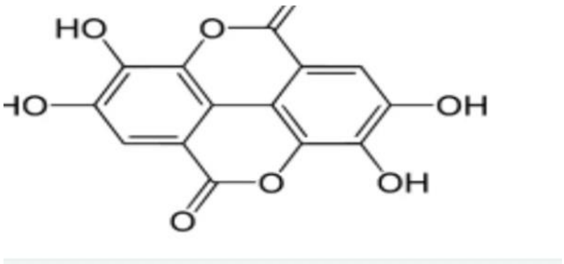

Fig. 3. Chemical structure of polyphenols

Polyphenols can be further categorized into the following groups:

Flavonoids: Flavonoids are one of the most well-known and abundant classes of polyphenols. They are characterized by their chemical structure, which consists of a 15-carbon containing two phenyl rings (A and B rings) connected by a heterocyclic ring (C ring) [18]. Flavonoids have various subclasses, each with distinct biological activities and functions. Some common subclasses of flavonoids include:

- **Flavonols:** Examples include quercetin, kaempferol, and myricetin. They are often found in fruits, vegetables, and beverages like tea [19].
- **Flavanols (Catechins):** These are found in high amounts in tea, cocoa, and some fruits (e.g., apples, grapes). Epigallocatechin gallate (EGCG) is a notable catechin with potential health benefits [20].
- **Flavanones:** Common in citrus fruits, flavanones include compounds like hesperidin and naringenin [21].
- **Anthocyanins:** Responsible for red, purple, and blue colors in fruits and flowers. They were discussed in the previous response [22].
- **Isoflavones:** Present in soybeans and soy products, isoflavones like genistein and daidzein are known for their potential hormonal effects [23].
- **Flavones**: Apigenin and luteolin are examples found in various fruits, vegetables, and herbs [24].

Phenolic Acids: Phenolic acids are another important subgroup of polyphenols. They are simple aromatic compounds with a phenolic structure. Phenolic acids can be classified into two main categories:

- **Hydroxybenzoic acids**: Examples include gallic acid and ellagic acid. They are often found in fruits, nuts, and seeds [25].
- **Hydroxycinnamic acids**: Substances including caffeine acid, ferulic acid, and p-coumaric acid are included in this category. They can be encountered in whole grains, coffee, fruits, and vegetables [26].

Stilbenes: Stilbenes are a smaller subgroup of polyphenols with a distinct structure characterized by two phenyl rings connected by a methylene bridge. One of the most well-known stilbenes is resveratrol, which is found in red grapes, red wine, and peanuts. The antioxidant and anti-inflammatory properties of resveratrol have drawn attention to its potential health benefits [27].

Lignans: Lignans are polyphenols found in seeds, whole grains, legumes, and some fruits. They have a complex structure and are metabolized by gut bacteria into bioactive compounds. Some lignans, like enterolignans, have potential hormone-modulating effects and are being studied for their role in human health [28].

3.7 Vitamins

Vitamins are essential naturally occurring compounds that are found in very little amounts but are necessary for life and carry out multiple chemical reactions in the body. Vitamins are important for the development of cells maintenance, and regulation of the body's processes. Vitamins are classified into two major categories [29].

1. **Fat – Soluble vitamins**

   Vitamin A
   Vitamin D
   Vitamin E
   Vitamin K

2. **Water –Soluble vitamins**

   Thiamin
   Riboflavin
   Niacin
   Biotin
   Pantothenic acid

Pyridoxal phosphate

   Foliate
   Vitamin B12
   Vitamin C

3.8 Vitamin E

Eight various kinds of vitamin E—four tocopherols and four tocotrienols—combine in order to produce tocopherols and tocotrienols. These isomers are all composed of aromatic rings with groups of hydroxyls that can provide atoms of hydrogen that contribute to the reduction of reactive oxygen species (ROS) [30]. Both the number and location of methyl groups within the ring have a role in the range of properties in isomers. Each type of vitamin E has its own distinctive characteristics, with tocopherol being among the most potent. In general, fatty seeds, olives, nuts, peanuts, avocados, and almonds have higher the quantities of vitamin E. However, the form of vitamin E can be especially prone to oxidation throughout storage and processing, and it functions as an antioxidant by safeguarding polyunsaturated fatty acids and vitamin A, maintaining the outer layers of cells, as well as regulating oxidase processes. The polyunsaturated oils found in plants, margarine, dressings for salads, shortenings, leafy green vegetables, wheat germ, whole grains, liver, egg yolk, and nuts are all excellent sources of this necessary vitamin [31].

3.9 Vitamin C

Ascorbic acid (AsA) is often referred to interchangeably with vitamin C, however the hormone dehydroascorbic acid (DHA), the first oxidation product of AsA, is additionally thought of as an important part of vitamin C. Even when the meal is being chewed while eating, ascorbic acid can undergo oxidation [32]. The initial AsA breakdown product, DHA, still possesses vitamin C action; however, if oxidation continues greater than this point, all activity is lost. Because it contains a 2,3-enediol group, ascorbic acid is a carbohydrate-derived molecular structure that is water soluble and exhibits acidic and antioxidant characteristics. The efficacy of AsA in disease prevention has been associated with its capacity to neutralize ROS. AsA is highly susceptible to oxidation, either directly or through the enzyme ascorbate oxidase, catalyzing the oxidation of AsA to DHA, with the concomitant reduction of molecular oxygen to water [33].

4. FUNCTIONS

Vitamin C plays a role in the manufacture of the protein collagen, and this strengthens the exterior of blood vessels and produces collagen scar tissue that serves as the framework for the development of bones. antioxidant that production of thyroxin, and metabolism of nitrogenous compounds increases the absorption of iron and improves susceptibility against illness [34].

4.1 Deficiency

The condition known as a plaque buildup from atherosclerosis, pinpoint hemorrhages, bone fragility, discomfort in the joints, inadequate wound healing, recurrent infections, bleeding gums, loose teeth, and other conditions are caused by a lack of vitamin C in the body. Aging of muscles and discomfort panic attacks, depression, Blunt bruising and rough skin [35].

4.2 Vitamin B12

It is an essential component of the coenzyme precursor methylcarbylamine and deoxy adenosyl cobalamin, which have significance to sustaining cells in the nervous system and to promote the development of cells that develop. Several fatty acids and amino acids can be broken down with the assistance of reform foliate coenzyme [36].

5. TERPENES

The broad category of phytochemicals referred to as terpenes are composed of isoprene units

(C_5H_8), which may be participated in together to create carbon skeletons with numbers that range from C5, C10, C15, C20, and up to C40. Low molecular weight terpenes are found in essential oil compounds like limonene, pinene, and linalool, among other substances. Oleanolic and maslinic acid, both of which possess exceptionally strong biological properties, are the most intriguing triterpenes. Additionally, citrus fruits include limonoids, which are among the most widely recognized tetraterpenes and include limonin, nomilin, and nomilinic acid [37].

6. SELENIUM

Selenium (Se), a mineral element, is a crucial micronutrient for maintaining good health in people. As a result of its antioxidant properties, it can be used as a cancer chemotherapy preventative agent as well as an essential food for the immune system. Its involvement in the 25 seleno proteins found in the human proteome, such as glutathione peroxidase and thioredoxin reductase, was said to be responsible for this activity [38]. Se often occurs in low concentrations in plants and fruits, which allows it to impact their chemical makeup and antioxidant qualities. However, at greater concentrations, Se can serve as a pro-oxidant and inhibit plant development. By preventing the production of ethylene, selenium can prevent the ripening and senescence of tomato fruit. Through the reduction of ethylene production and phenylalanine ammonia lyase activity, Se strengthened the long-term storage nutritional value of lettuce and chicory demonstrated that spraying leaves and fruit with sodium selenate boosted the se concentrations in peach and pear fruit, prolonging the fruit's shelf life and delaying softening [39].

7. BIOACTIVE COMPOUNDS AND PRODUCT QUALITY

Bioactive substances have been shown to have an influence on the storage capability of the fruits and vegetables they have been found in, in addition to having detrimental impacts on the well-being of humans when consumed in the diet. The antioxidant defense mechanism most certainly plays an important function in regulating both the beginning and pace of senescence. Reactive oxygen species are known to be involved in leaf senescence. Theoretically, a product with a substantial quantity of antioxidants is successfully safeguarded against oxidation and may thus preserve its quality for a longer period [40]. Therefore, increasing the concentrations of the presumptive advantageous substances in vegetable and fruit products could not only have positive health effects for those who consume them but could also extend shelf life and increase the resistance to stress, leading to lower losses following harvesting of produce. This can be accomplished through the field of biotechnology regulating and improving preharvest factors, or growing the right cultivars. Furthermore, since a high antioxidant concentration may relate to a fresh look, a fruit's or vegetable's freshness may, circumstances, be a signal for its nutritional value in terms of the presence of bioactive components [41].

8. VARIATIONS IN CONCENTRATION OF BIOACTIVE COMPOUNDS

Fruit and vegetable biologically active component concentrations are not constant and can be affected by a variety of beforehand and postharvest variables. While changes in a single element frequently result in higher or lower concentrations of a given compound, or even no change in concentration, in other circumstances, the impact of a given factor on a given molecule is obvious [42].

9. GENETIC VARIATION

While expected bioactive chemicals are discovered in all fruit and vegetables, others are exclusive to a particular family or even species, and the amount present may vary between cultivars. Ascorbic acid (or its oxidized form, dehydroascorbic acid) may be found in various amounts in all fruits and vegetables, unlike glucosinolates, which are mostly found in the Brassicaceae family [43]. Thus, a significant portion of the concentration of bioactive chemicals in fruits and vegetables is influenced by genetic variables. Additionally, there may be significant variation across cultivars of the same species.

10. PREHARVEST FACTORS

The concentration of bioactive chemicals is significantly influenced by climatic factors. Climate varies by growth site, by season, and from year to year. The chemical composition may be influenced by temperature, both the overall or average temperature and the extremes throughout the development phase. In lettuce heads, the outer leaves, which receive more light, have much greater amounts of vitamin C, carotenoids, and flavonoids than the inner leaves, which receive less light. Flavonoids are particularly sensitive to the UV portion of the spectrum certain carotenoids are implicated in photoprotection via the xanthophyll cycle [44]. These chemicals are influenced by cultural practices such as fertilizer and water availability as well as soil type that varies with growing site. The response to nitrogen availability might be challenging to predict; fertilization-induced increases and decreases in concentrations might happen, possibly depending on how the fertilization affects plant growth, leading to a relative dilution or accumulation of the compounds [45].

11. POSTHARVEST FACTORS

The content of bioactive chemicals varies greatly during the development and maturity of fruits and vegetables. The ripening of fruit, where carotenoid or flavonoid produce the color of the mature fruit, is probably where this difference is most noticeable. The timing of harvesting during the day is particularly crucial since concentrations may vary greatly and may be influenced by water content (when concentrations are supplied on a fresh weight basis) or light intensity. Harvesting might result in mechanical damage, which could have an impact on bioactive chemical concentrations [46].

12. MOLECULAR BREEDING AND GENETIC MANIPULATION

In higher plants, the biosynthetic pathways which generate a significant amount of bioactive chemicals, especially antioxidants, have been elucidated in recent years. In addition to plant modification, contemporary plant biotechnology has made several genomic, transcriptomic, metabolomic, and bioinformatic tools accessible. It is now feasible to generate novel cultivars, hybrids, and/or transgenic lines with better nutritional value using molecular markers related to health-promoting chemicals. It should be noted that this is a more recent trend in breeding programs; in contrast, the development of cultivars and hybrids with desirable appearance, disease and pest resistance, increased yield, and improved postharvest characteristics was prioritized in the last decades of the 20th century.

13. CONCLUSION

A type of molecule designated a bioactive compound is occasionally found in very small quantities in particular foods and plants. Bioactive substances are substances that have consequences for the body that could enhance health. More recently, the development of molecular markers associated to advantageous characteristics has recently related to breeding and biotechnological initiatives, hybrids enhanced with "health-promoting substances." Utilizing all possibilities and techniques as they become available is also crucial, including possible systems/synthetic biology processes used for manufacturing target bioactive chemicals in consumer-friendly hosts like fruit crops. The successful creation of fruit and vegetable types with improved nutritional properties will result from the identification and application of tissue-specific promoters, which are known to regulate the biosynthesis as well as the accumulation of bioactive chemicals. The interplay between genotype and environment cannot be overlooked, so future investigations to close this research gap.

Along with the typical breeding goals of yield, market life, and disease tolerance, new fruit cultivars should also be considered for their phytochemical properties. Investigating the phytochemical profiles of old or extinct indigenous cultivars is a growing field of study.

Citrus hybrids, European and Japanese pears, non-melting and stony-hard peaches, suppressed-climacteric and climacteric plums, and other fruit crops with different ripening patterns were all compared for their bioactive phytochemical content.

Investigations on the potential synergistic effects of several phytochemical groups during fruit ripening. Whenever possible, refrain from generalizing about fruits' health benefits. Results need to be supported, especially considering the phytochemicals' true bioavailability in fruits.

Due to the complexity of the fruit's many chemical constituents, it is advisable to use multiple methods for fruit antioxidant capacity detection, evaluation, and interpretation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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