Review

# Agro-industrial fruit co-products in Colombia, their sources and potential uses in processed food industries: a review

Co-productos de origen agroindustrial fruticola en Colombia, procedencia y sus usos potenciales en matrices alimenticias procesadas

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***Abstract***. *Fruit agribusinesses generate large amounts of by-products with diverse characteristics that are inherent to the fruits from which they come, which are a source of great use potential because their compositions include molecules that are currently of high interest (antioxidants and dietary fiber). It is clear that, without correct handling and disposal, theses fruits present a problem due to the environmental pollution that large quantities of residues can generate. Although there are varied uses for agro-industrial co-products, this review focused on the potential uses that co-products could have in different processed food matrices. In this sense, this paper led to the revelation that one of the principal objectives of the reviewed research was to condition co-products for use in processed foods in an attempt to take advantage of the bio-active compounds they contain, principally the natural antioxidant activity, which especially enjoys acceptance by consumers of processed foods.*

**Key words:** Agro-industrial by-products**,** environmental pollution, food industry branches, fruit agribusiness, bioactive compounds.

***Resumen***. La agroindustria frutícola genera grandes cantidades de subproductos *con características muy diversas inherentes a los frutos de los cuales provienen y así como son una fuente con un potencial de aprovechamiento muy grande debido a que en su composición se pueden hallar moléculas en las cuales se tiene un alto interés hoy en día (antioxidantes y fibra dietaria), es claro que sin una correcta manipulación y disposición de los subproductos estos corren un alto riesgo de volverse un problema debido a la polución ambiental que grandes cantidades de subproductos pueden generar. Aunque podrían existir usos muy variados para los subproductos agroindustriales éste documento hace una revisión enfocada en los potenciales usos que los co-productos podrían tener en diferentes matrices alimenticias procesadas; en este orden de ideas este documento permitió reconocer que uno de los principales objetivos en muchas de las investigaciones consultadas es el de poder acondicionar los co-productos para poder hacer la inclusión de éstos en alimentos procesados, buscando aprovechar los compuestos bio-activos presentes, principalmente por su actividad antioxidante de origen natural la cual goza de especial aceptación entre los consumidores de alimentos procesados.*

**Palabras claves:** Subproductos agroindustriales, contaminación ambiental, tipos de industrias alimenticias, agronegocios frutícolas, compuestos bioactivos.

In Colombia, there are nearly 48 perennial and non-perennial fruit species with different degrees of importance to the fruit sector, depending on their economic and social impact (Reyes *et al.*, 2006). Within the perennial category, the first 5 species that cover the largest cultivated area are the orange (*Citrus sinensis*), mango (*Mangifera indica*), avocado (*Persea americana*), guava (*Psidium* spp.) and tangerine (*Citrus* spp.), comprising 44.8% of the cultivated area (or 98,837 ha) intended for fruit production, not including domestic plantain and banana production; furthermore, these fruit species had production equaling 330,000, 222,000, 225,000, 80,000, and 104,000 t per year, respectively (Agronet, 2013). On the other hand, the transient crops or non-perennial species had a greater area of production (ha) (without taking into account species such as the plantain and banana); for example, the pineapple (*Ananas comosus*), blackberry (*Rubus ulmifolius*), tamarillo fruit (*Solanum betaceum*) and lulo (*Solanum quitoense*), which comprise 23.48% of the cultivated area, or 51,805 ha, with production that reached 480,000; 88,000; 131,750 and 58,000 t per year, respectively (Agronet, 2013). The remaining 31.72% ha, dedicated to fruit production were for other transient and perennial crops of lesser importance (Reyes *et al.*, 2006). The production of *Musa* genus fruits in Colombia, according to the FAO (2013), reached 2,815,050 and 2,034,340 t per year for plantain and banana with the use of 345,109 and 80,518 ha, respectively.

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*sinensis*), mango (*Mangifera indica*), avocado (*Persea americana*), guava (*Psidium* spp.) and tangerine (*Citrus spp*.), comprising 44.8% of the cultivated area (or 98,837 ha) intended for fruit production, not including domestic plantain and banana production; furthermore, these fruit species had production equaling 330,000; 222,000; 225,000; 80,000 and 104,000 t per year, respectively (Agronet, 2013). On the other hand, the transient crops or non-perennial species had a greater area of production (without taking into account species such as the plantain and banana); for example, the pineapple (*Ananas comosus*), blackberry (*Rubus ulmifolius*), tamarillo fruit (*Solanum betaceum*), lulo (*Solanum quitoense*), papaya (*Carica papaya*) and watermelon (*Citrullus lanatus*) which comprise 23.48% of the cultivated area, or 51,805 ha, with production that reached 480,000, 88,000, 131,750; 58,000; 170,000 and 150,000 t per year, respectively (Agronet, 2013). The remaining 31.72% of the ha dedicated to fruit production were for other transient and perennial crops of lesser importance (Reyes *et al*., 2006). The production of Musa genus fruits in Colombia, according to the FAO (2013), reached 2,815,050 and 2,034,340 t per year for plantain and banana with the use of 345,109 and 80,518 ha respectively. The fruit species mentioned above generate large amounts of waste, both at the harvest and the agro-industrial levels in Colombia and worldwide, because a lot of these fruit species correspond to fruit crops with high global production, as is the case of the banana, plantain, watermelon, orange, mango, pineapple, papaya, and avocado FAO (2013). Other fruits recognized as important crops in the global production as apple (*Malus domestica*), grape (*Vitis* spp), peach (*Prunus persica*) and lemon (*Citrus limon*) wich are reported 69,511975; 67,16,255; 20,528,283 and 13,933,864 t per year, respectively (FAO, 2012); in Colombia these fruits are produced in low quantities in respect to global production, in this case 1,200; 21,400; 20,800 and 81,000 for apple, grape, pech and lemon respectively (Agronet, 2013).

There are also fruit crops, such as the apple (*Malus domestica*), grape (*Vitis spp*.), peach (*Prunus persica*), and lemon (*Citrus lemon*), that are recognized around the world for their high production, for which the FAO (2013) reports 69,511,975, 67,116,255, 20,528,283, and 13,933,864 t, respectively. Colombia produces low quantities of these fruits, representing a very small percentage of global production, with 1,200, 21,400, 20,800, and 81,000 t for the apple, grape, peach and lemon, respectively (Agronet, 2013). These numbers demonstrated the fact that cultivated fruit production in Colombia reaches several million t and that it has been reported that up to 70% of a fruit's weight can correspond to the fractions composed of the seeds, peels and pulp remnants (Ayala *et al*., 2011). In this sense, this review aimed to discover how the co-products of some of the more representative fruit agro-industries of Colombia are generated along with uses that have been proposed by different research from around the world, which has mainly focused on revaluing and taking advantage of co-products, searching not only for a better economic yield specifically for the links of value agro-chins that correspond to the production and industrialization sectors but also for an offering of different types of solutions for other industries, such as chemical-pharmaceutical and processed food industries, in which phytochemicals have been developing a continuously more important role in recent years due to the fact that they correspond to natural molecules that are highly appreciated by consumers who are increasingly more conscious of products that can be found in different markets (Silva *et al*., 2014).

**Generation of agro-industrial by-products**

Due to the fact that many harvest products are not directly consumed by consumers without being submitted to processing to remove the non-edible parts, they generate a bulky amount of byproducts, such as peels and seeds (Ayala *et al*., 2010) and, in some cases, the excess residues are more than the product itself (Ayala *et al*., 2011; Lousada *et al*., 2007), as seen in pineapple, papaya, mango, plantain, banana, apple, grapes, citrus fruits, and guava, among others; of which natural or preserved pulps and derivatives, such as juices, are in high demand (Ayala *et al*., 2011; Schieber *et al*., 2001b).

The use of byproducts is difficult due to the bacterial spoilage of these materials, thereby limiting their potential, as well as the high cost of drying or storage (Schieber *et al*., 2001b). However, several authors still argue that the use of co-products as raw materials is a very inexpensive source of resources and/or substrates for biotechnological products, such as antioxidants, enzymes, etc. (Dhillon *et al*., 2011; Elleuch *et al*., 2011; Grigorevski De Lima *et al*., 2005; Schieber *et al*., 2001a). The fruit and vege production of various countries has seen, over the last few years, an increasing trend, generating more waste and by-products at harvest or when selling them in different markets. For example, in the case of Kampala, Uganda (a city of just 1,200,000 inhabitants), up to 18,000 t of waste are produced per year (including, mainly from the banana (*Musa acuminata*), potato (*Ipomoea batatas*), and nakati (garden eggs) (*Solanum aethiopicum*)), of which only a small portion is used for compost and animal feed, while most is not collected for different reasons, causing serious environmental problems and missed opportunities for potential uses due to the probability of higher contamination with other solid wastes (Katongole *et al.*, 2008).

The waste and byproducts of fruits and vegetables are highly heterogeneous materials because they come from different plants with different botanical origins and, additionally, during the processing of the different parts of the fruits, these byproducts might be exposed to different physical and chemical treatments that seek to remove the "economically important part". These operations affect the matrix of waste and byproducts, wherein non-starch polysaccharides, plus lignin, constitute a significant portion of the weight on a dry basis. The out-coming froth of vegetables is rich in dietary fiber and other components (Serena and Knudsen, 2007).

The aforementioned upticks in the production of fruits and vegetables are mainly attributed to the use of better techniques for handling raw materials, such as preservation, marketing and distribution systems. Furthermore, consumers have increased their demand for better sensory properties and the awareness of the benefits of consuming fruits and/or vegetables and their derivatives has also increased (Gonzalez *et al.*, 2010; Schieber *et al.*, 2001b).

The production of large amounts of waste and byproducts in agro-industries leads to great economic losses due to environmental requirements, which exacerbate the low-margin of profitability seen in the food industry and the high cost of raw materials, which should make the prudent use of residues attractive to the agro-industry in order to increase profitability (Akkerman and Van Donk, 2008).

This review took into account some of the more important fruits at the Colombian and global levels, considering the production and traditional data of the Colombian market along with reports from other countries because, currently, data on the domestic production of agro-industrial fruit co-products are practically nonexistent. In terms of the establishment and production of co-products for use in processed foods, all of the reviewed papers agreed with the use of processes that principally consist of a reduction in the particle size in order to facilitate manipulation, subsequent use, and drying in order to sufficiently decrease the moisture values to allow storage for extended periods of time (Ayala *et al.*, 2011; Khalili *et al.*, 2012; Schieber *et al.*, 2001b; Serena and Knudsen, 2007; Silva *et al.*, 2014; Viuda *et al.*, 2010a).

**Citrus fruits (Orange, lemon, tangerine)**

Marín *et al.* (2007) considered citrus fruit crops to be the most abundant in the world because, when crops of orange, lemon, and tangerine are included, they can reach a global total of 88 x $10^6$ t; but, there are fruit crops that can exceed this amount, such as the watermelon and banana, with global productions of up to 99 x $10^6$ and 102 x $10^6$ t, respectively, FAO (2013). However, the production of citrus fruits represents one of the largest worldwide and an enormous source of byproducts because 50% of the total amount of produced fruits are for processing and used primarily to get juice, jams and preserves, among others (Marín *et al.*, 2007).

Fruits intended for processing (mainly for the production of juices, canned fruits, jams and extracts of essential oils and flavonoids) represent 98% of the total of harvested fruits worldwide. So, it can be inferred that the quantity of co-products generated from the agribusiness of citrus fruits would be a great source of potential resources for the pharmaceutical and food industries (Fernández *et al.*, 2007; Izquierdo and Sendra, 2003; Romero *et al.*, 2011; Viuda *et al.*, 2010b). Other authors have reported the same (Annadurai *et al.*, 2002; Benoit *et al.*, 2006) for the residues of agro as potential low-cost substrates to get polyphenol-family molecules. Researchers have evaluated the antioxidant capacity of fruit residues, such as lemon, grapefruit and orange, in trapping free-radicals, revealing in all cases a better activity of the cellulose from the peels than the decorticated fruits and, also, pointing out that these types of resources are sources of polyphenols (Table 1). This same trend is also seen in fruits for highly valued components such as the total dietary fiber and the components: soluble and insoluble dietary fiber (Gorinstein *et al.*, 2001).

The dietary fiber from the co-products of the citrus fruits (mainly from the orange juice industry) has also been subjected to extensive research on its inclusion in food matrixes, such as in meat products. Various meat products, such as mortadella (Viuda *et al.*, 2010a), fermented salami (Fernández *et al.*, 2008), dry cured sausage (Fernández *et al.*, 2007), hamburger (Aleson *et al.*, 2005; Turhan *et al.*, 2005) and Bologna, a type of sausage, (Fernández *et al.*, 2004b) among others, have been used with these co-products because they contain significant levels of dietary fiber, complex carbohydrates, or bioactive compounds, such as polyphenols.

Ingredients with significant levels of complex carbohydrates help consumers to increase their intake of dietary fiber, according to the quantities recommended by some international entities which range between 25 g and 38 g per day for women and men, respectively, or 14 g per 1,000 kcal consumed (American Dietetic Association, 2008; Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, 2005).

**Apple**

The use of waste and/or agro-industrial co-products is a major economic aspect that could mitigate environmental impacts (Dhillon *et al.*, 2011) in countries such as Germany, where apple juice is one of the most popular fruit juices amongst the population and the production of juice reaches 700,000 t of apples per year and generates 250,000 t of co-products (Endreß, 2000) (mainly peels, seeds, stems, pulp and juice residue), which could be added-value products because some authors (Endreß, 2000; Rha *et al.*, 2011; Schieber *et al.*, 2003; Sudha *et al.*, 2007) consider these types of residues as a source of fiber, polyphenols and pectin; of which pectin is used in food products as gelling agents, emulsifiers and stabilizers, while polyphenols have gained importance due to their antioxidant properties and can be found in co-products of the apple industry, a low-cost material (Lu and Foo, 2000).

Dietary fiber is also considered very useful due to its inclusion in food matrix processes to improve consumer perception as a "natural product" (Viuda *et al.*, 2010a). In addition, dietary fiber is considered a functional ingredient (Fernández *et al.*, 2004a) and has several benefits, such as the prevention of certain chronic diseases. In addition, the intake of dietary fiber can be increased without generating radical changes in eating habits in consumers (Viuda *et al.*, 2010b) when mixed with other foods.

The composition of agro-industrial residues might be highly variable, although it is claimed that some co-products, for example apple residues, do not have an ideal use (Schieber *et al.*, 2001b); even so, other authors have tried to come up with alternative solutions for the use of these wastes and to produce citric acid by fermentation with *Aspergillus niger*, using apple co-products as a substrate (Dhillon *et al.*, 2011). The residues (mainly peels) from the apple juice industry are a rich source of polyphenols (Table 1), while the juice obtained in the processing stage also has levels of polyphenols, but in a lesser amount (Schieber *et al.*, 2001a). Some phenolic compounds that have been identified in agro-industrial wastes are: procyanidins, quercetin, catechin, phloretin and hidroxycinnamatos (Schieber *et al.*, 2001a). The phenolic compounds that have been identified in the co-products of apples, from the apple agro-industry, are considered similar to natural antioxidants, which can provide health benefits when included in human diets. Moreover, this type of molecule also has anti-allergic, anti-microbial and anti-inflammatory properties (Ajila *et al.*, 2007), as well as preventive activities and/or modulations of chronic diseases, such as arthritis and cancer (Fernández *et al.*, 2004c).

**Plantain and banana**

Bananas and plantains produce large amounts of co-products, although only a small part of bananas and plantains actually go into production lines. This is because the peel of these products, which includes the non-edible part, is between 30% and 40% of the fruit weight (Schieber *et al.*, 2001b; Tchobanoglous *et al.*, 1993). These fruits are also considered to be part of the larger harvests in the world, since they are produced in nearly 100 countries (Aurore *et al.*, 2009). According to the Food and Agriculture Organization - FAO (2014), 102 million t of bananas (mainly of the *Musa* species *Musa AA* and *AAA*) and 36.5 million t of plantains (mainly species of *Musa AAB, ABB Musa* and *Musa BBB*) were produced worldwide according to reports from Aurore *et al.* (2009), (2014); Fao (2014). Some of the potential uses for residues generated from *Musa* genus fruit species are animal feed, methane production, pectin production, biomass production, adsorbents for water purification and ethanol production, among others (Annadurai *et al.*, 2002; Clarke *et al.*, 2008; Essien *et al.*, 2005; Happi *et al.*, 2008).

Someya *et al.* (2002) reported that residues from the fruits of the *Musa* genus are sources of polyphenol-type antioxidants (Table 1), such as gallocatechin found in concentrations of 907 mg $g^{-1}$ 100 of dried peel. These molecules have also been reported by Alarcón *et al.* (2014), who used the bio-active compounds found in an intermediate food product obtained from a plantain peel co-product (*Musa AAB*) as an ingredient in order to mitigate the lipid and protein degradation in the model system of a meat product and obtained positive results for the decrease of the protein degradation rate of the meat product. In previous studies, these authors evaluated technological functional properties in terms of the capacity to retain water, the capacity to absorb oil, the capacity to absorb water and the capacity to absorb organic molecules found in the intermediate food product obtained from plantain peels (*Musa AAB*) in order to determine the usefulness of including this raw material as an ingredient in the formulation of processed meat products, reporting that this raw material contains relatively high values for the measured values as compared to other sources of dietary fiber obtained from co-products of different fruit products (Alarcón *et al.*, 2013). Other molecules found in and reported for this type of residue included phenols, such as dopamine (known as a neurotransmitter in humans that is involved in endocrine function) and L-dopa (a product of endocrine disorders that cause movement disorders in people (Oak *et al.*, 2000)). These molecules also showed antioxidant activity and the ability to scavenge free-radicals (González *et al.*, 2010). Another important component found in the peels of plantains and bananas is dietary fiber, which, according to data reported by Happi *et al.* (2007), can range between 32.9% and 49.7% on a dry weight basis depending on the ripening state (taking into account the color of the peel, with green representing an immature state and yellow the ideal state of maturation for consumption) and the type of banana or plantain. Other components change concentrations during the ripening of the fruit, such as starch, which sees a reduction of between 0.1% and 39.3% on a dry weight basis due to the action of several endogenous enzymes,

**Table 1.** Concentration of polyphenols in different agro-industrial residues.

| Resource | Concentration of polyphenols | Reference |
|---|---|---|
| Orange peel (*C. aurantium* cv. Canoneta) | 0.51±0.03 mg EAG/100g MS | Garau *et al.* (2007) |
| Orange peel (*C. sinensis*) | 0.37±0.03 mg EAG/100g MS | Li *et al.* (2006) |
| Apple waste | 0.15 mg EAG/100g MS | Ajila *et al.* (2011) |
| Tangerine peel (*C. reticulata*) | 0.61±0.08 mg EAG/100g MS | Li *et al.* (2006) |
| Lemon peel (*C. limon*) | 190±10.6 mg AC/100g fresh fruit | Gorinstein *et al.* (2001) |
| Orange peel | 179±10.5 mg AC/100g fresh fruit | Gorinstein *et al.* (2001) |
| Apple peel | 169 mg ECG/100 g MS | Wolfe and Liu (2003) |
| Unripe mango peel | 0.92±0.03 mg EAG/100g peel extract | Kim *et al.* (2010) |
| Ripe mango peel | 0.70±0.046 mg EAG/100g peel extract | Kim *et al.* (2010) |
| Kernel of mango seed | 112 mg EAG/100g dry seed | Abdalla *et al.* (2007) |
| Ripe banana peel | 1.8 g±0.1 g EAG/100g MS | González *et al.* (2010) |
| Banana peel | 907 mg C/100g MS | Someya *et al.* (2002) |
| Avocado seed | 88.2±2.2 mg EAG/g lyophilized sample | Soong and Barlow (2004) |
| Guava seed | 72 to 176 mg EAG/100g MS | Castro *et al.* (2010) |
| Sarcotesta from papaya seeds | 2.34 to 2.78 mg EAT/100g methanol extract | Tokuhisa *et al.* (2007) |
| Sclerotesta from papaya seeds | 2.02 to 3.68 mg EAT /100g methanol extract | Tokuhisa *et al.* (2007) |
| Papaya peel | 3.44 mg EAT/100g of methanol extract | Khalili *et al.* (2012) |

EAG: gallic acid equivalents; EAT: tannic acid equivalents; ECG: equivalent of cyanidin3-glucoside, C: catechin, CA: Chlorogenic acid such as amylases, glycosidases, phosphorylases, sucrosesynthetase and invertase; this action is affected in the same way as dietary fiber with respect to the maturation and type of fruit (Adão and Glória, 2005). Similarly, Adão and Glória (2005) and Happi *et al.* (2007) also reported that the levels of soluble sugars presented a significant increase, mainly for monosaccharaides such as glucose and fructose; dimers, such as sucrose, may increase during maturation development up to Day 14 of the post-harvest period, but lowered afterwards, when the monosaccharaides found their highest points at 21 to 35 days of the post-harvest period.

During maturation, fruits also present a phenomenon of water migration from the peel to the pulp; this generates, along with starch changes, other desirable modifications in the appearance and the perception of softness in the pulp at the time of consumption (Mota *et al.*, 1997).

**Mango**

The mango (*Mangifera indica*) enjoys worldwide popularity, especially in the European market where they are imported from developing countries (mainly Brazil and Peru) at an estimated 231,613 t (Food and Agriculture Organization, 2009). The mango is a fruit that generates one of the largest amounts of co-products because the peels and seeds constitute up to 60% of the fruit (Cerezal *et al.*, 1995). Scientific studies have reported that mango co-products are a source of dietary fiber, carbohydrates, oil and phenolic compounds (Abdalla *et al.*, 2007; Maisuthisakul and Gordon, 2009; Vergara *et al.*, 2007). The co-products generated from processing mango (composed of peels (10-20%), seeds (10-25%) and pulp remnants) are a source of potential resources, but their usage depends on the mitigation of the environmental problems linked to poor disposal of this type of material. Besides the aforementioned aspects, about 20% of mango production goes to processing for the creation of products such as purées, nectars and canned products, among other things.

The use of mango co-products allows for the creation of different products; one report stated that mango peels have bioactive compounds such as polyphenols, carotenoids, and dietary fiber (Ajila *et al.*, 2007), while the seed has a kernel in its interior and is a resource for oil production. A study performed by Abdalla *et al.* (2007) reported on the composition of the almond and discovered it had high levels of unsaturated fat (55%), mainly consisting of fatty acids such as oleic (46.1%), followed by linoleic (8.2%) and linolenic acid (1.2%).

The search for bioactive compounds in fruits, such as the mango, has led to the characterization of mango peels in order to assess the levels of polyphenols and carotenoids in the residues of the peels.

Based on the above, Ajila *et al.* (2007) reported that the levels of polyphenols in mango peels, for the raspuri and the badami varieties, have fluctuating figures, from 37.92 to 73.88 mg $g^{-1}$ for dried, mature mango peels and 33.31 to 46.31 mg $g^{-1}$ for dried, unripe mango peels; these quantities match the ethanol extracts of a mango peel. In terms of the carotenoids for the same varieties, the researchers found that, contrary to the polyphenol levels that showed lower figures when the fruit was in advanced stages of maturation, the carotenoids had their highest levels in the mature state; these data reflected between 365 and 493 µg $g^{-1}$ for dry mango peels from unripe fruits and between 1,400 and 3,945 µg $g^{-1}$ for dry mango peels from ripe fruits (Ajila *et al.*, 2007).

As for the phenolic compound profile, Berardini *et al.* (2005) and Ajila *et al.* (2010) reported that the Tommy atkins mango presents a profile with components such as manguiferina, isomanguiferina, manguiferina gallate, isomanguiferina gallate, and quercetin (with residues of galactose, glucose, xylose, arabinopyranose, arabinofuranose, nammnosa, gallicacid and ellagicacid, among others).

There are different bioactive compounds in mango peels and the level of dietary fiber can fluctuate between 44% and 78% of the total dietary fiber, depending on the ripeness for the varieties raspuri and badami, which also have a higher level of total dietary fiber in their more mature states and vice versa (Ajila *et al.*, 2007). There are studies that showed the potential use of mango residues in common food products, such as cookies.

Ajila *et al.* (2008) reported there were increased levels of dietary fiber, carotenoids and polyphenols in products such as biscuits when adding mango peel flour with 51.2% dietary fiber, 96 mg $g^{-1}$of polyphenols and 3,092 µg $g^{-1}$of carotenoids. Mango peel flour was added to the food matrix of biscuits at levels of up to 0.5, 7.5, 10, 15 and 20%. After these additions, the authors reported significant changes in the reduction of the diameter and thickness of the cookie type products when 15 and 20% were used, which were attributed to a dilution effect of the gluten; in the same way, these two addition levels presented a significant increase in resistance to breakage of the product structures and also contributed to the expansion of the structure formed by the gluten in the food matrix.

**Avocado**

The avocado is one of the most important perennial crops in Colombia, ranking third in production with 212,500 t (Reyes *et al*., 2006), and a representative crop worldwide with 3,891,626 t FAO (2013). This crop is ranked 21 for the most cultivated fruit and generates a great amount of co-products, regardless of the different forms of exploitation (for consumption in fresh and processed fruit). These residues generate a quantity equal to the 12 to 16% peel and 14 to 24% seeds, in terms of the fresh fruit weight (Bressani, 2009); thus, it is necessary to use this type of co-product. In accordance with the above, Bora *et al*. (2001) conducted a study to examine the seed of the avocado and identify the potential uses that its composition affords: 56.04 ± 2.58% humidity, 1.87 ± 0.31% fat, 1.95 ± 0.16% raw protein, 1.87 ± 0.24% ash, 5.10 ± 1.11% fiber and 33.17 ± 2.73% carbohydrates, all calculated by differences. Other studies for the description of the avocado seed showed that the polyphenol content has gallic acid at 88.2 ± 2.2 mg $g^{-1}$ of a lyophilized sample, which would explain the antioxidant capacity that the water-ethanol extract (50:50) of an avocado seed has. These figures are similar to the antioxidant capacity of the ascorbic acid at 236.1 ± 45.1 μmol $g^{-1}$ for a fresh sample and 725 ± 39.4 μmol $g^{-1}$ for a lyophilized one (Soong and Barlow, 2004).

As for the avocado, Cano *et al*. (2007) conducted a study to identify the compounds presented in the peel of a Hass avocado, identifying essential oils, such as ciclohexasiloxanos, Copaene, caryophyllene, germacrenos D and B, and fatty acids, such as erucic, oleic, stearic and palmitic acids, among others. The authors also argued that some of these compounds are reliant on the maturation state, when, at day 21 after the harvest of the fruit, most of these compounds were identified.

One study on the use of co-products from avocado peels and seed extracts from Hass and Fuerte avocados showed that the existence of bioactive compounds in avocado co-products might be used in meat food matrixes, such as the Patty type, in order to prevent the deterioration of food products during cold storage. These bioactive compounds from the extracts of avocado peels and seeds allowed for a reduction with significant differences ($p<0.05$) for malonaldehyde in meat products, as compared to meat products that did not contain the extracts; this indicated greater stability of the fats (Rodríguez *et al*., 2011). Moreover, they inhibited protein degradation because a measurement of the carbonyl groups in the amino-acid residues indicated an oxidative change and they were much lower ($p<0.05$) in the meat products with avocado peels and seed extracts added than in the control treatment. Furthermore, the Hass avocado extracts showed a greater effect than the Fuerte avocado extracts in the inhibition of protein oxidation (Rodríguez *et al*., 2011).

**Guava**

The guava is a fruit grown in tropical and sub-tropical areas such as Brazil, Colombia, South Africa, Peru, Ecuador and India, amongst other countries. It is also a fruit in high demand in North America, Europe and the Middle East (Corporacion Colombiana Internacional, 2013).

The consumption of fresh or processed guava in order to create products such as juice, nectar, purée, jam and jelly (Kashyap *et al*., 2001) generates residues such as peels, seeds, and small remnant pulp portions (Thongsombat *et al*., 2007). These co-products have been studied together because they are produced in the guava process industry without separating the components (waste of pulp, seeds and peels).

El-Deek *et al*. (2009a) reported bromatology type characteristics associated with guava residues, such as a humidity of 5.9%, raw protein of 9.08%, ethereal extract of 10%, raw fiber of 39.5%, ash of 2.55%, and 32.97% nitrogen-free extract on a dry weight basis. This research aimed to test these residues at levels of inclusion of 2%, 4%, 6% and 8% in a diet specifically formulated to feed broilers in the last phase of their growth cycle (from 30 to 42 days of age). They demonstrated that there was not a significant effect ($p>0.05$) from the guava co-products with the different levels of inclusion in the diet on the final weight of the animals or on the weight of the chicken carcasses; however, the abdominal fat in the broilers was effected when 8% guava co-products were used, generating lower levels of abdominal fat. Therefore, El-Deek *et al*. (2009a) concluded that the guava co-products used in the research were appropriate for the diet of chickens at the end of the growth cycle.

El-Deek *et al*. (2009b) also had similar results for the bromatological composition of guava residues and reported for the same material (waste of pulp, seeds and peels) the following data: moisture content of

6.94%, raw protein of 9.78%, ethereal extract of 4.52%, raw fiber of 40%, nitrogen-free extract of 33.14%, and ash of 5.62% on a dry basis. Furthermore, the guava co-products were used to fed animals, such as laying hens from 32 to 48 weeks of age. The authors reported that there were no adverse effects using this material in the diet of the hens; thus, the authors concluded that the dry residues could be included at up to 15% in the diet of animals with the same physiological and environment characteristics. In regards to guava seeds, several studies have reported that they could be a non-conventional source of fat, but the fat content is much lower than that of oilseeds, ranging between 4.2% and 14.1%, and depends on the type of solvent used for the extraction. In addition, the highest quantity of product was obtained with the use of a mixture of super critical $CO_2$ and ethyl acetate. The report also stated that earlier methods of oil extraction had fatty acids such as palmitic, stearic and linoleic acid (Castro *et al.*, 2010).

Moreover, there are other reports on the polyphenol content and the antioxidant capacity that are found in guava seeds: the level of polyphenols are equal to gallic acid figures, between 72 and 176 mg 100 $g^{-1}$ of crushed and dry seeds, which are directly related to the antioxidant capacity because, with a greater quantity of polyphenols, there is a greater oxidant capacity, ranging from 0.3 to 1.3 mmol $mg^{-1}$ trolox of gallic acid (estimation with the DPPH method), where the higher antioxidant capacity figures were associated with the higher levels of polyphenols and vice versa (Castro *et al.*, 2010).

Packer *et al.* (2010) assessed the antioxidant capacity of guava co-products (material composed of peels and seeds) using ethanol extracts with residues; the solvent was removed through a rotary-evaporator at a temperature of 50°C and 2 g (equivalent of 2 g of polyphenols) of this product were mixed with 50 mL of water, called an aqueous extract of guava nuts and seeds by the authors. Then, they applied the aqueous extracts to chicken meat (thighs), without bones or skin, at dosages to generate 20, 40 and 60 mg $kg^{-1}$ of polyphenols of meat to compare the three dosages of polyphenols and assess which might be more effective in preventing lipid oxidation.

**Papaya**

There is high production and consumption of this fruit worldwide, with 11,568,346 t FAO (2013), and Colombia contributes about 145,000 t (Agronet, 2013). This high production in turn generates a large amount of co-products, which are normally considered waste and used for animal feed, but most of the time, they are not well-managed or given adequate treatment and have become a focus of phytosanitary diseases that represent a risk to human health (Chaiwut *et al.*, 2010).

Papaya co-products mainly consist of peels and seeds, the latter being a potential source of polyphenol compounds according to the research of Tokuhisa *et al.* (2007), who reported that the sarcotesta (outermost layer of integument with soft and fleshy consistency) and the esclerotesta (hard cover) of papaya seeds are rich in polyphenols. The sarcotesta presented between 2.34 and 2.78 mg tannic acid equivalent/100 g of methanol extract and the esclerotesta from 2.02 to 3.68 mg tannic acid equivalent/100 g of methanol extract. Moreover, the authors reported that, among the most abundant phenolic compounds found in papaya seeds, there are: caffeic, chlorogenic, dihidrocafeico, sinapic and p-hydroxybenzoic acids. In addition, Khalili *et al.* (2012) reported a polyphenol content of 3.44 mg for papaya peels, gallic acid equivalent/100 g of methanol extract, similar to the contents of the seed fractions mentioned above. Furthermore, the peel extract was compared in terms of percentage of antioxidant activity and the capacity to scavenge free-radicals with synthetic antioxidants, such as butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA), and a statistically significant difference ($p<0.05$) was found, with the extract of papaya peels having a lower percentage of antioxidant activity, as well as a lower capacity to scavenge free-radicals when compared to the synthetic antioxidants (BHT and BHA).

The use of papaya co-products has been reported in various fields for the extraction of protease from peels (Chaiwut *et al.*, 2010). The proteases in papaya peels are highly appreciated by different fields, such as health fields (for medical applications in the areas of ophthalmology, urology, neurosurgery, etc.), the beer industry and cosmetics industry (Caygill, 1979; Salas *et al.*, 2008), among others. Therefore, Chaiwut *et al.* (2010) evaluated the three-phase extraction method and argued this method was more effective than the normal two-phase method of purification (upper phase and aqueous phase) since the third phase formed by t-butanol (solvent) allows for the removal of low molecular weight compounds, such as lipids and phenols, in contrast to the traditional method.

### Potential problems associated with the consumption of molecules found in co-products

Considering the above content, agro-industrial co-products offer a natural source of molecules of catalogued antioxidants, such as polyphenols, that show reported benefits when included in the diets of people (Soobrattee *et al.* , 2005), but other authors have suggested that an excess of polyphenols can cause damage to human health rather than provide beneficial effects. For example, in the case of the tannins, which are associated with the inhibition of vasoconstriction, the benefit is only seen when consumed in moderate amounts (Taiz and Zeiger, 2006), while excesses are associated with possible carcinogenic roles and toxicity to the thyroid gland, among others (Balasundram *et al.* , 2006); this coincides with a widely known concept wherein polyphenols are a heterogeneous group of molecules and part of the secondary metabolism of plants used to protect themselves not only from pathogen agents, but also from potential predators, causing digestive problems when plant tissues are consumed because, in some cases, tannins generate a protein precipitation related to the covalent bonds between them (Taiz and Zeiger, 2006).

## CONCLUSIONS

The use of agro-industrial co-products allows for the mitigation of environmental problems and the nutritional improvement of food products, among others. Because these co-products can comprise up to 70% of the fresh fruit, depending on the fruit species, and due to the poor disposal of these materials as simply trash, pollution problems are generated everywhere they are deposited. However, with appropriate processing, it is possible to exploit the content of bioactive compounds, such as dietary fiber, polyphenols, and proteases, which are currently highly appreciated by consumers and the health and pharmaceutical sectors because their nutritional properties go beyond simply providing simple calories and other components, such as proteins, carbohydrates and fats, and may come to be recommended for ingestion with processed products in order to avoid the appearance of chronic diseases. Considering the above, along with the elevated quantity that is produced by some of the mentioned fruit species, this review evidenced the large industrial, chemical-pharmaceutical and new product development potential for processed foods that exists in Colombia, which can be realized through the discovery, appropriate manipulation, and processing of agro-industrial fruit co-products.

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