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REVIEW ARTICLE

Citrus peel as a source of functional ingredient: A review

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Abstract Citrus plants belonging to the family Rutaceae which include fruits such as orange, mandarin, lime, lemon, sour orange and grapefruitappear as a well known promising source of multiple beneficial nutrients for human beings. Processing of citrus by-products potentially represents a rich source of phenolic compounds and dietary fibre, owing to the large amount of peel produced. These citrus fruit residues, which are generally discarded as waste in the environment, can act as potential nutraceutical resources. Due to their low cost and easy availability such wastes are capable of offering significant low-cost nutritional dietary supplements. The utilization of these bioactive rich citrus residues can provide an efficient, inexpensive, and environment friendly platform for the production of novel nutraceuticals or for the improvement of older ones. This review systematically summarized the potential components present in citrus peel, which generally discarded as waste.

Contents

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1. Introduction

Risk of chronic diseases can be reduced by frequent consumption of fruits and vegetables. A common component of food products is dietary fibre which consists of variety of non-starch polysaccharides such as cellulose, hemi celluloses, pectin, β-glucans, gums and lignin (Elleuch et al., 2011) and due to their beneficial effects on food nutritional properties are consumed as foods. Consumption of dietary fibre plays a significant role in the prevention, reduction and treatment of chronic diseases such as bowel, gastrointestinal disorders, obesity, diabetes, cardiovascular disease, cancer and also promotes physiological functions such as lowering blood triglycerides and glucose control (Figuerola et al., 2005). By-products from fruits, vegetables and whole grains are assuring sources of dietary fibres and functional compounds (Larrauri, 1999). The recommended dietary fibre intake of 25–30 g/day can help to overcome the fibre deficit diet and has been related to several physiological and metabolic effects (Drzikova et al., 2005). Cholesterol ester accumulation which led to the risk of heart disease can be controlled by phenolic compounds present in fruits and vegetables (Meyer et al., 1997; Williams and Elliot, 1997). In addition to this, other properties such as anti-inflammatory and anticarcinogenic have also been reported (Carrol et al., 1999; Maeda-Yamamoto et al., 1999). The phenolic compounds are known to comprise of an antioxidant activity (Shahidi, 1997).

Citrus (Citrus L. from *Rutaceae*) is one of the most popular world fruit crops, contains active phytochemicals that can protect health. In addition to this, it provides an ample supply of vitamin C, folic acid, potassium and pectin. The contribution of citrus species in deterrence of life threatening diseases have been assessed (Proteggente et al., 2003; Gorinstein et al., 2004; Anagnostopoulou et al., 2006; Guimarães et al., 2009) and it has been reported that citrus fruits, citrus fruit extracts and citrus flavonoids exhibit a wide range of promising biological properties due to their phenolic profile and antioxidant properties (Middleton and Kandaswami, 1994; Montanari et al., 1998; Samman et al., 1996). Citrus fruits are highly consumed worldwide as fresh produce, juice and most often the peel is discarded as waste which contains a wide variety of secondary components with substantial antioxidant activity in comparison with other parts of the fruit (Manthey and Grohmann, 2001). Global production of citrus fruit has significantly increased during the past few years and has reached 82 million tons in the years 2009–2010, of which oranges – commercially the most important citrus fruit accounts for about 50 million tons (USDA, 2010) and 34% of which was used for juice production, yielding about 44% peel as by-product (Li et al., 2006). Therefore, a large amount of peel is produced every year. Citrus peel, the primary waste, is a good source of molasses, pectin and limonene and is usually dried, mixed with dried pulps and sold as cattle feed (Bocco et al., 1998). Citrus peels are subdivided into the epicarp or flavedo (coloured peripheral surface) and mesocarp or albedo (white soft middle layer) as shown in Fig. 1. A number of studies have recognized the presence of polyphenols, vitamins, minerals, dietary fibres, essential oils and carotenoids content which makes citrus a health-benefit promoting fruit. To this regard several examples about the use of citrus fruits as therapeutic remedies can be cited: oranges to cure scurvy (Magiorkinis et al., 2011) orange, lime, and lemon juices as remedies for the prevention of kidney stones formation (Pak, 2004), grapefruits as agents able to lower blood pressure and to interfere with calcium channel blockers (Sica, 2006), citrus flavonoids as effective in vivo agents able to modulate hepatic lipid metabolism (Cha et al., 2001), orange juice to prevent and modulate inflammatory processes (Assis et al., 2013), kumquat peel polyphenolics as effective antioxidant agents (Sadek et al., 2009), grapefruit juice having anti-genotoxic effects (Alvarez-Gonzales et al., 2010) and several others. Rarely occurring valuable biologically active components such as oxyprenylated natural products for example, 3,3-dimethylallyloxy-(C5), geranyloxy-(C10), and the farnesyloxy-(C15) related compounds have been recognized in the last 12 years in citrus varieties (Munakata et al., 2012; Curini et al., 2006). Citrus fruits were also seen to be a good source of many natural compounds:

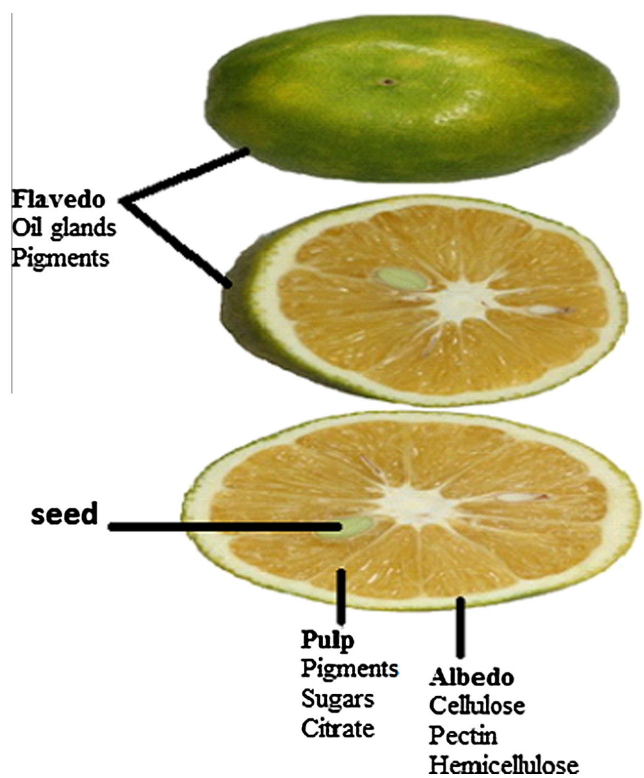

Figure 1 Anatomy of citrus fruit.

prenyloxycoumarins such as auraptene, bergamottin, imperatorin, heraclenin, oxypeucedanin and many others which have been isolated from the citrus juice and peel extracts (Epifano and Genovese, 2013; Epifano, 2014). There is a growing acceptance that phenols, amino acids, essential oils, pectin, carotenoids, flavonoids, and vitamin C present in citrus fruits exert beneficial effects in the prevention of degenerative diseases (Wang et al., 2014). Antioxidants are currently employed to retard the formation of compounds that result in decrease in sensory and nutritional quality such as butylated-hydroxyanisole, butylated hydroxytoluene (BHA, BHT) and studies have shown that these are sometimes toxic (Burlow, 1990). Clinical trials on rats have shown that these synthetic antioxidants such as BHA stimulate the development of cancerous cells (Ito et al., 1983). These findings have shifted the researchers as well as consumers preference for natural foods and food ingredients that are believed to be health-giving and unadulterated than their synthetic analogues (Cozzi et al., 1997; Farag et al., 1986). Thus, identification and isolation of bioactive compounds from by-products of the food processing industries can result in value addition (Moure et al., 2001). This review refers to main three components of citrus peel, which have very high functional properties.

2. Phenolic compounds

Major bioactive compounds known for health benefits are phytochemicals, especially phenolics in fruits and vegetables. Studies have reported that plant phenolics are not only present in edible parts of plant but their presence with multiple biological effects have also been reported in non-edible parts of the plants. The mechanisms behind the contribution of phytophenolics in health promotion and disease prevention are related to cell differentiation, pro-carcinogenes deactivation, DNA repair maintenance, suppression of N-nitrosamine formation and change of oestrogen metabolism, amongst others (Shahidi, 1997). Major mechanisms for the antioxidant effect of phenolics in functional foods include free radical scavenging and metal chelation activities. Reactive oxygen species (ROS), such as the superoxide radical ($O_2^{\bullet -}$), hydrogen peroxide (H_2O_2), hypochlorous acid (HOCl) and the hydroxyl radical ($HO^{\bullet}$) have found to be supportive in pathogenesis of human beings. (Halliwell, 1996; Halliwell et al., 1992; Aruoma, 1994, 2003). Phytophenols provide effective means for preventing and treating free radical-mediated diseases such as cancer (Huang et al., 2001), diabetes (Boynes, 1991), neurodegenerative diseases (Perry et al., 2000), process of ageing (Hensley and Floyd, 2002) and cardiovascular dysfunctions by scavenging free radicals and quenching ROS (Hool, 2006). In addition, many of the antioxidants found in plants exhibit a wide range of biological effects, including antibacterial, antiviral, anti-inflammatory, antiallergic, antithrombotic and vasodilatory actions (Cook and Sammon, 1996).

One of the most popular world fruit crops namely citrus (Citrus L. from *Rutaceae*) contains a host of active phytochemicals that can protect health. In addition to this, it provides an ample supply of vitamin C, folic acid, potassium and pectin. Citrus species of various origins have been evaluated for their phytochemical composition and its contribution in health promotion (Proteggente et al., 2003; Gorinstein et al., 2004; Anagnostopoulou et al., 2006; Guimarães et al., 2009) and it has been recognized that citrus species exhibit promising biological properties including antiatherogenic, anti-inflammatory, antitumor activity, anticlotting and strong antioxidant activity (Middleton and Kandaswami, 1994; Montanari et al., 1998; Samman et al., 1996). During the winter months a citrus fruit variety grown in north Indian states, mainly in Punjab and Rajasthan namely Kinnow or Tangerine (Citrus reticulata) is processed into juices by the industry and fruit vendors and 30–34% of kinnow peel is obtained as a major processing by-product. This Kinnow peel is found to be a rich source of health beneficial compounds including vitamin C, carotenoids and polyphenolic antioxidants (Anwar et al., 2008). On the other hand the major causes of food deterioration especially meat products are lipid oxidation and auto-oxidation. Synthetic antioxidants have been used from years to prevent this lipid oxidation which may produce changes in meat quality parameters such as colour, flavour, odour, texture and even nutritional value (Fernandez et al., 1997). To overcome the disadvantages of using synthetic anti-oxidants in meat products, Devatkal et al. (2010) replaced them with kinnow rind powder extract successfully and the results revealed that extracts are rich sources of phenolic compounds having free radical scavenging activity and concluded that the extracts of citrus powders have potential to be used as safer alternative to synthetic ones. Another encouraging study was carried out by Benamrouchea and Madania (2013) to confirm that by-products (peels and leaves) of two orange varieties cultivated in Algeria (*Citrus sinensis* L. and *Citrus aurantium* L.) as potent antioxidants. During the last decade interesting phytochemicals such as 4′-Geranyloxyferulic (GOFA) and boropinic acid have been discovered as valuable pharmacological effects as cancer chemo preventive, anti-inflammatory, neuroprotective, and anti-helicobacter pylori agents. *C. sinensis* and kumquat (*Fortunella japonica*) are the richest sources of phytochemicals such as GOFA (0.141 ± 0.011 mg/g of exocarp fresh weight) and boropinic acid (0.206 ± 0.002 mg/g of exocarp fresh weight) respectively (Genovese et al., 2014). Comparative literature data on total phenol content of peel (flavedo + albedo) extracts of citrus fruits measured by the Folin–Ciocalteu assay are shown in Table 1.

3. Flavonoids

Flavonoids are polyphenolic compounds having a phenyl benzopyrone structure, representing as two benzene rings (C6) joined by a linear three-carbon chain (C3), with a carbonyl group at the C position. Although flavonoids are generally regarded as non-nutritive agents, their potential role in the prevention of major chronic diseases has attracted the focus of many researchers. The citrus flavonoids include a class of glycosides, namely, hesperidin and naringin and another class of O-methylatedaglycones of flavones such as nobiletin and tangeretin, which are relatively two common polymethoxylated flavones (PMFs) (Li et al., 2014). In citrus fruits, peels are reported to possess highest amounts of PMFs compared to other edible parts of the fruit (Manthey and Grohmann, 2001; Wang et al., 2014). The citrus flavonoids have been found to have a health-related property, which include anticancer, antiviral and antiinflammatory activities, reduce capillary fragility, and restricts human platelet aggregation (Huet,

Table 1 Comparative literature data on total phenol content of peel (flavedo + albedo) extracts of citrus fruits measured by the Folin–Ciocalteu assay.

Citrus fruit	Total polyphenol (μg/g FW)	Method of extraction	Expression of results	Origin	Reference
Grapefruits	1550[a]	Homogenization of 10 g of fresh peel in 125 mL 95% ethanol followed by boiling in water bath	CAE	Grown in Israel	Gorinstein et al. (2004)
Sweet oranges	1790[a]				
Lemons	1900[a]				
White grapefruits	282[b]	Vortexing of 50 mg of lyophilized sample in 5 mL 80% methanol for 1 min. Heating at 90 °C for 3 h with vortexing every 30 min	GAE	Grown in Israel	Gorinstein et al. (2004)
Jaffa sweetie grapefruits	376[b]				
Lemons (cv. Meyer)	598[a]	Extraction of 2 g of frozen citrus peel powder with 16 mL of 72% ethanol for 3 h	GAE	Bought in New Zealand	Li et al. (2006)
Lemons (cv. Yenben)	1190[a]	Centrifugation, filtration and evaporation of Solvent under pressure. Dissolving of extract in water			
Grapefruit a	1616[a]				
Mandarin (cv. Ellendale)	1211[a]				
Sweet orange (cv. Navel)	736[a]				
Lemons	1882–2828	Extraction of 100 mg of lyophilized sample with 12 mL of 80% methanol over 3 days	GAE	Grown in Mauritius	Ramful et al. (2010)
Mandarins	2649–6923	Centrifugation, decantation and use of extract as is			
Sweet orange	4509–6470				

Source: Ramful et al. (2010).
CAE: chlorogenic acid equivalent.
GAE: gallic acid equivalent.
[a] Values were converted from original values expressed in mg/100 g FW.
[b] Values were converted from original values expressed in μmoL/g FW.

1982; Benavente-Garcia et al., 1997). Some glycosylated flavanones can be easily converted into the corresponding dihydrochalcones, which are potent natural sweeteners (Bor et al., 1990). The wide biochemical functions of flavonoids in orange peel have been studied extensively recently. They increased serum antioxidant capacity against lipid peroxidation (Assini et al., 2013) and reduced the elderly oxidative stress. These compounds possess the beneficial effects of anti-inflammation, antitumor (Romagnolo and Selmin, 2012; Park and Pezzuto, 2012), and antiatherosclerosis (Mulvihill and Huff, 2012). In Addition to this, these also serve as supplementary of drug chemotherapy (Meiyanto and Hermawan, 2012), diabetes health food (Aruoma et al., 2012), and neuroprotective drug (Hwang et al., 2012). Ramful et al. (2010) examined flavedo extracts of different varieties of citrus fruits grown in Mauritius for their total phenolic, flavonoid and vitamin C contents and antioxidant activities. Flavonoid derivatives, expressed in quercetin equivalents, in Mauritian citrus flavedos were generally high (> 2000 μg/g FW for the majority of samples analysed) and the reason probably might be high sunlight conditions which could induce the accumulation of flavonoids (Li et al., 1993). Using the same assay system but with Catechinas standard, three types of flavonoids generally occur in citrus fruits: flavanones, flavones and flavonols. HPLC analyses of nine flavedo extracts showed that the flavanone glycoside hesperidin is found to be present in highest concentrations (83–234 mg/g FW) in all the extracts (Londono-Londono et al., 2010). The flavanones glycosides poncirin, didymin, narirutin and flavone glycosidesdiosmin and isorhoifolin were present in all flavedo extracts where as the flavanone glycoside naringin was present only in Mandarin variety (Tomás-Barberán and Clifford, 2000). Several reports highlighted the structure–antioxidant activity relationship of flavonoid subclasses in citrus extracts. Data evidence suggests that glycosylation, O-methylation, O-glycosylation influence greatly the antioxidant potency of citrus flavonoids (Di-Majo et al., 2005). Antioxidant activity decreases with glycosylation and was enhanced with hydroxylation and the presence of C2–C3 double bond in conjugation with a 4-oxo function (Rice-Evans et al., 1996). Strong associations between high dietary intakes of natural compounds with a reduced risk in development of neurodegenerative diseases, such as Alzheimer's disease, Parkinson's disease, amyotrophic lateral sclerosis and multiple sclerosis have consistently been reported in numerous epidemiological studies (Glass et al., 2010). These natural compounds possessed neuroprotective ability and resulted suppression of activated microglia-mediated neuroinflammation (Lee et al., 2003; Pan et al., 2008; Zheng et al., 2008). Dried tangerine peel (*Citri reticulatae*) is used as traditional Chinese medicine, pericarpium called *chen-pi* to cure a wide array of ailments, including bronchial asthma, dyspepsia, and cardiac circulation, (China Pharmacopoeia Committee, 2010). A number of scientific studies report it as a rich source of many flavonoids, especially flavanone glycosides and polymethoxy flavones, which play a great contribution in protection against life threatening diseases such as cancer, atherogenesis, (Tripoli

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Table 2 Sources of dietary fibre (% dry matter).

Sources of fibre	Total dietary fibre content	Analytical methods	References
Lime peel	66.7–70.4	Enzymatic chemical method: NSP + Klason lignin	
Orange peel	64.3	Enzymatic gravimetric method	Figuerola et al. (2005)
Grapefruit peel	44.2–62.6	Enzymatic gravimetric method	Figuerola et al. (2005)
Limon peel	60.1–68.3	Enzymatic gravimetric method	Figuerola et al. (2005)

et al., 2007; Benavente-Garcia and Castillo, 2008) and neurodegeneration disorders (Youdim et al., 2004; Hwang et al., 2012). Inhibiting microglial activation-mediated neuroinflammation has become a convincing target for the development of functional foods to treat neurodegenerative diseases. Tangerine peel (*Citrireticulata e*pericarpium) has potent anti-inflammatory capacity; however, its anti neuro-inflammatory capacity and the corresponding active compounds remain unclear. Hesperidin has been found as the most predominant flavonoid in tangerine peel, followed by tangeretin and nobiletin. It has been reported that hesperidin, nobiletin, and tangeretin individually possess mild inhibitory activity against neuroinflammation but their collective effect is found to be significant (Su-Chen and Chun-Ting, 2014).

4. Dietary fibre

Dietary fibre which is often classified as soluble dietary fibre and insoluble dietary fibre consists of a mixture of plant carbohydrate polymers, both oligosaccharides and polysaccharides e.g., cellulose, hemicelluloses, pectin substances, gums, resistant starch, inulin and in association with some non-carbohydrate moiety (Fuentes-Zaragoza et al., 2010). Few sources of dietary fibre (% dry matter) are shown in Table 2. The fibre source should have SDF/IDF ratio close to 1:2 to be acceptable as a food ingredient (Jaime et al., 2002). Dietary fibre not only helps in evading hydrolysis, digestion and absorption in the human small intestine, but also achieves one of these functions: faecal bulking efficiency, enhances colonic fermentation, maintains insulin level and reduces pre-prandial cholesterol levels (Champ et al., 2003; Fuentes-Zaragoza et al., 2010). Health conscious people prefer natural supplements fearing that synthetic ingredients may be the source of toxicity, fibre-rich by-products, rich in dietary fibre and bioactive compounds act as a prize to food processors. Supplementation with dietary fibre can result in safer and economical foods with multiple health benefits. The average daily requirement of dietary fibre is 21–25 g per day for women and 30–38 g per day for men (Food and Nutrition Board, Institute of Medicine, 2001). Most nutritionists and diet experts suggest that 20–30% of our daily fibre intake should come from soluble fibre. In addition to health related benefits dietary fibre shows some functional properties such as water holding capacity, oil holding capacity, viscosity or gel formation, bile acid binding capacity emulsion stabilization, and enhances shelf-life. Cereal, fruit and vegetable by-products produced in large amounts every day can be utilized as a value added products. They supply dietary fibre as well as bioactive compounds such as polyphenols and essential oils, providing economic benefit to the producer as well as consumer. One typical example is the residue obtained from the industrial processing of citrus peel (Braddock, 1999). Garcia et al. (2002) reported that the addition of cereal or fruit fibre, specifically 1.5% orange fibre, can be used as a fat replacer in dry fermented sausages. Citrus fibre, which possesses bioactive functions due to the presence of polyphenol-like components, can be used as effective inhibitors of lipid oxidation in meat products, thereby improving their oxidative stability and prolonging their shelf life (Fernandez-Gines et al., 2003; Sayago-Ayerdi et al., 2009). Citrus fibre could also be used for reduction of residual nitrite levels (Fernandez-Gines et al., 2003). Citrus peel could be considered to be a potential source of pectin which is composed of white, spongy and cellulosic tissue (Terpstra et al., 2002). Frequent consumption of dietary fibre is associated with low risk of life threatening chronic diseases such as bowel, gastrointestinal disorders, obesity, diabetes, cardio vascular disease, cancer and also promoting physiological functions including reduction in blood cholesterol level and glucose attenuation (Figuerola et al., 2005). The effectiveness of citrus peel in lowering the plasma liver cholesterol, serum triglyceride level, serum total cholesterol, liver total lipids, and liver cholesterol (Terpstra et al., 2002) is proven by many epidemiological studies. The peel fibre derived from orange fruit is involved in the improvement in intestinal function and health (Chau et al., 2005). Peel, pulp and peel fibre from *Citrus hystrix* and *Citrus maxima* (red and white variety), could be used as potential dietary fibre sources in the enrichment of foods because of their high physicochemical properties.

5. Conclusion

Recent research concerning functional properties of citrus by-products especially peel has added to our knowledge. Due to the low cost and easy availability of fruit residues which otherwise would be discarded as waste in the environment should be regarded as potential nutraceutic resources, capable of offering significant low-cost, nutritional dietary supplements. Rich in bioactive compounds, these unwanted cast-offs of manufacturing could be recycled as value added food supplements, that provide advantageous dietary fibre and polyphenols. They serve as non-caloric bulking agents, enhance water and oil retention, improve emulsion and could prevent us from a wide range of diseases caused due to oxidative stress. The extracts from fruit peel hold promise in food industry as sources of bioactive compounds. In addition, an established use of the citrus peel would also help alleviate pollution problems caused because of the poor disposal of such residues. More research is needed to establish bioavailability and real benefits of these peel extracts obtained from citrus peel in vivo.

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