Guava: nutritional profile and opportunities

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Guava (Psidium guajava L.), is a fruit considered native to the American tropics. It is of great economic importance in many countries of the world, due to its high production and diversity of products derived from its fruit. It can be consumed fresh or processed.

Keywords: guava ; waste ; nutraceuticals ; by-products

1. Introduction

Guava (Psidium guajava L.) is a fruit native to the American tropics; it is also known as guayaba, guara, arrayana, and luma in some regions [1]. It ranges from Mexico to Peru, but because of its adaptability, it is cultivated in tropical and subtropical zones of Europe, Africa, and Asia This fruit was carried across the Pacific by the Spanish to the Philippines, and by the Portuguese to India [2], and it was rapidly adopted as a crop in Asia and some areas of Africa; it is now found in Egypt, Palestine, Algeria, and the French Mediterranean coast [2]. It is grown in almost all tropical and subtropical countries, at elevations ranging from 0 to 2000 meters (m), in a wide range of climates and soils, with annual rainfall ranging from 1000 to 2000 mm and average temperatures ranging from 20 to 30 °C [3].

India, Brazil, the Philippines, Mexico, Colombia, Peru, Ecuador, South Africa, the United States of America, Venezuela, Costa Rica, Cuba, and Puerto Rico are the primary producers of this fruit. The majority of the varieties sold in Europe are imported from South Africa and Brazil. Commercially, they are classified as white or red depending on the color of the pulp [3].

Guava is considered a super fruit by some researchers due to the high content of phenols and other antioxidant substances [4]. Fresh guava trade is limited internationally, but processed guava products, such as preserves and drinks, are becoming more common in many countries [5]. Because of its sensory properties and the presence of bioactive compounds, this fruit and its by-products have the potential to be integrated into healthy processed foods [4]. The valorization of agroindustrial waste has emerged as an appealing option for using them and creating new goods while minimizing the emissions they represent [6].

By-products of fruit and vegetable processing are the most studied substrates for the extraction of different antioxidants and dietary fibers [7]. Guava by-products have a higher total dietary fiber content than cereals and pseudocereals like oats (Avena sativa), barley (Hordeum vulgare), rye (Secale cereale), quinoa (Chenopodium quinoa Willd.), amaranth (Amaranthus caudatus), and chia (Salvia hispanicaL.) [8].

All taxonomic Information on guava is well known [11,12].

Guava is a plant in the Myrtaceae family [3][9], which includes about 133 genera and 3800 tree and shrub species. The genus Psidiumcontains about 150 species, the most notable are P. cattleianum Sabine, P. fredrichsthalianum (Berg) Nied, and P. guajava L. These are known for their economic and commercial importance [3][10], the high nutritional value of their fruits, which are high in vitamins A, B, and C, the numerous medicinal applications for which its fruits, leaves, flowers, bark roots, and stems are used [11], as well as the profitability of its cultivation [10].

P. cattleianum, known as arazá, is a native Brazilian fruit [12][13]. Its fruit is small, slightly round in shape, 2–3 cm in diameter, with thin violet-red skin; its pulp is soft, white, and juicy, with a sweet, acidic, and spicy taste. It has a lot of tiny, white-colored seeds [2][12].

P. friedrichsthalianum, known as “cas” or “Costa Rican guava” in Costa Rica, is native to Honduras and is cultivated from northern South America to southern Mexico [13]. The fruit is rounded in shape, slightly flattened at the ends, with a length of 3.56 cm and a diameter of 4.29 cm, yellow skin, and mildly acidic pulp; it is used to make candy, juices, and jellies [2][13].

Guava is the most resistant tropical fruit tree due to its adaptability and high production rate [14]. It exhibits a high level of variability in populations, with distinct fruit sizes, pulp and peels color, seed number, and other morphological characteristics [11].

Depending on the climatic conditions and variety, bushes or trees up to 10 m tall with a short and twisted stem can be found [9]. It can produce roots up to five meters deep, depending on the type of soil and water table, giving it excellent anchorage [15]. The tree grows quickly, bears fruit in two to four years, and continues to bear fruit for another 40 to 60 years [14]. Guava trees flower and bear fruit all year in temperate and tropical temperatures [2].

2. National and International Production

Guava cultivation is of great economic significance in many countries around the world, owing to its high yield and the variety of products derived from its fruit [16][17][18]. India is the world's biggest guava producer, followed by China and Kenya [2], with Brazil and Venezuela also standing out [18]. Mexico ranks fifth in the world with a production of 302,718 tons per year (2017), and an increase is expected due to a 5% increase in the harvested area; 4% of total production is exported, primarily to the United States and Canada [19]. Guava crops can be found almost everywhere in the country; there are commercial, wild plantations and family or backyard gardens; the most important producing areas are in the states of Michoacán, Aguascalientes, and Zacatecas, particularly in the "Calvillo-Caones" region [18][20].

3. Industrialization and Generation of By-Products

Agro-industry generates millions of tons of waste worldwide [21], which increases production costs in developed countries and has a serious environmental effect [6]. Although some waste is processed and used as a fiber source in animal feed or fields, the vast majority is discarded untreated [21][22]. Several studies have shown that these residues are high in bioactive compounds that can protect against oxidative damage caused by free radicals. Fruit and vegetable peels are high in bioactive ingredients like fiber and antioxidants [21].

During guava processing, the pulp is obtained as the primary product, with seeds and peels obtained as by-products [23], which can account for up to 30% of the volume of the fresh fruit [9]. **Table 1** illustrates the values reported in the various studies on the physicochemical characterization of guava and its by-products that were consulted. The values of the references correspond to values on a dry basis.

Table 1. Physicochemical composition of pulp and seeds of *Psidium guajava*.

Proximate Analysis.	Pulp	Seeds	Reference
Moisture (%)	[b] 85; [f] 6.41 ± 0.11; [g] 84.9	[a] 6.68 ± 0.00; [c] 8.3 ± 0.03; [d] 9.3 ± 0.03	[a] [24], [b] [19], [c] [27], [d] [6], [f] [7], [g] [8]
Protein (g/100 g)	[b] 0.3 [f] 5.13 ± 0.26 [g] 0.88	[a] 11.19 [d] 4.8 ± 0.10 [h] 7.71	[a] [2], [b] [4], [d] [26], [f] [28], [g] [8], [h] [29]
Fiber			
Total dietary fiber (g/100 g)	[b] 2.4 [f] 43.21 ± 0.09	[a] 63.94 [d] 69.1 ± 0.17 [h] 69.63	[a] [24], [d] [26], [f] [28], [h] [29]
Insoluble dietary fiber (g/100 g)	[f] 42.56 ± 0.06	[a] 63.55 [d] 57.7 ± 0.15	[a] [24] [d] [26], [f] [28]
Soluble dietary fiber (g/100 g)	[f] 0.65 ± 0.04	[d] 11.1 ± 0.09	[d] [26], [f] [28]
Ether Extract (g/100 g)	[b] 0.1 [f] 4.32 ± 0.24 [g] 0.53	[d] 1.4 ± 0.10 [h] 10.12	[b] [19], [d] [26], [f] [28], [g] [8], [h] [29]
Carbohydrates (g/100 g)	[b] 15 [g] 13.2	[d] 22.2 ± 0.14 [h] 11.51	[b] [19]; [d] [26], [g] [8], [h] [29]
Ashes (g/100 g)	[b] 0.5 [e] 0.52 ± 0.05 [f] 5.04 ± 0.39 [g] 0.43–0.7	[a] 1.18 ± 0.02 [d] 2.4 ± 0.10 [e] 0.66 ± 0.04 [h] 1.01	[a] [24], [b] [19], [d] [26], [e] [30], [f] [28], [g] [8], [h] [29]

Proximate Analysis.	Pulp	Seeds	Reference
Vitamins and minerals			
Vitamin A (IU/100 g)	[b] 109 [g] 200–400	[h] 50.13	[a] [24], [g] [8], [h] [29]
Thiamine (B1) (mg/100 g)	[b] 0.06 [g] 0.046		[b] [19], [g] [8]
Riboflavin (B2) (mg/100 g)	[b] 0.06[g] 0.03–0.04		[b] [19], [g] [8]
Niacin (B3) (mg/100 g)	[b] 1.3 [g] 0.6–1.068	[h] 0.16	[b] [19], [g] [8], [h] [29]
Ascorbic acid (C) (mg/100 g)	[b] 190 [g] 100	[a] 87.44 [h] 0.20	[a] [24] [b] [19], [g] [8], [h] [29]
Zinc (mg/100 g)		[a] 3.31	[a] [2]
Calcium (mg/100 g)	[b] 15 [g] 9.1–17	[c] 0.05 ± 0.14 [h] 60.07	[b] [19], [c] [27], [g] [8], [h] [29]
Phosphorus(mg/100 g)	[b] 16 [g] 17.8–30	[h] 160.55	[b] [19], [g] [8], [h] [29]
Iron (mg/100 g)	[b] 0.3 [g] 0.30–0.70	[a] 13.8 [h] 3.32	[a] [24], [h] [29] [b] [19], [g] [8]
Potassium (mg/100 g)	[b] 292	[h] 300	[b] [19], [h] [29]
Sodium (mg/100 g)	[b] 6		[b] [19]
Calories kcal /100 g	[b] 54.97 [g] 36–50	[a] 182	[a] [24], [b] [19], [g] [8],
Unsaturated fatty acids (%)		[a] 87.06	[a] [24]
Bioactive Compounds			
Ascorbic acid (mg/100 g)		[a] 87.44	[a] [24]
Total carotenoids (mg/100 g)		[a] 1.25	[a] [24]
Total phenols (mg GAE/g)	[f] 44.04 ± 0.56		[f] [28]

The fruit can be round or pear-shaped, and its weight can range from 25 to 500 g [15][16]. It is 4–12 cm long and 4–7 cm wide, and it is distinguished by its aromatic, soft, and sticky pulp. The color of the pulp varies greatly: it may be white, yellow, pink, orange, or salmon [9][16], while commercially they are classified as white and red based on the color of the pulp. The pulp can be dense with few seeds in the center or thin with multiple seeds being part of the pulp [16].

According to the Mexican Norm NMX-FF-040-1993, the guava is a “fruit with a globose, ovoid, or pyriform shape, yellow-green on the outside or light yellow at full maturity; the pulp is yellowish-white, pink, or red, with a sweet or acid and aromatic flavor; the seeds are abundant and yellow, belonging to the Myrtaceae family, genus Psidium, and species guajava. Guava production and consumption in Mexico is concentrated on the “Chinese media” and “Peruvian” varieties, which were picked from germplasm; it can be eaten fresh or processed into a variety of products [24].

Guava is commonly consumed in Latin America and around the world, either as fresh fruit or in products such as juices and candies. Aside from its pleasant flavor, the rising demand has been boosted by new lifestyle trends that encourage society to adopt healthy habits [25][26][27][28]. The fruit has low carbohydrate, fat, and protein content and high water content [1], as well as vitamins A, B, and C. The vitamin C content is between 180 and 300 mg per 100 g of fruit, which is far greater than that found in citrus fruits like oranges and lemons [27][28], which is why it is referred to as a “superfruit” [4][29].

Guava is a fruit that is known around the world as a food, but it is also used as medicine by several indigenous peoples in Central America and Africa, and it is present in many traditional medicines. According to Gutiérrez et al. [1], various research and clinical studies have been developed to explain the specific bioactivity of individual phytochemicals extracted from guava.

Documented scientific research on the medicinal properties of guava dates back to the 1940s [1], and it has been shown that the guava plant, fruit, and processing residues contain significant amounts of essential oils, vitamins (A and B), calcium, iron, potassium, pectins, and antioxidant substances such as phenolic compounds, ascorbic acid, carotenoids, lycopene, volatile organic compounds, and elements. They have the potential to aid in the prevention of chronic and degenerative diseases such as cancer [3][4][14][30][31][32].P. guajavaL. has been shown in studies to have hepatoprotective, antiallergic, antimicrobial, antigenotoxic, antiplasmodial, cytotoxic, antispasmodic, cardioactive, antidiabetic, anti-inflammatory, and antinociceptive properties [1]. The compounds, particularly those extracted from the leaves and fruits, have beneficial pharmacological properties.

The chemical composition and concentration of these components differ dramatically depending on the species or variety, fruit maturity, cultivation conditions, soil type, environment, and agricultural practices [14]. Because of all of these compounds found not only in the fruit and by-products, but also in the plant, guava fruits are considered ethnopharmaceutical drugs, traditionally used to treat diarrhea, throat inflammation, and for their high antibacterial activity against Salmonella, Serratia,and Staphylococcus [27].

The phenolic compound content of powder of guava ranges from 44 to 516 mg GAE/100 g [33][30]. Pink pulp has values ranging from 170 to 300 mg GAE/100 g [33]. Gallic acid, chlorogenic acid, ellagic acid, catechin, and rutin are the most common phenolic compounds contained in pulp [30]. The antioxidant activity of the extracts correlates with the presence of a wide range of phenolic compounds [2][30].

The tree's leaves are leathery, oval, or oblong-elliptical in shape, with short, smooth, and light green to dark green petioles arranged in semi-alternating pairs [15], with a midrib and several secondary leaves that emphasize a plain perspective [10]. When smashed, the approximately 3–16 cm long and 3–6 cm wide oblong [2][9] presents a distinctive scent, which is characteristic of essential oil, and the smell depends on the cultivar [10].

The leaves of guava have been used in traditional medicine in Taiwan, Japan, China, and Korea [34]. Guava has been shown to have anti-diabetic activity in vitro by Khaleel and Kumari [35] and Díaz-de-Cerio et al. Guava has also been used as a hypoglycemic agent in Taiwanese traditional medicine [36]. The presence of bioactive plant molecules such as phenolic compounds is attributed to the biological properties described in guava polyphenols, also known as phenolic compounds, which are a type of secondary metabolite that has been used in preventive medicine for centuries [37]. Guava leaves have gotten a lot of attention because they contain more phenolic compounds than the rest of the tree [1]

The guava leaves have a high total phenolic content ranging from 7.5 to 483 mg/g dry weight. These are also high in proanthocyanidins, which could be used in nutraceutical formulations [38].

Purification of guava leaf extracts results in the isolation of quercetin, quercetin-3-arabinoside, and Asian acid with wide antimicrobial activity against bacteria, fungi, viruses, and parasites, capable of treating diarrhea, gastroenteritis, dental plaque, acne, childhood rotavirus enteritis, and even malaria, as well as antioxidant properties and an inhibitory effect on the frequency of cough. Other compounds in guava leaves, such as β-sitosterol, flavonoids, triterpenoids, and volatile oil, may explain some of the advantages in traditional and ethnomedical uses of the plant in the management or control of some diseases, particularly dermatological disorders [1].

Polyphenols are the principal phytochemical compounds found in guava leaves, pulp, and peels. [39] used UHPLC-DAD-MS/MS to identify 61 polar compounds in the peel and pulp of guava.Table retention periods and m/z values for the principal phenolic compounds identified by the authors. The phenolic compounds were extracted using an ultrasound bath and a mixture of ethanol/water (80/20,v/v) and methanol/water (9/1,v/v) for the leaves and peel/pulp, respectively.

The phenolic compounds found in the leaves of guava belong to the flavonols (76%), flavan-3-ols (45%), gallic and ellagic acid derivatives (35%), and flavanones families (1%). Díaz-De-Cerio et al. [34] investigated the identification and quantification of polar compounds in guava leaf extracts (ultrasound aqueous extract and infusions).

According to the quantification findings, the polar compound concentrations in all samples were flavonols > flavan-3-ols > gallic and ellagic acid derivatives [39], the phenolic compounds found in the pulp and peel of guava belong to the family of ellagitannins, flavones, flavonols, proanthocyanidins, dihydrochalcones, and anthocyanidins, as well as non-flavonoids such as phenolic acid derivatives, stilbenes, etc. The antioxidant activity and phytochemical composition of guava, on the other hand, differ substantially depending on cultivar, growing conditions, and extraction method [40].

Because of good manufacturing practices, ethanol and water are the most widely used extraction solvents in food systems [41]. [38] tested pure ethanol and various hydroethanolic mixtures, such as ethanol/water ratios of 90:10, 80:20, 70:30, 60:40, and 50:50 (v/v). The selection of a suitable method for the release of all phenolic compounds is critical in order to achieve bioactive extracts with high antioxidant power. Infusions are used in conventional medicine to extract bioactive molecules; however, green technologies have piqued the science community's interest.

The primary new methods for extracting bioactive molecules from the guava plant are ultrasound-assisted extraction [42], supercritical fluid extraction [43], and microwave-assisted extraction [44]. Furthermore, biotechnological processes such as solid-state fermentation with microorganisms such as mushrooms and bacteria can be used [45]. [46] found that fermenting guava leaves withMonascusandBacillusincreased the release of bound polyphenolics. The antioxidant properties were substantially enhanced using the solid-state fermentation method.

[46]. Guava extracts were discovered to have high antioxidant activity. The antioxidant mechanisms of guava extract's bioactive components may be attributed to their ability to scavenge free radicals [36]. Total polyphenols extracted from guava leaf showed higher bioactivities in scavenging 1,1-Diphenyl-2-picrylhydrazyl (DPPH) and 2,2-Azino-bis 3-ethylbenzothiazoline-6-sulfonic acid diammonium salt (ABTS) The fruit of guava has a high potential for valorization in the selection of strong bioactive compounds; as a result, their use can be recommended for application in polyphenol-based food products or medication with enhanced health advantages and antioxidant functions.

The light yellow or cream seeds are flattened in a kidney shape, measuring between 3 and 5 mm long and 2 to 3 mm wide; the number of seeds per fruit can range between 100 and 500 [16][17], accounting for between 1.6 and 4% of the fruit's weight [16].

Guava seeds contain approximately 92% dry matter, of which 80% is fiber, 8 to 12.75% oil, 6 to 10% protein, and 0.5 to 6.62% ash [47][48]. According to Vasco-Méndez et al. [48], the fiber contains 25% lignin and 65% hemicellulose, and the ethereal extract contains the following fatty acids: 79% linolenic, 8% palmitic, 7% oleic, and 5% stearic. [21], the yield of guava seed meal is 54% when compared to other fruits in the same family, such as coronilla guava (P. acetabulum) with 55.01% and guava arazá (Eugenia stipitata) with 63%, and this has been attributed to the number of seeds present in guava.

According to chemical composition studies, the pulp, peel, and guava seed have pH values of 4.1, 3.9, and 4.30 ± 0.03, respectively. Because it is close to the value (4.5) that restricts microorganism growth, low pH values provide relative resistance to microbial attack [21][49]. The acidity of the fruit varies depending on factors such as variety and maturity; studies report values ranging from 1.21 ± 0.16 to 2.18 ± 0.08 g of citric acid/100 g [21].

Pelegrini and Franco [27] discovered and characterized Pg-AMP1, an antimicrobial peptide that belongs to a group of glycine-rich proteins found in guava seeds and is distinguished by its low molecular weight and three-dimensional structure. In vitro analysis revealed that it could inhibit the growth of gram-negative bacteria. [47] investigated guava seed flour as a nitrogen source in alcoholic fermentation and discovered increased product yield and substrate conversion. These findings support the use of guava seed flour as a sustainable and low-cost source of nitrogen for fermentation alcoholics.

Guava processing by-products, mostly seeds, peels, and pulp, have a water-holding capacity of 10.2 g water/g sample [27], which is greater than that reported for certain foods such as rice bran (5.21 g water/g sample) [50] and durum wheat (1.5–2.1 g water/g sample) [51], indicating its potential use in food production. However, some studies report that it has a negative impact when added to baked foods, resulting in a loss of volume and a sandy texture in the final product [50].

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