academicJournals

Vol. 12(19), pp. 1602-1606, 11 May, 2017
DOI: 10.5897/AJAR2017.12141
Article Number: 1114FA864135
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Review

Berries: Cultivation and environmental factors effects on the phenolic compounds content

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Received 10 January, 2017; Accepted 21 February, 2017

Berries are rich in bioactive compounds, such as vitamins, fiber, macro and microelements and have high content of polyphenols, plant secondary metabolites. The consumption of a diet rich in polyphenols has in epidemiological studies been associated with a lower incidence of degenerative diseases including cancer, cardiovascular and other diseases. The preventive effects are often attributed, in part, to phenolic compounds and suggested to be due to their antioxidant, and anti-inflammatory effects as well as other beneficial effects. This review describes the effect of cultivation methods and environmental factors on the composition and content of phenolic compounds in some berries. Methods for extraction and analyses of phenolic compounds and reported potential mechanisms of action through which polyphenol compounds may exert protective actions are also reviewed.

Key words: Berries, bioactive compounds, phenolic compounds.

INTRODUCTION

Berries are reddish-purple fruits, normally small-sized and highly perishable. This group includes strawberry, gooseberry, blackberry, raspberry (black or red), blueberry, bilberry cranberry and other berries of minor economic importance (Manganaris et al., 2014; Hussain et al., 2016). Usually the term ‘soft fruit’ has been used to refer to different commodities including strawberries, blueberries and several species of the genus *Rubus. Rubus* is a highly diverse genus of flowering plants in the world, with 12 subgenera, some of which group hundreds of species *Rubus* berry species (includes e.g. both raspberries and blackberries) grow especially well in cool climate but have also been found to grow well in subtropics climates. Raspberry and blackberries are closely related to strawberries (Vicente and Sozzi, 2007).

Despite the incongruent definitions, one unifying trait among “berries” (with few exceptions) is that they contain anthocyanins, which are pigment polyphenol compounds

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that give them their distinctive color (Joseph et al., 2014; Yamamoto et al., 2015).

PHENOLIC COMPOUNDS

Phenolic compounds are essential for the quality of plant-derived food products through their contribution to oxidative stability and organoleptic characteristics. Phenolics are broadly distributed in the plant kingdom and are the most abundant secondary metabolites of plants. Plant polyphenols have drawn increasing attention due to their potent antioxidant properties and their suggested effects in the prevention of various oxidative stress associated diseases such as cancer. Compared to other fruits, the content of phenolic compounds in berries is often higher (Balasundram et al., 2006).

Phenolics found in edible berries include flavonoids, ellagitannins, phenolic acids, and stilbenoids. Further properties that have been proposed are anti-inflammatory properties, ability to induce carcinogen detoxification enzymes, and modulate signaling pathways of cancer cell proliferation and apoptosis (Seeram, 2008). Ferulic, caffeic and p-coumaric acids and caffeoylquinic esters are the major hydroxycinnamates identified in berries; benzoic acid derivatives that have been primarily identified in berry fruits include gallic, salicylic, p-hydroxybenzoic and ellagic acids (Szajdek and Borowska, 2008).

CULTIVATION

The most common berry fruits produced globally are strawberries, raspberries, blackberries and black/red currents and especially the rapid expansion of the blackberry industry has been remarkable. As new cultivars are developed that combine the industry’s need for high quality arrivals with increased flavors and extended growth periods, the blackberry industry is expected to grow further (Clark and Finn, 2014; Da Pasa et al., 2014). This trend is similar for berries in general, and especially for blackberries, blueberries, cranberries, gooseberries, raspberries and strawberries (Hussain et al., 2014; USDA, 2016).

ENVIRONMENTAL AND PREHARVEST FACTORS AFFECTING QUALITY OF BERRIES

Berries are highly appreciated for their intense color, delicate texture and unique flavor. Despite having a number of common attributes, the group is quite diverse and comprises simple (that is, blueberry, cranberry) and composite fruits derived from single or multiple fused fertilized ovaries (that is, strawberry, mulberry, raspberry, blackberry) (Manganaris et al., 2014).

These varieties have a strong need for cold, requiring many hours at low temperature e.g. raspberries which requires at least 600 h at temperatures below 7ºC. Other crucial factors for the cultivation and quality of these fruits refers to the soil, which must be drained and with good water retention capacity as well as the presence of organic matter (Vicente and Sozzi, 2007; Curi et al., 2014).

The harvesting need to be planned and the timing of the harvest should be determined according to the parameters of the fruit ripeness according to the further and final utilization. Harvest maturity depends on the cultivar and is mainly determined by size and color of the fruit. Other maturity indices include corking of lenticels and internal ethylene concentration. The quality assessment is based on visual aspects of the berries like the texture, flavor, uniform size and shape, bruising, scars, insect damage, as well as other defects (Szalai and Basile, 2010).

All berry fruits are susceptible to various organisms, mostly fungi, that cause fruit rot or fruit rot-like diseases. *Botrytis cinerea* is the main fungus causing rots in strawberries, raspberries and blackberries. To limit deterioration the fruit has to be harvested and taken care of and further processed or consumed as soon as possible. Normally a storage with prompt forced air cooling is needed and a storage at 0ºC in 90 to 95% Relative Humidity (RH) in order to slow down the development of *Botrytis Rot* (Grey Mold), caused by *Botrytis cinerea*, which is the major cause of postharvest strawberry losses. Raspberry is considered to be the most perishable fruit among berry crops. It can only be stored for 2 to 5 days at 0±0.5°C and 90-95% RH. For Blueberry the optimum storage conditions are at 0±0.5°C and RH 90 to 95%. Shelf life at these conditions is usually two weeks. Modified atmosphere packaging for shipment with 10 to 15% carbon dioxide reduces the growth of *B. cinerea* (Szalai and Basile, 2010).

POST-HARVEST EFFECTS ON CONTENT OF PHENOLIC COMPOUNDS

Even before the fruit enters the laboratory for phytochemical extraction and analysis their phenolic profiles and concentrations will vary because of genetic (that is, genus, species, cultivar/genotype) and environmental (that is, fruit maturity, plant age, growing season, field location) factors (Lee et al., 2012).

However, after the harvesting of fruits or berries, their concentrations of polyphenols maybe significantly affected by storage conditions, and furthermore, many compounds maybe destroyed during processing. The optimal timing of the harvest of fruits and berries is not simple when trying to optimize the levels of phenolic compounds. The ideal time of fruit and berry harvesting occurs when fruits are not fully ripe and, hence, are also suitable for long-term storage; this stage is optimal with respect to the concentrations of flavanols and many flavonols (Kårlund et al., 2014).

In the study by Vagiri et al. (2015) Blackcurrant (*Ribes nigrum L*.) leaves were investigated as essential source of phenolic compounds as well as their variation from the leaf positions and date of collection. The content of phenolic compounds varied between harvest dates, although leaf position in the aerial part and interactions also played an important role. The content of quercetin-malonyl-glucoside, kaempferol-malonyl-glucoside isomer and kaempferol-malonyl-glucoside were higher than other phenolic compounds identified, while the minor epigallocatechin was investigated for all sheet positions and harvest dates. The content of the neo chlorogenic acid, epigallocatechin, kaempferol-3-*O*-rutinoside, kaempferolmalonyl-glucoside and kaempferol-malonyl-glucoside isomer was higher in June, whereas quercetin-glucoside, kaempferol-glycoside and total phenols, increase towards the end of the season. The leaf position influenced the content of myricetin-malonyl-glucoside, malonyl-glucoside yricetin-isomer, quercetin-malonyl-glucoside and kaempferol glucoside at the end of the season. Knowledge related to the influence of ontogenetic time and harvest in specific phenolic content can contribute to the adaptation of functional foods or pharmaceuticals, using blackcurrant leaves as natural ingredients.

As reported by Veberic et al. (2015), the anthocyanidin composition of *Ribers, Rubus, Vaccinium* and *Fragaria* genus or the less known species of *Crataegus, Morus, Amelanchier, Sorbus, Sambucus* and *Aronia* genus, did not differ significantly between the fruit of wild growing and cultivated species, but the total content of anthocyanidins was in general different between the different species.

HEALTH BENEFITS

Plant-derived dietary polyphenols may improve some disease states and promote health. Berry fruits contain appreciable amounts of flavonoids, particularly anthocyanins, which are responsible for the distinctive red-blue-purple coloring of berries. A diet rich in plant flavonoids is associated with a lower risk of chronic disease development and epidemiological studies suggest that regular and long-term consumption of fruits and vegetables lowers rates of premature mortality and decreases the risk of developing chronic diseases such as heart disease, stroke and several cancers. Berries are often used as medicinal food, and the applications of berries as chemopreventive anti-inflammatory or anti-cancer agents, as anti-inflammatory remedies, as cancer treatment adjuvants, have been the subject of a large number of patents and clinical trials (Scalbert et al., 2005; McCullough et al., 2012; Joseph et al., 2014; Nile and Park, 2014).

Oxidation is an essential process to aerobic organisms and our metabolism; free radicals are produced naturally as a result of this oxidation process, or by some biological dysfunction. In these radicals, the unpaired electron is in the oxygen or nitrogen atom, and therefore these radicals are classified as reactive oxygen species (ROS) or reactive nitrogen species (RNS) (Pham-Huy et al., 2008).

The oxidative processes that occur naturally in the human body contribute to the development of many major diseases due to an insufficient defense system. A diet rich in oxidised product components results in a reduction in antioxidant potential oxidative state or in an organism, increasing the risk of disease.

The finding that diets rich in fruits and vegetables reduce the risk of chronic diseases interfere with specific physiological targets, boosted research that identified nutrient substances and nutrients that do not interfere in the pathogenic processes of certain diseases. This evidence resulted, among other things, changes in the recommendations of the dietary guidelines, which started to indicate eating more servings of fruits and vegetables in the diet. The antioxidant action in common phenolic compounds, for example, due to the oxidation-reduction potential of certain molecules, the ability of these molecules to compete for the active sites and receptors in the different cell structures or even to modulation of gene expression encoding proteins involved in intracellular defense mechanisms against oxidative degenerative processes of cellular structures such as membranes and DNA.

Berry research has traditionally focused on their antioxidant properties. Berries (or their extracts) rank highly on *in vitro* antioxidant measures, such as oxygen radical absorbance capacity (ORAC) and ferric reducing antioxidant capacity (FRAP) analyses (Wolfe et al., 2008; White et al., 2010) and have been shown in various in vitro assay systems to mitigate oxidative stress (Seeram, 2008; Hurst et al., 2010). The most significant health benefits are ascribed to phenolic compounds and vitamin C (Szajdek and Borowska, 2008).

Polyphenols, including anthocyanins, have antioxidant capability; however, biologically, several studies suggest that their effects *in vivo* are not through antioxidant scavenging properties. Current hypotheses suggests polyphenols work via activation/inhibition of various cell signaling processes such as modulating kinase activity resulting in transcription factor activation (e.g., Nrf-2, NF-κB), altering receptor activation (PRR dimerization) as well as possible direct ligand activity (e.g., PPAR-γ) (Scalbert et al., 2005, Tangney and Rasmussen, 2013).

The main goal in this area is the generation through breeding programmes of novel berry cultivars with improved nutritional properties. In certain cases, increasing AOX accumulation would be beneficial from both plant and human perspectives. A study demonstrated the successful combination of interspecies back-crosses and intra-species crosses in order to improve the nutraceutical content of strawberry fruit (Ruel et al., 2009).

From a breeder's perspective, the availability of 'highly nutritious berries' with enhanced health-promoting properties would be a strong asset, encouraging both berry producers and consumers. The antioxidant potency in combination with phenolic content of fruits has been proposed as a standardized method for the evaluation of fruit germplasms (Basu et al., 2011; Dohadwala et al., 2011).

Chiva-Blanch and Visioli (2012), in a revision of article for the periodical "Journal of Berry Research" discusses that polyphenols exhibit a wide variety of different biological effects whose quantification *in vivo* is currently hampered by the lack of robust biomarkers. Indeed, some trials do show positive modulation of surrogate markers of cardiovascular disease and cancer following the administration of defined amounts of polyphenols to human volunteers. These healthful activities are the results of manifold and complex actions of polyphenols that do extend beyond their mere antioxidant actions. All of this, obviously - applies to berries and their minor components, which play multiple roles in human physiology and should not be heralded as mere antioxidants, but, rather, as multi-functional and biologically-important compounds.

The bioactive berry components, can effectively inhibit oxidative DNA damage caused both *in vivo* and *in vitro* (Aiyer et al., 2008). Cranberry juice (2 cups/day) significantly reduces lipid oxidation and increases plasma antioxidant capacity in women with metabolic syndrome (Basu et al., 2011).

The potential of (poly)phenols to improve neurological health appears to be related to a number of mechanisms, including their ability to interact with intracellular neuronal and glial signaling, to influence the peripheral and cerebrovascular blood flow, and to reduce neuronal damage and losses induced by neurotoxins and neuroinflammation. While a number of *in vitro* experiments have suggested that (poly)phenols may influence carcinogenesis and tumor development (Del Rio et al., 2013).

CONCLUSION

For the future of berry production, some factors necessary for expansion include the use of more efficient production practices. There are no specific studies, but, it is suggested that the quality and flavour of locally produced fruit is recognized as unique. Resistance to insect and disease-causing organisms is of immeasurable benefit to the environment, the producer and, the consumer.

Berries are rich in phenolic compounds, macro and microelements. Several lipophilic and hydrophilic compounds are found in berries it is believed that the additional effect additive and / or synergistic result of the various components may be responsible for beneficial biological properties rather than one chemical compound or class. Currently it is believed that the combination of vitamins, minerals, antioxidants, fiber and phenolic compounds is responsible for the desired effect on health, that help combat the effects of degenerative diseases associated with aging is a major factor in the future expansion of berry crop production.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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