Agro-industrial potential of exotic fruit byproducts as a source of food additives


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Abstract

Exotic fruit consumption and processing is increasing worldwide due to the improvement in preservation techniques, transportation, marketing systems and consumer awareness of health benefits. The entire body of tropical exotic fruits is rich in bioactive compounds, such as phenolic constituents, carotenoids, vitamins and dietary fiber. However, the fruit processing industry deals with the large percentage of byproducts, such as peels, seeds and unused flesh, generated in the different steps of the processing chains. In most cases, the wasted byproducts can present similar or even higher contents of bioactive compounds than the final produce does. The aim of this review is to promote the production and processing of exotic fruits highlighting the possibility of the integral exploitation of byproducts rich in bioactive compounds. Amongst the possible uses for these compounds that can be found in the food industry are as antioxidants (avoiding browning and lipid oxidation and as functional food ingredients), antimicrobials, flavoring, colorants and texturizer additives. Finally, the importance of extraction techniques of bioactive compounds designated as food additives is also included.© 2011 Elsevier Ltd. All rights reserved.

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1. Introduction

Tropical exotic fruit production, trade and consumption have increased significantly on the domestic and international markets due to their attractive sensory properties and a growing recognition of its nutritional and therapeutic value (Bicas et al., 2011; Gonzalez-Aguilar, Villa-Rodriguez, Ayala-Zavala, & Yahia, 2010; Rufino et al., 2010; Yang, Jiang, Shi, Chen, & Ashraf, 2011). Examples of tropical exotic crops include coffee, macadamia, pineapple, taro, papaya, and mango (Miljkovic & Bignami, 2002). In many cases the raw tropical exotic fruit is not consumed directly by humans, but first undergoes processing to separate the desired value product from other constituents of the plant tissue. For instance, processing of coffee generally involves separating the desired beans from the byproducts of processing, which consist of the fruit skin and other undesirable constituents (Vignoli, Bassoli, & Benassi, 2010). Likewise, tropical exotic crops such as pineapple, taro, papaya, and mango are typically valued for their fruit. Processing of these crops typically involves...
separating the valuable fruit part from byproducts such as skin and seeds (Ayala-Zavala, Rosas-Domínguez, Vega-Vega, & González-Aguilar, 2010).

The mass of byproducts obtained as a result of processing tropical exotic crops may approach or even exceed that of the corresponding valuable product affecting the economics of growing tropical exotic crops (Miljkovic & Bignami, 2002). In the past, this costly problem has been mitigated to some extent by processing the byproducts further to yield a product that presents less of a disposal problem or that has some marginal economic value (Sun-Waterhouse, Wen, Wibisono, Melton, & Wadhwa, 2009). The economics of processing tropical crops could be improved by developing higher-value use for their byproducts. For instance, several patents have been published relating the use of tropical crops as a source of nutraceutical compounds (Andrews & Andrews 2008; Garrity et al., 2008; Miljkovic & Bignami, 2002). It has now been reported that the byproducts of tropical exotic fruits contain high levels of various health enhancing substances that can be extracted from the byproducts to provide nutraceuticals (Gorinstein et al., 2011).

This review analyzes the potential uses of tropical exotic fruit byproducts; where one of the majors can be as food additives (antioxidants, antimicrobials, colorants, flavorings, and thickener agents). Vitamin C, a natural compound obtained from several plant tissues is the best example of the potential use in the food industry. The antimicrobial power of plant and herb extracts has been recognized for centuries, and mainly used as natural medicine, however, the trends in using these compounds as food preservatives is increasing now days (Ayala-Zavala & González-Aguilar, 2011). In addition, plants produce a wide range of volatile compounds, some of which are important for flavor quality factors in fruits, vegetables, spices, and herbs (Lanciotti et al., 2004). Ever since, natural colors from spices and herbs as well as fruits and vegetables have been part of the everyday diet of humans. It is well known that agro industrial byproducts are rich in dietary fibers (DF). The DF additive provides economic benefits to the food, cosmetic and pharmaceutical industries (Ajila, Aalami, Leelavath, & Rao, 2010). Apart from the well known health effects, DF shows some functional properties as food additives, such as water-holding capacity, swelling capacity, increasing viscosity or gel formation which are essential in formulating certain food products.

On the other hand, foods are perishable products as a cause of their intrinsic characteristics. Microbial growth, sensorial attribute decay, and loss of nutrients are amongst the major causes that compromise the quality and safety of food produce (Ayala-Zavala, del-Toro-Sanchez, Alvarez-Parrilla, & Gonzalez-Aguilar, 2008; Janevska, Gospavic, Pacholewicz, & Popov, 2010). Chemical synthetic additives can reduce food decay, but consumers are concerned about chemical residues in the products (Ayala-Zavala & González-Aguilar, 2011; White & McFadden, 2008). Regarding the food safety issues, one of the major emerging technologies is the application of natural additives.

We have to consider that the high content of bioactive compounds present in exotic fruit byproducts can be used as natural food additives. If this approach is realized, it would be feasible to fulfill the requirements of consumers for natural and preserved healthy food. In addition, the full utilization of fruits could lead the industry to a lower-waste agribusiness, increasing industrial profitability. In this context, the main goal of this review article is to highlight the agro industrial potential of exotic fruit byproducts as a source of natural antioxidants (avoiding browning and lipid oxidation and as functional food ingredients), antimicrobials, flavoring, colorants and texturizer additives, and their possible uses in the food industry.

### Table 1

<table>
<thead>
<tr>
<th>Compound</th>
<th>Forms</th>
<th>Solubility</th>
<th>Mode of action</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascorbic acid</td>
<td>Ascorbic acid, dehydroascorbic acid</td>
<td>Hydrosoluble</td>
<td>Free radical scavenging activity, enzymatic reduction due to direct electron donation from hydroxyl groups</td>
<td>Jacobsen, Adler-Nissen, and Meyer (1999); Pokorny, Yanishlieva, and Gordon (2001)</td>
</tr>
<tr>
<td>Phenolic compounds</td>
<td>Phenolic acids</td>
<td>Hydrosoluble</td>
<td>Electron donation, metal ion chelation, ascorbic acid sparing, radical scavenging activity due to hydroxyl groups and conjugated double bonds</td>
<td>Balasundram et al. (2006)</td>
</tr>
<tr>
<td>Carotenoids</td>
<td>Carotenoids</td>
<td>Liposoluble</td>
<td>Electron donation, radical scavenging activity due to conjugated double bonds and hydroxyl groups in xanthophylls</td>
<td>Jim and Hong-Shum (2003); Krinsky and Johnson (2005)</td>
</tr>
<tr>
<td>Tocopherol</td>
<td>α-Tocopherol, β-Tocopherol, δ-Tocopherol</td>
<td>Liposoluble</td>
<td>Electron donation, radical scavenging activity due to conjugated double bonds</td>
<td>Hong-Bo, Li-Ye, Ming-An, Jaleel, and Hong-Mei (2008)</td>
</tr>
</tbody>
</table>
Tropical exotic fruits depend on the evaluated product (Table 2) and contribute to the antioxidant capacity, respectively. Phenolic compounds appear to play an important role in fruits’ protection against pathogenic agents, penetrating the cell membrane of microorganisms, causing lysis (Ayala-Zavala & González-Aguilar, 2011). Flavonoids are polyphenols with diphenylpropane (C₆H₅C₆H₅) skeletons (Alothman, Bhat, & Karim, 2009). Among these compounds, mirecite, mangiferin, gallic acid and hydrolysable tannins, which are most likely gallotannins, constitute the major antioxidant polyphenolics found in some tropical exotic fruits (González-Aguilar et al., 2008). Papayas (Carica papaya cv. Maradol), pineapples (Ananas comosus cv. Premium cayenne), and mangoes (Mangifera indica cv. Kent), analyzed for the phytochemical content and antioxidant status, corroborated the above information (Ayala-Zavala et al., 2010). The peel and seed of mango showed the highest values of bioactive compounds and antioxidant capacity. The peel presented values of 5.997 mg of gallic acid/g, 100.0 mg of quercetin/g on a fresh weight basis and 93.4% of DPPH radical scavenging activity at the concentration of 322 mg/mL. On the other hand, the seed showed 37.279 mg of gallic acid/g, 35.954 mg of quercetin/g on a fresh weight basis and 47.97% DPPH radical scavenging activity at the concentration of 322 mg/mL. The ABTS, FRAP and FCR values for the pulp of mango, longan, and jackfruit were: 762, 448, 236.1 and 7.4 mg of gallic acid equivalents/g, respectively. The ABTS, FRAP and FCR values for the seeds of mango, longan, and jackfruit were: 7.2, 3.7, 4.9 and 6.8 mg of gallic acid equivalents/g, respectively. Phenolics and flavonoids, with antioxidant, antimicrobial and colorant properties, were found that the peel and seed of “Uba” Mango had a total phenolic content of 0.0572 mg/g and 0.08254 mg/g of dry matter, these values were 4.6 and 7.3 times higher than those in the pulp, respectively. It was also found that the phenolic content in the peel of this mango cultivar was

### Table 2

Functional compounds found in different tissues of exotic tropical fruit.

<table>
<thead>
<tr>
<th>Fruit</th>
<th>Part of the fruit</th>
<th>Phenolics (mg/100 g)</th>
<th>Ascorbic acid (mg/100 g)</th>
<th>Carotenoids (μg/100 g)</th>
<th>Fiber (mg/100 g)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avocado</td>
<td>Seed</td>
<td>5160**</td>
<td>9**</td>
<td>630*</td>
<td>–</td>
<td>Leong and Shui (2002); Wang et al. (2010)</td>
</tr>
<tr>
<td></td>
<td>Pulp</td>
<td>490**</td>
<td>9**</td>
<td>590**</td>
<td>5000**</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peel</td>
<td>1250**</td>
<td>9**</td>
<td>1520*</td>
<td>–</td>
<td>Someya, Yoshi, and Okubo (2002); Subagio, Morita, and Sawada (1996)</td>
</tr>
<tr>
<td>Banana</td>
<td>Pulp</td>
<td>2322</td>
<td>12.3**</td>
<td>75**</td>
<td>400**</td>
<td>4000**</td>
</tr>
<tr>
<td></td>
<td>Peel</td>
<td>928</td>
<td>–</td>
<td>400**</td>
<td>7680**</td>
<td></td>
</tr>
<tr>
<td>Guava</td>
<td>Seed</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Charoensiri, Kongjachaisai, Sukniam, and Sungpuag (2009); Jimenez-Escrig, Rincon, Pulido, and Saura-Calixto (2001); Lim, Lim, and Tee (2007); Mahattanataweewee et al. (2006)</td>
</tr>
<tr>
<td></td>
<td>Pulp</td>
<td>159.93**</td>
<td>13–14**</td>
<td>13,800*</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peel</td>
<td>5870</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Soong and Barlow (2004)</td>
</tr>
<tr>
<td>Jackfruit</td>
<td>Seed</td>
<td>2770</td>
<td>–</td>
<td>1910</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pulp</td>
<td>90</td>
<td>8.0–10**</td>
<td>4530**</td>
<td>1600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peel</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Soong and Barlow (2004)</td>
</tr>
<tr>
<td>Longan</td>
<td>Seed</td>
<td>6260</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pulp</td>
<td>160</td>
<td>60.1**</td>
<td>4530**</td>
<td>1100</td>
<td></td>
</tr>
<tr>
<td>Mango</td>
<td>Seed</td>
<td>11,700**</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Larrauri, Rupérez, Borroto, and Saura-Calixto (1996); Leong and Shui (2002); Robles Sánchez et al. (2009); Soong and Barlow (2004)</td>
</tr>
<tr>
<td></td>
<td>Pulp</td>
<td>240.0</td>
<td>19.2**</td>
<td>4530**</td>
<td>1000.0**</td>
<td></td>
</tr>
<tr>
<td>Pomegranate</td>
<td>Seed</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td>Li et al. (2006); Opara, Al-Ani, and Al-Shaibi (2009)</td>
</tr>
<tr>
<td></td>
<td>Pulp</td>
<td>24,990.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Peel</td>
<td>24,400.0</td>
<td>10,200.0**</td>
<td>–</td>
<td>–</td>
<td></td>
</tr>
</tbody>
</table>

– No results were found.
* Dry weight.
** Fresh weight.

#### 2. Occurrence of functional compounds in tropical exotic fruits

The most common bioactive compounds present in tropical fruits are vitamins C, E, carotenoids, phenolic compounds and dietary fiber (Table 1) (González-Aguilar et al., 2008). As health related compounds, these have been attributed to lowering the risk of developing cancer, alzheimer, cataracts and Parkinson, among others. These beneficial effects have been attributed mainly to their antioxidant and radical scavenging activities which can delay or inhibit the oxidation of DNA, proteins and lipids. Indeed, these compounds have shown antimicrobial effects, playing an important role in fruits’ protection against pathogenic agents, penetrating the cell membrane of microorganisms, causing lysis (Ayala-Zavala & González-Aguilar, 2011).

The content of functional compounds in different tissues of tropical exotic fruits depend on the evaluated product (Table 2) (Soong & Barlow, 2004). In general, vitamin C is uniformly distributed in fruits, carotenoids occur mainly on the surface of the tissues such external pericarp and peel, while phenolic compounds are located preferentially in peel and seeds and in a lesser extent in the flesh (Fig. 1) (Kalt, 2005).

Flavonoids are polyphenols with diphenylpropane (C₆H₅C₆H₅) skeletons (Alothman, Bhat, & Karim, 2009). Among these compounds, mirecite, mangiferin, gallic acid and hydrolysable tannins, which are most likely gallotannins, constitute the major antioxidant polyphenolics found in some tropical exotic fruits (González-Aguilar et al., 2008). Papayas (Carica papaya cv. Maradol), pineapples (Ananas comosus cv. Premium cayenne), and mangoes (Mangifera indica cv. Kent), analyzed for the phytochemical content and antioxidant status, corroborated the above information (Ayala-Zavala et al., 2010). The peel and seed of mango showed the highest values of bioactive compounds and antioxidant capacity. The peel presented values of 5.997 mg of gallic acid/g of fresh weight (fw), 4,455 mg of quercetin/g fw and 47.97% DPPH radical scavenging activity at the concentration of 322 mg/mL. On the other hand, the seed showed 37.279 mg of gallic acid/g, 35.954 mg of quercetin/g on a fresh weight basis and 93.4% of DPPH radical scavenging activity at the concentration 307 mg/mL. The content of functional compounds in different tissues of tropical exotic fruits depend on the evaluated product (Table 2) (Soong & Barlow, 2004). In general, vitamin C is uniformly distributed in fruits, carotenoids occur mainly on the surface of the tissues such external pericarp and peel, while phenolic compounds are located preferentially in peel and seeds and in a lesser extent in the flesh (Fig. 1) (Kalt, 2005).

![Fig. 1. Main functional bioactive compounds in tropical exotic fruits and their general distribution in tissues.](image)

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**Notes:**
- Table 1: Functional compounds found in different tissues of exotic tropical fruit.
- Table 2: Functional compounds found in different tissues of exotic tropical fruit.
- Fig. 1: Main functional bioactive compounds in tropical exotic fruits and their general distribution in tissues.
3.3 times higher than that found in apple peel. DPPH radical scavenging activity of mango peel showed a higher inhibition value (53.3%) followed by the seed (24.2%) and finally the pulp. This higher antioxidant activity of the peel was related to the higher content of antioxidant compounds in comparison to other parts of the fruit.

The antioxidant capacity of seed, peel and pulp of eight varieties of avocado was determined. For all cultivars, seeds contained the highest total phenolic contents and antioxidant capacities, whereas the pulp had the lowest. Total phenolic contents in the seeds ranged from 19.2 to 51.6 mg of gallic acid equivalents/g. “Hass” avocado contained higher phenolic content and antioxidant capacities than all the non-Hass cultivars (Wang, Bostic, & Gu, 2010). Similarly, other studies have also reported that the phenolic content of pomegranate peels was 10 times higher (249.4 mg/g) than that found in the pulp (24.4 mg/g) (Li et al., 2006). Considering that peels and seeds of most exotic fruits are not consumed and rarely approached, the high amount of bioactive compounds presented in these non-edible parts could be used for different purposes in the food industry such as enrichment or development of new products.

Carotenoids are phytochemicals presented in considerable amount in tropical exotic fruit tissue (Rufino et al., 2010). Carotenoids play a potentially important role in human health by acting as biological antioxidants, protecting cells and tissues from the damaging effects of free radicals and singlet oxygen and are used as natural colorants in the food industry (Oreopoulou & Tzia, 2007). The carotenoid content was found to be 4–8 times higher in ripe mango peels compared to raw fruit peels (Ajila, Bhat, & Rao, 2007).

The crude fiber contents of mango peel represent mainly cellulosic fractions, which is a major part of insoluble dietary fiber (Ajila et al., 2010). The dietary fiber content in mango peels of different varieties has been estimated. The total dietary fiber content in dry peel varied from 45% to 78% (Ajila et al., 2010). The soluble dietary fiber content in both raw and ripe mango peels are more than 35% of total dietary fiber. Insoluble dietary fiber relates to both water absorption and intestinal regulation whereas soluble dietary fiber associates with cholesterol in blood and diminishes its intestinal absorption (Palafoux-Carlos, Ayala-Zavala, & González-Aguilar, 2010). The characteristic feature of some tropical exotic fruit byproducts like mango peel is that it has high contents of soluble dietary fiber, which is reported to have more health beneficial effects. The waste generated during the processing of passion fruit mainly consists of peel and seed. Dietary fiber from yellow passion fruit (Passiflora edulis) peel was reported to be prepared as an alcohol insoluble material which may be suitable to protect against diverticular diseases (Yapo & Koffi, 2008).

Another bioactive attribute of exotic fruit byproducts are their antibiotic properties. The peel and seed of three varieties of avocado (Shepard, Hass and Fuerte) showed activity against yeast, gram-negative and gram-positive bacteria (Chia, Wah, & Dykes, 2010). The peel and seed extracts of avocado Hass with a minimum inhibitory concentration value of 104.2 μg/mL is the most effective against Salmonella enteritidis and Zygosaccharomyces bailii, respectively (Chia et al., 2010).

Despite the high content of bioactive compounds in the skins and seeds of exotic fruits, attention must be paid to antinutritional and toxic factors, like high tannin content in these tissues (Abdalla, Darwish, Ayad, & El-Hamahmy, 2007; Miljkovic & Bignami, 2002). Tannins are considered nutritionally undesirable because they precipitate proteins, inhibit digestive enzymes and affect the utilization of vitamins and minerals. However, many tannin molecules have been reported to reduce the mutagenicity of a number of compounds (Chung, Wei, & Johnson, 1998) and it all depends on the concentration at which it is used or consumed. To avoid these problems it is recommended that during the preparation of extracts from these byproducts, acidic and/or alkaline hydrolysis are recommended in order to inactivate these compounds.

3. Generation of fruit byproducts

In the horticultural sector, there has been a growth in both acreage and agricultural production to fulfill the requirements of global food demand (Schieber, Stintzing, & Carle, 2001). This intensity of production generates large amount of plant products, estimated to be around 800,000 tons/year of fresh fruits and vegetables, without considering the losses and wastage during processing. The full utilization of horticultural produce is a requirement and a demand that needs to be met by countries wishing to implement low-waste technology in their agribusiness (Kroyer, 1995).

In many cases the raw tropical exotic fruit is not consumed directly by humans, but first undergoes processing to separate the desired value product from other constituents of the plant (Ayala-Zavala et al., 2010; Miljkovic & Bignami, 2002). Some examples of tropical exotic fruit byproducts that have found a successful opportunity at the secondary process of extraction of bioactive compounds are coffee, macadamia, mango, and papaya (Miljkovic & Bignami, 2002). Processing of coffee generally involves separating the desired beans from the byproducts of processing, e.g., the so-called “coffee cherry,” which consists of the fruit skin and other undesirable constituents. On the other hand, macadamia is a tropical exotic fruit that contains an inner and outer shell, and a nut. Processing generally involves separating the valuable nut (main product) from the shells considered as byproducts. Also, pineapple, taro, papaya, and mango are typically appreciated for their flesh but processing of these crops involves separation and removal of the skin and seed byproducts. For instance, U.S. Patent application US 2002/0187239 A1 have proposed the use of coffee cherry, macadamia, mango, taro and papaya byproducts as a source of nutritional constituents (Miljkovic & Bignami, 2002).

Other successful examples of non exotic fruit byproducts that can show the profitability of the extraction of bioactive compounds are citrus and grapes. Citrus is the most abundant crop in the world. Its worldwide production is over 88 × 10^6 tons and one-third of the crop is processed. Oranges, lemons, grapefruits and mandarins represent approximately 98% of the entire industrialized crop. Citrus fruits are processed, mainly to obtain juice, but also, in the canning industry, to produce jam and segments of mandarin (Izquierdo & Sendra, 2003). Worldwide industrial citrus wastes may be estimated at more than 15 × 10^6 tons, as the amount of residues obtained from the fruits accounts for 50% of the original whole fruit mass, which are exploited by the chemical industry to extract flavonoids and essential oils (Marín, Soler-Rivas, Benavente-García, Castillo, & Pérez-Alvarez, 2007).

Grapes (Vitis vinifera L.) belong to the world’s largest fruit crops with a global production of around 69 × 10^6 tons in 2006 (FAOSTAT, 2007). Since about 80% of the total amount is used in winemaking, some 10 million tons of grapes arise within a few weeks of the harvest campaign. Seeds constitute a considerable proportion of the grape, ranging from 38–52% on a dry matter basis. The seed oil is rich in unsaturated fatty acids (particularly linoleic acid) and phenolic compounds and is produced in all Europe (Maier, Schieber, Kammerer, & Carle, 2009; Schieber, Müller, Röhrig, & Carle, 2002).

Byproducts resulting from the processing of papaya, pineapple and mango represent approximately 10–60% of fruit weight (Cerezal, Larrauri, & Pihera, 1995; Larrauri, 1994; Larrauri & Cerezal, 1993). Several kinds of minimally processed fruits produced variable amount of byproducts to the extent even exceeding the edible portion depending on the fruit in question. Foo, Lu, and Watson (2010) patented an extract from the skin of passion fruit, which showed the effect of lowering blood pressure and serum nitric oxide levels, providing a hepatoprotective effect, as well as antioxidant and anti-inflammatory effects in mammals. Within the revised literature the number of studied byproduct sources has been augmented considerably, which is caused by the value of recycling and integral exploitation interest of the agri-food industry, but also increasing information on the specific location of active compounds.
(Peschel et al., 2006). In this context, the use of the entire plant tissue could have economic benefits to producers and a beneficial impact on the environment, leading to a greater diversity of products (Cerezo & Duarte, 2005). This situation can be extrapolated to different food processing areas, including the oils, jams, juices, nectars, wines, syrups and the fresh-cut fruit industry (Ayala-Zavala et al., 2010). However, practical aspects that need to be considered include extraction efficiency, availability of sufficient raw materials, and toxicity or safety issues (Balasundram, Sundram, & Samman, 2006).

4. Possible uses of byproducts in the food industry

Several potential uses can be considered for tropical exotic fruit byproducts, one of the majors can be as food additives (antimicrobials, antioxidants, colorants, flavorings, and thickener agents) (Ayala-Zavala & González-Aguilar, 2011). However, it can be observed in the next section that very few studies on the use of tropical exotic fruit byproducts have been performed to accomplish this goal, however, other fruits have been used.

4.1. Byproducts as antibrowning additives

Tropical exotic fruit byproducts are sources of a great variety of antioxidants, and their particular properties may be useful in maintaining food quality avoiding enzymatic browning in fruits. The enzymatic browning caused by polyphenoloxidase (PPO) is a major detrimental factor of the quality of fresh-cut fruits and vegetables (González-Aguilar, Wang, & Buta, 2006). To avoid this problem, several additives have been applied mainly by dipping, spraying or vacuum impregnation. Antioxidants and terpenoids may be used in accordance to their mode of action, i.e., as acidulants, reducing and/or chelating agents and enzyme inhibitors. Therefore their beneficial effects may differ among treated product and matrix applied.

The optimum pH for polyphenoloxidase activity has been reported to be from acid to neutral in most fruits and vegetables, and the optimum activity is observed at pH 6.0–6.5 while the minimum activity is detected below pH 4.5. This is the reason behind the use of chemicals that decrease the product’s pH or acidulants to control the enzymatic browning. Acidulants are used in conjunction with other treatments because reducing browning by controlling only the pH is difficult. Acidulants, such as citric, malic, and phosphoric acids, are capable of lowering the pH of a system, thus reducing the polyphenoloxidase activity (Rojas-Grati, Grasa-Guillem, & Martín-Belloso, 2007).

Gorny, Hess-Pierce, Cifuentes, and Kader (2002) determined that 2% ascorbic acid with 1% calcium lactate reduced the browning of fresh-cut peaches initially, but after 8 days at 0°C the difference was minimal with respect to non-treated peaches. Gil, Gorn, and Kader (1998) determined that 2% ascorbic acid was effective in reducing the browning of fresh-cut Fuji apple slices when combined with low oxygen atmosphere storage. González-Aguilar et al. (2005) compared N-acetyl cysteine with ascorbic acid and isoascorbic acid as anti-browning agents for fresh-cut pineapple stored for 14 days at 10°C. While the treatment with N-acetyl-cysteine (0.05 M) was the most effective in reducing browning and better appearance, higher levels of sugars and vitamin C (0.05 M) resulted from isoascorbic acid (0.1 M) and ascorbic acid. The level of anti-browning agents used, did not affect other sensory characteristics. Also, the combination of citric acid and ascorbic acid showed effective results. When 3% ascorbic acid + 1% citric acid + 1% sodium hexametaphosphate that had a pH of 2.9 was applied to fresh-cut apples, sodium hexametaphosphate induced tissue breakdown in both varieties tested but only at 10°C. No formal sensory evaluation was performed but some sour flavor was detected (Pilzota & Sapers, 2004).

Extracts from pomegranate and apple juice browning but in a lesser extent than other tested antioxidants like hexylresorcinol and cysteine (de la Rosa et al., 2011). On the other hand, it is important to mention the plant phenolic compounds as a large group of natural antioxidants ubiquitous in a diet high in fruits (Arts & Hollman, 2005). These compounds are divided in two groups: phenolic acid and flavonoids, which both exhibit remarkable antioxidant activity (Palafax-Carlos et al., 2010). Exotic fruits like mango, kiwi, guava, red dragon, papaya, longan, sapodilla, etc., exhibit important antioxidant capacity and significant polyphenol contents among other fruits (Mahattanatawee et al., 2006). Certainly, these compounds are a serious candidate to be applied as additives in food products to preserve and enhance quality, avoiding food oxidation. However, there are no studies approaching aspects such as antibrowning effects and antioxidant benefits of phenolic compounds applied on food products. This is a topic that needs attention to find new applications and uses of exotic fruits as sources of these compounds.

4.2. Byproducts as antimicrobial and flavoring agents

Natural antimicrobial compounds are a re-emerging alternative to food preservation. The antimicrobial power of plant and herb extracts has been recognized for centuries, and mainly used as natural medicine. The most studied natural antimicrobial compounds in plant extracts are essential oils (EOs). Essential oils are volatile, natural, complex compounds characterized by a strong odor and are formed by aromatic plants as secondary metabolites (Bakkali, Averbeck, Averbeck, & Idaomar, 2008). Among EO constituents we found terpenes, which form structurally and functionally different classes. They are made from combinations of several 5-carbon-base (C5) units called isoprene. Evidence about the antimicrobial activity of terpenes have been well demonstrated. Terpenes or terpenoids are active against bacteria (Ahmed et al. 1993; Amaral, Ekins, Richards, & Knowles, 1998), fungi (Ayar, TchueBndem, Nyasse, Tillequin, & Anke 1994; Harrigan et al., 1993), virus (Fujjoka et al. 1994; Hasegawa et al., 1994), and protozoa (Cowman 1999; Ghosal, Prasad, & Lakshmi, 1996). It was reported that 60% of EO derivatives examined to date were inhibitory to fungi while 30% inhibited bacteria (Chaurasia & Vyas, 1977). To date, the mechanism behind the antimicrobial activity of terpenes is unclear. The generally accepted hypothesis establishes that EOs comprise a large number of components and it is likely that their mode of action involves several targets in the bacterial cell. The hydrophobicity of EOs enables them to partition in the lipids of the cell membrane and mitochondria, rendering them permeable and leading to leakage of cell contents. Physical conditions that improve the action of EOs are low pH, low temperature and low oxygen levels (Burt, 2004). In addition plant volatiles have been widely used as food flavoring agents, and many are generally recognized as safe (GRAS).

The citrus industry produced large amounts of byproducts. Oils obtained from skin have been used for different applications. Studies of the application of lemon extract on dairy products have also been performed (Conte, Scrocco, Singaglia, & Del Nobile, 2007). Different antimicrobial packaging systems including lemon extracts have been used to preserve Mozzarella cheese. Results showed an increase in the shelf life of all active packaged Mozzarella cheeses, confirming that lemon extract may exert an inhibitory effect on the microorganisms responsible for spoilage phenomena without affecting the functional microbiota of the product (Conte et al., 2007).

The antimicrobial and antioxidant potentials of pomegranate peel and seed extract were investigated in chicken products (Kanatt, Chander, & Sharma, 2010; Li et al., 2006). Pomegranate peel extract (PE) showed excellent antioxidant activity while the seed extract did not have any significant activity, probably to the difference in the type and amount of bioactive compounds present in both tissues. Pomegranate peel extract showed good antimicrobial activity against Staphylococcus aureus and Bacillus cereus. In general, addition of pomegranate peel extract to popular chicken and meat products enhanced its shelf life by 2–3 weeks, during chilling temperature.
storage. PE was also effective in controlling oxidative rancidity in these chicken products (Kanatt et al., 2010).

Since the antimicrobial activity of EOs has been demonstrated, consequently tremendous potential and application opportunities are approaching. Studies with fresh meat, meat products, fish, milk, dairy products, vegetables, fruit and cooked rice have shown that the concentration needed to achieve a significant antibacterial effect is around 0.5–20 μL g⁻¹ in foods and about 0.1–10 μL mL⁻¹ in solutions for washing fruit and vegetables (Burt, 2004). Synergism has been observed between carvacrol and its precursor p-cymene and between cinna moldehyde and eugenol. Synergy between EO components and mild preservation methods has also been observed. Some EO components are legally registered flavorings in the EU and the USA. However, undesirable sensorial effects can be a limiting factor and careful selection of type and concentration of EOs according to the type of food must be considered (Burt, 2004).

On the other hand, phenolic compounds have demonstrated remarkable antimicrobial activity. Some of the molecules consist of a single substituted phenolic ring with some hydroxyl groups like cinnamic and caffeic acids (Dorman & Deans, 2000). Others like flavonoids, present three phenolic rings with several hydroxyl groups. The site(s) and number of hydroxyl groups on the phenol group are thought to be related to their antioxidant and antimicrobial capacity and relative toxicity to microorganisms, with evidence that increased hydroxylation results in increased microbial toxicity (Cowan, 1999).

Some studies about the antimicrobial activity of phenolic extract from exotic fruits have been achieved as follows. The antimicrobial properties of mango seed kernel phenolic extracts were investigated. Minimum inhibitory concentrations of the mango kernel extract against 18 species of 43 strains, containing food-borne pathogenic bacteria were determined using the agar dilution method. The mango kernel extracts had a broad antimicrobial spectrum, and was more active against gram-positive than gram-negative bacteria with a few exceptions. These results also indicated that the active component of the Mango Kernel extract was a type of polyphenol (Kabuki et al., 2000). Water infusion of Cocos nucifera L. husk fiber has been used in northeastern Brazil traditional medicine for treatment of diarrhea and arthritis. The crude extract rich in catechin revealed antimicrobial and antiviral activities. Catechin and epicatechin together with condensed tannins (B-type procyandin) were demonstrated to be the components of the water extract from Cocos by-products (Esquenazi et al., 2002).

Mandalari et al. (2007) evaluated a flavonoid-rich extract from the peel of Bergamot citrus fruit, an important byproduct in the processing industry, against different bacteria and yeast. The enzyme preparation pectinase 62L efficiently converted common glycosides into their aglycones from bergamot extracts, and this deglycosylation increased the antimicrobial potency of Citrus flavonoids. Pair wise combinations of eriodictyol, naringenin and hesperidins showed both synergistic and indifferent interactions that were dependent on the test indicator organism. This study concluded that Bergamot peel is a potential source of natural antimicrobials that are active against gram-negative bacteria.

The antimicrobial activities of quince (Cydonia oblonga Miller) fruit have also been evaluated. Chlorogenic acid (5-O-caffeoylquinic acid) was the most abundant phenolic compound in the pulp (37%), whereas rutin (quercetin 3-O-rutinoside) was in the peel (36%). Quince peel extract was the most effective for inhibiting bacteria growth, it seems that flavonoids in the peel in conjunction with chlorogenic acid acts in synergism inhibiting antimicrobial growth (Fattouch et al., 2008).

In this context, the exotic fruits and moreover their byproducts, are promising new sources of phenolic antimicrobial compounds, offering new commercial opportunities to food industries. However, to date there are very scarce information and studies on EOs extracted from exotic fruit byproducts and their application in food products. This is an important area of research that needs immediate attention.

4.3. Colorants

Color is one of the most important quality attributes for the food industry. While synthetic pigments are increasingly rejected by the consumer and are supposed to be unwholesome, proven or not, the acceptance of natural or nature-derived alternatives is promoted by their psychological comprehension of being healthy and of good quality (Stintzing & Carle, 2004). Ever since, natural colors from spices and herbs, fruits and vegetables have been part of the everyday diet of humans.

Fruit byproducts have become into an important source of those pigments and colors, mainly because they present high color stability and purity (Pszczola, 1998). Further criteria toward new viable sources of natural pigments are: good availability, a low price and high yielding material (Stintzing & Carle, 2004). All those characteristics can easily be presented in tropical exotic fruit byproducts. The great activity in this field is supported by data from a survey by Frost and Sullivan (2002), who forecast an expansion of the European color market by 1% per year till 2008, whereas coloring foodstuff is estimated to grow even by 10–15% in the same period.

Anthocyanins are important colorants and can be extracted principally from plant byproducts such as grape pomace or banana bracts (Stintzing & Carle, 2004). Commonly applied preparations obtained from byproducts include red cabbage, red radish, purple sweet potato, black carrot, aronia, cherry, elderberry and blackberry. In general, vegetable sources such as radish (Otsuki, Matsufuji, Takeda, & Goda, 2002; Terahara et al., 1999), purple sweet potato (Terahara et al., 1999), red-fleshed potato (Rodriquez-Saona, Giusti, & Wrolstad, 1999), or red cabbage (Dyrby, Westergaard, & Stapelfeldt, 2001) have been shown to provide a higher percentage of acylated anthocyanins than fruits which reflects in higher tinctorial strength of the respective extracts at food pH (Stintzing & Carle, 2004). Amongst tropical exotic fruits acerola, guajira, jambolao, jussara and acai have shown to be a good source of anthocyanins and other flavonoids (de Brito et al., 2007).

4.4. Byproducts as dietary fiber additives

It is well known that agro industrial byproducts are rich in dietary fibers (DF). DF in byproducts contained attached appreciable amount of colorants, antioxidant compounds or other substances with positive health effects, while some of them, like the oilseed meals, are rich in proteins. The DF additive provides economic benefits to the food, cosmetic and pharmaceutical industries (Ajila et al., 2010). Apart from well known health effects, DF show some functional properties, such as water-holding capacity, swelling capacity, increasing viscosity or gel formation which are essential in formulating certain food products. Formulated food products with high dietary fiber contents are now commercially available. DF incorporated in these products is obtained mainly by cereals. However, the use of byproducts from other fruits and vegetables seems promising, since all these materials are rich in soluble dietary fibers.

Byproducts, rich in dietary fiber are a prize to food processors, especially since consumers prefer natural supplements, fearing that synthetic ingredients may be the source of toxicity. Also, DF possesses remarkable beneficial nutritive and human protective effects, such as prevention of colon cancer and diverse types of cardiovascular diseases (Palafax-Carlos et al., 2010; Spiller, 2005). Incorporation of rich-fiber byproducts, including wheat bran in breakfast cereals, rice bran, sugarcane bagasse, wheat bran in bread and peach dietary fiber concentrate in jam have been investigated by Elleuch et al. (2011). DF from different sources has been included in different functional food such as bar fruits, bread, beverages and other processed foods.
In real terms, the fiber from exotic fruit byproducts may be of great interest to the food technologist. Exotic fruits exhibit the important content of DF. Amongst the exotic fruits with major fiber content includes guava, carambola, maney, mango, sapodilla and raspberries (2.70, 2.78, 3.0, 3.10, 5.31 and 6.50 g/100 g, respectively) (Mahattanatwatee et al., 2006; Nittitham, Komindr, & Nichachotsalid, 2004; USDA, 2010). The food industry can take advantage of the physicochemical properties of fiber to improve the viscosity, texture, sensory characteristics and shelf-life of their products (Elleuch et al., 2011).

Additionally, fiber-rich byproducts may be incorporated into food products as inexpensive, non-caloric bulking agents for partial replacement of flour, fat or sugar, as enhancers of water and oil retention and to improve emulsion or oxidative stabilities (Elleuch et al., 2011). However, the percentage of fiber that may be added to foods is finite, because it can cause undesirable changes in color, taste and texture of foods (Elleuch et al., 2011).

The literatures contain many reports about addition of dietary fiber to food products such as baked goods, beverages, confectionery, dairy, frozen dairies, meat, pasta and soups. Most commonly, dietary fibers are incorporated into bakery products to prolong freshness, thanks to their capacity to retain water, thereby reducing economic losses and at the same time to enhance digestion. Muffin batter supplemented with peach dietary fiber, and cake dough enhanced with prickly pear cladode fiber at levels up to 5% were deemed as acceptable as the control, based on sensory scores reported by consumer panelists (Ayadi, Abdelmaksoud, Ennouri, & Hamadi, 2009). Other studies, mainly on breads for special diets, have shown that the addition of dietary fiber from maize and oat in gluten-free formulations gave breads with significantly higher loaf volume and crumb softness, compared to the control non-fiber gluten-free bread, improving their acceptability (Sabanis, Lebesi, & Tzia, 2009).

The use of fibers in dairy products is also widespread (Elleuch et al., 2011): e.g. fiber improves the texture of ice cream, providing a uniformly smooth bulk, desirable resistance to melting, and improves handling properties primarily by hindering crystal growth, as temperature fluctuations during storage (Regand & Goff, 2003). Soukoulis, Lebesi, and Tzia (2009) showed the potential use of dietary fibers (oat, wheat, apple and inulin) as crystallization and recrystallization controllers in frozen dairy products.

Antioxidant capacity is another important property of DF that is given by the presence of different antioxidant linked compounds. Antioxidants associated with the dietary fiber matrix are substances that are not detected in the usual analytical procedures for either dietary antioxidants (targeting antioxidants extracted by aqueous organic solvents) or DF (targeting carbohydrates and lignin) quantification. However, these antioxidant compounds make up a substantial portion of the dietary antioxidant capacity; they are not minor constituents of DF, and as such they may contribute significantly to the health effects attributed to DF and dietary antioxidants (Saura-Calixto, 2011).

In this perspective, exotic fruits and their byproducts could be seriously taken into consideration to be utilized as valuable sources of DF useful for several applications in the food industry. However, it is necessary to advance the practices of DF extraction as DF from exotic fruits is extracted and may successfully be implemented in diverse innovative applications in food products. Utilization of fibers from exotic fruit byproducts would not only open new businesses and profits, but would also contribute to give alternate uses to the huge quantities of the byproducts wasted in the food industry.

5. Extraction of bioactive compounds from tropical exotic fruit byproducts

During the extraction procedures of bioactive compounds from tropical exotic fruit byproducts several operational units and conditions can be applied. Milling, solvent extraction and drying are amongst the main operations that can be used. Wet milling is necessary to facilitate and improve the yield of the following extraction steps. Too small particle size of the raw material, however, will result in retention of high amounts of water and will cause difficulties in pressing. Hammer mills are preferred to colloidal mills, in order to obtain a good control of particle size.

Organic solvents are used for the extraction of carotenoids, and acetone results in the highest yield compared to ethanol, petroleum ether, and hexane (Calvo, 2005). It is important to consider that acetone is an unrestricted solvent permitted for use in the preparation of food ingredients in the European Union (Marriott, 2010). In addition, if fresh, wet raw material is used, initial washing with water removes most free sugars and other soluble compounds, like flavonoid glycosides, and increases the purity of the extracts. A sequential washing with acetone removes water and facilitates carotenoid extraction in the following steps. Successive extractions are needed for quantitative recovery (Oreopoulou & Tzia, 2007). The extracted carotenoids may be obtained as a crude pigment, after solvent evaporation at low temperature, if preceding washings were accomplished. Alternatively, a purification step is needed by solvent–solvent transfer to hexane, however, special attention must be paid to the use of this solvent considering that it is restricted in the preparation of food ingredients (Oreopoulou & Tzia, 2007).

Tocopherols and flavonoids and related compounds like coumarins, cinnamic acid derivatives, and chalcones; phenolic diterpenes; and phenolic acids are isolated by solvent extraction (Oreopoulou & Tzia, 2007). Nonpolar solvents (hexane, petroleum ether) can be used for the recovery of tocopherols and certain phenolic terpenes. Ethyl ether and ethyl acetate are very efficient for the recovery of flavonoid aglycons, low-molecular-weight phenolics, and phenolic acids. Solvents of higher polarity (ethanol or ethanol–water mixtures) additionally can extract flavonoid glycosides and higher molecular weight phenolics, resulting in higher yields of total extracted polyphenols (Oreopoulou & Tzia, 2007). It is important to point out that ethyl acetate and ethanol are unrestricted solvents permitted for the use in the preparation of food ingredients (Marriott, 2010). However, the economic point of view must be considered and the generated effluents have to be treated. Therefore several solvents must be evaluated to yield the higher amount of molecules of interest and to decrease concomitantly the treatment costs.

Isolation of DF from tropical exotic fruit byproducts can follow the recovery of other constituents, like carotenoids, antioxidants, or proteins (Palafax-Cardos et al., 2010). Depending on the process followed the dietary fiber product has a different composition, and therefore different functional and nutritional properties. Pectin belongs to dietary fibers and has excellent gelling properties. Pectin extraction is accomplished by the use of mineral acids, usually hydrochloric or nitric acid (Oreopoulou & Tzia, 2007). The extract is separated from the solid residue and pectin is precipitated by the addition of ethanol or AICl solution. Purification of the precipitated pectin involves washing with acidified, alkaline, and finally neutral alcohol. Pectin extraction may follow a carotenoid and antioxidant recovery step or may be applied to the raw material just after juice extraction. In the current practice pectin is produced from the dried coarsely ground raw material, which remains wasted after juice extraction (Oreopoulou & Tzia, 2007). However, it would be interesting to contemplate the possibility of enzymatic extraction of pectin, and other pectic oligosaccharides that are known to reduce coliform adhesion on human gut, and to exhibit various effects on the human microflora, and on cancer cells.

6. Conclusion

We conclude that exotic fruit byproducts represent a potential source of natural food ingredients. However, no major exploitation of these sources was appreciated in this context; there is a great
opportunity for agribusiness in this area. These fruits represent an opportunity for local growers to gain access to special markets where consumers lay emphasis on exotic character and the presence of nutrients capable of preventing degenerative diseases. In addition, the phytochemicals in these fruits could have greater application in the food industry for increasing the stability and shelf life of food products. We can consider that several studies on the treated topic must be undertaken: toxicological analysis of bioactive extracts, studies on the metabolism of bioactive compounds, their bioavailability and bioaccessibility, and the sensorial and nutritional aspects of the food products added with bioactive compounds from tropical exotic fruits. In addition the analysis of the economic availability of the extraction processes and marketing of natural bioactive extracts must be contemplated. In this perspective, the integral exploitation of the entire plant tissue could have economic benefits to producers and a beneficial impact on the environment, leading to a greater diversity of products directed mainly to human usage. These new products represent a new class of functional foods that has not been completely exploited and that could also contribute to different health benefits to consumers.

References


