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Factors influencing levels of phytochemicals in selected fruit and vegetables during pre- and post-harvest food processing operations

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ABSTRACT

Phytochemicals are important natural bioactive compounds of fruit and vegetables and are widely recognised for their nutraceutical effects and health benefits. This review analyses different factors influencing the level of phytochemicals in selected fruit and vegetables at different processing stages in the production chain. The level of phytochemicals present in fruit and vegetables may vary within and across cultivars. Available literature correlates the level of phytochemicals with many factors including cultivar type, environmental and agronomic conditions, harvest and food processing operations, and storage factors. The optimisation of food processing and storage factors is an essential step to reduce the degradation of phytochemicals for potential health benefits. Cultivar selection and maturity at harvest may be critical for food processors to maintain high levels of phytochemicals in fruit and vegetables.

1. Introduction

Epidemiologic studies have shown many health benefits associated with fruit and vegetable consumption (Hung et al., 2004; McCann et al., 2005). Intake of fruit and vegetables aid in quenching free-radicals, thus reducing the oxidative damage which can lead to several chronic diseases (Hung et al., 2004; Prior, 2003). This positive effect has been attributed mainly to the presence of various phytochemicals. Phytochemicals are a group of metabolites found in many plants and their presence in fruit and vegetables are positively correlated with many health benefits (McCann et al., 2005). Many researchers (Jenkins et al., 2008; Leonti et al., 2010) have extracted phytochemicals from fruit and vegetables to formulate homeostatic health benefits in both humans and animals. A range of phytochemicals have been reported in fruit and vegetables and are typically grouped based on function, chemical structure and also based on source. The level of a particular phytochemical in different fruit and vegetables varies according to cultivar (Nuutila, Puupponen-Pimiä, Aarni, & Oksman-Caldentey, 2003; Sariburun, Şahin, Demir, Türkben, & Uylaşer, 2010; Singh, Upadhyay, Prasad, Bahadur, & Rai, 2007). In addition to cultivar variation, climatic conditions, growing locations, agronomic factors, harvest factors (including maturity stage) also significantly influence the level of phytochemicals in fruit and vegetables (Naczk & Shahidi, 2006; Padilla, Cartea, Velasco, de Haro, & Ordás, 2007; Vallejo, Tomás-Barberán, & García-Viguera, 2003). Apart from these pre-harvest factors, various post-harvest stages, including food-processing operations, also have a major influence on the stability of phytochemicals in fruit and vegetables and their products. Conventional (thermal), modern or non-thermal (e.g. high pressure processing pulsed electric field, ultrasound/sonication, ozone, ultraviolet), domestic (e.g. washing, peeling, cutting) and industrial (e.g. canning, drying) processing are widely reported to degrade the level of phytochemicals in processed food products (Aaby, Wrolstad, Ekeberg, & Skrede, 2007; Rawson, Koidis, Rai, Tuohy, & Brunton, 2010; Volden, Bengtsson, & Wicklund, 2009).

Literature sources indicate that the level of phytochemicals is dependent on several pre- and post-harvest stages of the fruit and vegetable production chain. In order to retain the nutraceutical and pharmacological properties of phytochemicals in processed fruit and vegetable products, the food processor must optimise relevant processing steps in order to restrict the loss of phytochemicals. The objective of this review was to critically analyse and discuss the factors influencing the level of major phytochemicals in selected berries and vegetables belonging to Brassica, Compositae (lettuce), Apiaceae (carrots and parsnip) and Allium (onions) families, during both pre- and post-harvest processing stages throughout the production chain. Specific fruit and vegetables were selected due to increased interest in these products, which are readily available in Europe, commonly consumed and recognised as containing high phytochemical levels.

2. Phytochemicals and their potential health benefits

Phytochemicals, such as polyphenols, carotenoids, alkaloids, organosulphur compounds, nitrogen containing compounds and other groups, present in fruit and vegetables are classified into several

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groups (refer Table 1 and Fig. 1). Health benefits associating with the consumption of fruit and vegetables have been extensively reviewed. Consumption of berry fruits such as strawberries, blueberries, blackberries, raspberries and cranberries are known for their antiproliferative activities and cardio-protective effects (Basu, Rhone, & Lyons, 2010). Verkerk et al. (2009) reviewed the Brassica vegetables containing glucosinolates with specific isothiocyanates which posses many physiological and health benefits, including anticarcinogenic properties. Similarly, polyacetylenes (falcarinol) present in carrots (Brandt et al., 2004) and flavonols (quercetin) in allium vegetables (e.g. onions) (Nemeth & Piskula, 2007) are reported for cytotoxic and anti-tumour activity. Table 2 details the health benefits associated with the consumption of fruit and vegetables. In light of the reported health benefits, food manufacturers have increased efforts on utilising phytochemicals by incorporating them into food and food products. For example carotenoids and anthocyanins are a potential replacement for synthetic food colourant incorporated in to jams, jellies and other sugar confectionaries (Bridle & Timberlake, 1997).

3. Factors influencing levels of phytochemicals

Fruit and vegetables can be either consumed raw or after suitable processing. Both raw and processed fruit and vegetables contain varying levels of phytochemicals (Table 1). Variations in the level and type of phytochemicals found in fruit and vegetable largely depend on the biosynthetic pathway during plant growth and development. Biosynthetic pathway is regulated by several enzymes as shown in Fig. 2. Within the farm-to-fork chain several factors during pre- and post-harvest stages can influence the level of phytochemicals in finished products. Fig. 3 outlines the main factors impacting the level of phytochemicals in fruit and vegetables from pre- and post-harvest processing, including different food operations.

4. Pre-harvest factors

4.1. Cultivar variation

Berry fruits are rich in polyphenolic content and are reported to have interspecies and intraspecies variations. A high phenolic content is reported in wild blueberry (*Vaccinium myrtillus*) cultivars (up to 600 mg of gallic acid equivalent (GAE)/100 g FW), compared to cultivated blueberries (*Vaccinium corymbosum*) with a content of up to 310 mg of GAE/100 g FW (Giovanelli & Buratti, 2009). Within a cultivar, strawberry seeds are reported to contain approximately 13.6% higher levels of phenolics and 1.24% higher levels of anthocyanin when compared to the strawberry flesh (Aaby, Skrede, & Wrolstad, 2005).

Members of the Brassica family (including cabbage, cauliflower and broccoli) and lettuce (Compositae family) are known to contain significant levels of phytochemical. In a scientific study, red lettuce cultivars were reported to contain high total phenolics compared to

Table 1
Polyphenols present in fruit, vegetables and their food products.

Fruit, vegetables and food products	Total phenolics	Total flavonoids	Total anthocyanins	References
Blueberries	251 to 310[a]		92 to129[b]	Giovanelli and Buratti (2009)
Blackberries	74 to 2809[a]	41 to 54[c]	52 to 84[b]	Amakura, Umino, Tsuji, and Tonogai (2000); Sariburun et al. (2010)
Cranberries	81 to 82[a]	8.3 to 12[c]		Häkkinen et al. (1999) ; Amakura et al. (2000)
Raspberries	356 to 2066[a]	24 to105[c]	0 to 58[b]	Sariburun et al. (2010)
Strawberries - fruit	222 to 228[a]	50 to53[c]	52.56[d]	Chun et al. (2005); Aaby et al. (2007)
Strawberries-seeds	197[a]		35.57[b]	Aaby et al. (2007)
Blackberries- Jam	76 to 78[a]			Amakura et al. (2000)
Cranberry jam	83 to 86[a]			Amakura et al. (2000)
Raspberry jam	30 to 32[a]			Amakura et al. (2000)
Strawberry jam	31 to 34[a]			Amakura et al. (2000)
Strawberries-puree / smoothies	457.4[e]		0.29 to 0.36[b]	Aaby et al. (2007); Keenan et al. (2010)
Broccoli	44.5 to 82.9[a]			Singh et al.(2007)
Brussels sprouts	35 to 40.4[a]			Singh et al.(2007)
Cabbage	12.6 to 34.4[a]			Singh et al.(2007)
Cabbage -red	131 to 679[a]		38 to 80[b]	Amin and Lee (2005) ; Podsędek, Sosnowska, Redzynia, and Anders (2006)
Cauliflower	16.3 to 21.8[a]			Singh et al.(2007)
Lettuce- white	21.3[f]	4.3[g]		Ferreres et al.(1997)
Lettuce-green	57.0[f]	24.4[g]		Ferreres et al.(1997)
Lettuce-red	169.6[f]	138.4[g]		Ferreres et al.(1997)
Carrots	0.20 to 3.56[e]			Metzger and Barnes (2009)
Black carrots	17.9 to 97.9[a]		1.5 to 17.7[h]	Montilla et al. (2011)
White Onion	2449[h]	399 [i]	2.83[j]	Gorinstein et al. (2008)
Red Onion	2972[h]	384 [i]	46.02[j]	Gorinstein et al. (2008)
Red Onion -Skin	7982[h]			Nuutila et al. (2003)
Yellow Onion -Skin	2610.5[h]			Nuutila et al. (2003)
Onion-Juice	118.56 to 183.96 [c]	57.90 to 214.64[k]		Roldán, Sánchez-Moreno, de Ancos, and Cano (2008)
Onion-Paste	238.95 to 441.31[c]	671.48 to 4431.21[k]		Roldán et al. (2008)
Onion-Bagasse	330.40 to 407.64[c]	600.72 to 2230.89[k]		Roldán et al. (2008)

[a] mg of Gallic acid equivalent (GAE)/100 g FW.
[b] mg of Cyanidin 3-glucoside (Cya-3-glu)/100 g FW.
[c] mg of Chlorogenic acid equivalent (CAE)/100 g DW.
[d] mg of Pelargonidin-3-glucoside (Pl-3-glu)/100 g FW.
[e] mg Gallic acid equivalent (GAE)/100 g DW.
[f] mg of Caffeic acid derivatives/100 g FW.
[g] mg of Catechin Equivalents (CE)/100 g FW.
[h] mg of Cyanidin 3-glucoside equivalent (CGE) /100 g FW.
[i] mg of Catechin Equivalents (CE)/100 g DW.
[j] mg of Cyanidin 3-glucoside equivalent (CGE) /100 g DW.
[k] mg of total quercetin /100 g DW.