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Review

Edible berries: Bioactive components and their effect on human health

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ABSTRACT

The importance of food consumption in relation to human health has increased consumer attention in nutraceutical components and foods, especially fruits and vegetables. Berries are a rich source of a wide variety of non-nutritive, nutritive, and bioactive compounds such as flavonoids, phenolics, anthocyanins, phenolic acids, stilbenes, and tannins, as well as nutritive compounds such as sugars, essential oils, carotenoids, vitamins, and minerals. Bioactive compounds from berries have potent antioxidant, anticancer, antimutagenic, antimicrobial, anti-inflammatory, and antineurodegenerative properties, both in vitro and in vivo. The following is a comprehensive and critical review on nutritional and non-nutritional bioactive compounds of berries including their absorption, metabolism, and biological activity in relation to their potential effect on human health.

Introduction

Increased consumption of fruits and vegetables is recommended in dietary guidelines worldwide and the intake of fruits like berries which are rich in nutrients and phytochemicals can prevent various diseases and disorders. Most berries are delicious and powerful disease-fighting foods and make up the largest proportion of fruit that is consumed in the human diet [1]. Berry fruits are popularly consumed not only in fresh and frozen forms but also as processed and derived products, including dried and canned fruits, yogurts, beverages, jams, and jellies [2]. Among the colorful fruits, berries such as blackberry (*Rubus* species), black raspberry (*Rubus occidentalis*), blueberry (*Vaccinium corymbosum*), cranberry (*Vaccinium macrocarpon*), red raspberry (*Rubus idaeus*), and strawberry (*Fragaria ananassa*) are popularly used in the human diet either fresh or in processed forms. Additionally, there has been a growing trend in the use of berry extracts as ingredients in functional foods and dietary supplements, which may be combined with other colorful fruits, vegetables, and herbal extracts. Extracts of fruits from various blackberry, raspberry, and gooseberry cultivars act effectively as free radical inhibitors [3]. Berries provide significant health benefits because of their high levels of polyphenols, antioxidants, vitamins, minerals, and fibers [4]. Polyphenols comprise a wide variety of compounds, divided into several classes like hydroxybenzoic acids, hydroxycinnamic acids, anthocyanins, proanthocyanidins, flavonols, flavones, flavanols, flavanones, isoflavones, stilbenes, and lignans that occur in berry fruits. It has already been demonstrated that a wide diversity of phytochemical levels and antioxidant capacities exist within and across genera of small fruits [5,6]. Furthermore, accumulating evidence suggests that genotype has a profound influence on concentrations of bioactive compounds in berries [7]. Berry extracts are widely consumed in botanical dietary supplement forms for their potential human health benefits. Many laboratory and animal studies have shown that berries have anticancer, antioxidant, and antiproliferative properties [2,8]. Berry bioactive components impart anticancer effects through various complementary and overlapping mechanisms of action, including the induction of metabolizing enzymes, modulation of gene expression and their effects on cell proliferation, apoptosis, and subcellular signaling pathways [9]. Some berries, such as strawberries and black raspberries, have been identified as sources of phenolic compounds like gallic and ellagic acid, which have potential cancer chemopreventive activity [10]. These different bioactive phenolic compounds, including flavonoids, tannins, and phenolic acids, have received considerable interest in bearing possible relations to human health. This review focuses specifically on recent data, related to in vitro and in vivo studies that have been conducted with berries, emphasizing the role of phytochemicals. It is noteworthy that recent and significant advances have been made in understanding the

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bioavailability and metabolism of phenolic acids and flavonoids present in berries, which are discussed herein. Studies on the absorption, metabolism, tissue distribution, in vitro and in vivo biological effects, and mechanisms of action of berry phenolic acids and flavonoids are necessary to evaluate their effect on human health and diseases. In fact, the chemistry and biology of phenolic acids and flavonoids are important in the context of their biological effects exerted in the human body.

General chemical composition

Berries contain high levels of a diverse range of phytochemicals, most of which are phenolic molecules. These phytochemicals include a variety of beneficial compounds, such as essential minerals, vitamins, fatty acids, and dietary fibers. Berries are an important source of provitamin A, minerals, vitamin C, and B-complex vitamins. Berry fruits contain about 15% soluble solids (mainly sugars) and their high level of fructose makes them valuable for individuals with diabetes. The high dietary fiber content is important because fruit pectin acts as an intestinal regulator [11]. Some of the known chemopreventive agents present in berries include vitamins A, C, and E, and folic acid; calcium and selenium; carotene and lutein; phytosterols such as sitosterol and stigmasterol; triterpene esters; and phenolic molecules such as anthocyanins, flavonols, flavanols, proanthocyanidins, ellagitannins, and phenolic acids (Fig. 1). The chemistry of berry phenolics directly influences their bioavailability, metabolism, and biological effects in vivo [12]. The structural diversity of berry phenolics is observed in several ways including the following:

1. Their degree of oxidation and the substitution patterns of hydroxylation,
2. Their abilities to exist as stereoisomers,
3. Glycosylation by sugar moieties and other substituents, and
4. Conjugation to form polymeric molecules such as tannins and other derived molecules [2,9].

The berry phenolis serve many diverse biological functions including roles in plant growth, development, and defense. They provide pigmentation, antimicrobial and antifungal functions, insect-feeding deterrence, ultraviolet radiation protection, chelation of toxic heavy metals, and antioxidant quenching of free radicals generated during photosynthesis [13,14].

Bioactive compounds

Vitamins

Berries contain a large amount of vitamins A, C, and E, and the B complex vitamins. These vitamins help to boost the immune system and reduce inflammation. They also are considered antioxidants, which help to fight the effects of oxidative stress leading to chronic diseases such as heart disease, diabetes, and certain cancers. Vitamins are highly concentrated in honeyberry and blackcurrants varieties, which are greater than the concentrations in strawberries, raspberries, gooseberries [15,16]. Berries are very important sources of ascorbic acid, which is a water-soluble compound that fulfills several roles in living systems. It is widely distributed in fresh fruits and vegetables. The content of vitamin C in berry fruits is determined by numerous factors, including species, variety, cultivation, climate, weather conditions, ripeness, region, storage time, and conditions. Vitamin C is reported in high amounts in blackcurrant and strawberries, which are the richest source among all the berry fruit species reported [17].

Minerals

Berries are rich in both macro- and micronutrients, among which honeyberry is a rich source of these minerals. The major mineral elements found in berries are phosphorus, potassium, calcium, magnesium, iron, manganese, copper, sodium, and aluminum. Berries accumulate much iron, calcium, phosphorus, and sodium minerals from environment and retain leadership among all other fruiting plants [18]. Mineral nutrients are scientifically recognized as essential or potentially essential constituents for human health as they play an important role in development of bones and teeth and provide strength to muscles in humans. These major and trace mineral elements are involved in various important physiological and biochemical processes in humans by affecting water and electrolyte balance, metabolic catalysis, oxygen binding, and hormone functions and are important factors for bone and membrane formation. Table 1 presents the selective mineral content of berries [19].

Anthocyanins

Anthocyanins are a subgroup of flavonoids that are commonly found in nature. They are widely distributed in fruits and vegetables, such as blueberries, blackberries, raspberries, strawberries, blackcurrants, elderberries, grapes, cranberries, red cabbage, red radishes, and spinach. Anthocyanins are colored pigments that act as powerful antioxidants; they are especially abundant in berries with red, blue, or purple pigments. These colors have been associated with a lower risk for certain cancers, urinary tract health, improved memory, and normal aging. Along with fresh berries, a variety of berry products such as juice, wine, jam, and food colorants (extracted from grape skin, blackcurrants, and other plant materials) contribute significantly to the intake of anthocyanins [20]. There is considerable current interest in the possible health effects of anthocyanins in humans owing to their potential antioxidant effects and their reported positive effects on blood vessels. More intensive use of berry anthocyanins as food colorants as well as antioxidants is an interesting prospect for the food scientist. Anthocyanins are important in the food industry, being regarded as potential replacements for synthetic food colorants, and in human nutrition as agents that protect against some diseases [21]. Anthocyanins from berries have extensively been examined for their effects on mouse model of endotoxin-induced uveitis (EIU) that shows retinal inflammation, as well as uveitis, by injecting lipopolysaccharide. Anthocyanin-rich berry extract prevented the impairment of photoreceptor cell function, as measured by electroretinogram. At the cellular level, he found that the EIU-associated rhodopsin decreased and the shortening of outer segments in photoreceptor cells was suppressed in the berry extract-treated animals. Moreover, the extract prevented both STAT3 activation, which induces inflammation-related rhodopsin decrease, and the increase in interleukin-6 expression, which activates STAT3. In addition to its anti-inflammatory effect, the anthocyanin-rich berry extract ameliorated the intracellular elevation of reactive oxygen species (ROS) and activated nuclear factor-κB, a redox-sensitive transcription factor. These findings strongly suggest that anthocyanins are absorbed and display several physiological activities and health benefits. Oral administration of berry anthocyanins may be a safe and promising supplement for patients with open angle