

# Effect of preharvest conditions on the quality of important Myrtaceae fruits in Colombia. A review

## Efecto de las condiciones precosecha sobre la calidad de frutas mirtáceas importantes en Colombia. Una revisión



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**Fructification of the feijoa tree. The fruiting behavior on the trunk is curious.**

Photo: H.B. Balaguera-López

### ABSTRACT

The aim of this review is to provide information on the conditions that facilitate the production of high-quality Myrtaceae fruits that are important in Colombia. Many fruits of the Myrtaceae family possess very important nutritional, functional, and economic characteristics. In Colombia, commercially cultivated fruit trees of the Myrtaceae family include guava (*Psidium guajava* L.), feijoa (*Acca sellowiana* [Berg] Burret), arazá (*Eugenia stipitata* McVaugh), and champa (*Campomanesia lineatifolia* R. & P.). Each species and its varieties require a suitable climate, soil and altitudinal range, which influence their quality (nutraceutical, organoleptic, and physicochemical). Furthermore, the crop must be managed with the best cultural practices that guarantee the achievement of its genetic potential. These practices include pruning, which guarantees a physiological balance between vegetative and reproductive branches; nutrition, depending on the content of elements assimilable in soil; and tools such as foliar analysis. Regarding water, sites with a bimodal rainfall regime can guarantee two harvests per year, except in the case of champa, for which only one is reported, although irrigation can advance this schedule. Effective pollination is a requirement for fruit formation and quality. Regarding quality, guava and feijoa stand out for their high content of phytochemical substances (phenols, ascorbic acid, carotenoids, and antioxidant activity), which support their own defense in stressful conditions and could help human consumers to counteract chronic diseases. Unfortunately, there is a lack of studies on these crops regarding, for example, the cultural practices that can increase these bioactive compounds in the

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fruit. More research is needed in Colombia to improve the quality of these fruits, especially champa, which is grown only in the department of Boyaca and is the least studied.

**Additional keywords:** *Psidium guajava*; *Acca sellowiana*; *Eugenia stipitata*; *Campomanesia lineatifolia*; fruit quality; tropical fruits; crop management.

## RESUMEN

El objetivo de esta revisión es proporcionar información sobre las condiciones que facilitan la producción de frutas de alta calidad de la familia Myrtaceae, de importancia en Colombia. Muchos frutos de la familia Myrtaceae poseen características nutricionales, funcionales y económicas muy importantes. En Colombia, los frutales comerciales de la familia Myrtaceae cultivados comercialmente se encuentran la guayaba (*Psidium guajava* L.), la feijoa (*Acca sellowiana* [Berg] Burret), el arazá (*Eugenia stipitata* McVaugh) y la champa (*Campomanesia lineatifolia* R. & P.). Cada especie y sus variedades requieren de un clima, suelo y rango altitudinal aptos, que influyen en su calidad (nutracéutica, organoléptica y físico-química); además, el cultivo debe manejarse con las mejores prácticas culturales que garanticen el aprovechamiento de su potencial genético. Estas prácticas incluyen la poda, que garantiza un equilibrio fisiológico entre las ramas vegetativas y reproductivas, la nutrición, en función del contenido de elementos asimilables en el suelo; y herramientas como el análisis foliar. En cuanto al agua, los sitios con régimen de lluvia bimodal pueden garantizar dos cosechas por año, excepto en el caso de la champa, para la cual solo se reporta una, aunque el riego puede adelantar este cronograma. La polinización efectiva es un requisito para la formación y calidad de los frutos. En cuanto a la calidad, la guayaba y feijoa se destacan por su alto contenido de sustancias fitoquímicas (fenoles, ácido ascórbico, carotenoides, actividad antioxidante), que apoyan su propia defensa en condiciones del estrés y podrían ayudar a los consumidores humanos a contrarrestar enfermedades crónicas. Lastimosamente, hay una carencia de estudios sobre estos cultivos en cuanto, por ejemplo, a las prácticas culturales que pueden aumentar estos compuestos bioactivos en el fruto. Se necesita más investigación en Colombia para mejorar la calidad de estos frutos, especialmente la champa, que se cultiva solo en el departamento de Boyacá y es la menos estudiada.

**Palabras clave adicionales:** *Psidium guajava*; *Acca sellowiana*; *Eugenia stipitata*; *Campomanesia lineatifolia*; calidad de la fruta; frutas tropicales; manejo del cultivo.

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## INTRODUCTION

In Colombia, “exotic” fruits with sensory characteristics offer high nutritional and economic value (Combariza and Aranda, 2012). Due to increased awareness of their nutritional and health benefits, the consumption of tropical fruits has risen nationally and internationally in recent years (FAO, 2024). This has benefited Andean countries, which have significantly increased their export volumes in this century (Moreno-Miranda *et al.*, 2019).

Many fruits in the Myrtaceae family possess highly promising nutritional, functional, and economic characteristics (Lima *et al.*, 2016; Araújo *et al.*, 2019). In Colombia, the most prominent of the

commercially grown Myrtaceae family fruits are guava (*Psidium guajava* L.) (Fig. 1A), feijoa (*Acca sellowiana* (Berg) Burret) (Fig. 1B), arazá (*Eugenia stipitata* McVaugh) (Fig. 1C), and champa or chamba (*Campomanesia lineatifolia* Ruiz and Pavon) (Fig. 1D), the last of which is currently grown to a lesser extent but has great potential. These fruits are well-received by consumers (Balaguera-López *et al.*, 2022), their seeds have bioherbicidal potential (Martínez *et al.*, 2022; Maestre *et al.*, 2023), and their leaves possess medicinal properties (Neves *et al.*, 2023). Guava is native to Central America and southern Mexico (Blancke, 2016), feijoa to southern Brazil, Uruguay, the highlands of western Paraguay, and northeastern

Argentina (Parra-Coronado and Fischer, 2013), arazá to the western Amazon region between the Marañon and Ucayali rivers and near Requena city (Peru) and the headwaters of the Amazon River (Hernández *et al.*, 2006); and champa to the Amazon regions of

Brazil, Peru, Colombia, and Bolivia (Villachica *et al.*, 1996). The fruits of these Myrtaceae species can be consumed fresh due to their rich flavor. It is also common for them to undergo agro-industrial processes to produce juice, yogurt, jam, ice cream, and various



**Figure 1.** Some Myrtaceae fruits, grown in Colombia. A, guava (photo: G. Fischer); B, feijoa (photo: G. Fischer); C, arazá (photo: J. Barrera), and D, champa (photo: A.L. Balaguera).

**Table 1.** Area and production of guava, feijoa, arazá, and champa in Colombia, including the two departments with the highest production (MinAgricultura, 2024).

Species	Year	Area (ha)	Production (t)	Yield (t ha <sup>-1</sup> )	Departments (% national production)
Common guava	2022	12,292.5	163,115.67	13.27	Santander (38.89%) Meta (19.46%)
Feijoa	2022	339.3	3,133.3	9.23	Boyaca (71.98%) Cundinamarca (23.38%)
Arazá	2022	227.8	771.24	3.39	Amazonas (48.75%) Putumayo (25.48%)
Champa	2022	8.1	89.7	11.07	Boyaca (100%)

other derivatives of great market interest (Farias *et al.*, 2020).

The latest statistics on the area and production of these crops, according to MinAgricultura (2024), indicate that guava has the largest planted area and highest yield, while champa has the second-highest yield, but a small planted area. The production of these Myrtaceae crops is mainly concentrated in six departments. MinAgricultura (2024) also reports data for guava pear ('Palmira ICA-1'), with a planted area of 6,504 ha in 2018, predominantly in the department of Meta (52.2% of national production); and the hybrid 'Manzana', with 220 ha in 2017, especially in the department of Huila (61.6%).

The Myrtaceae family stands out for its botanical abundance and agro-industrial importance, including 5,800 species across 121 genera that develop aromatic fruits. According to Farias *et al.* (2020), it is one of the most notable commercial families globally. The species of this family are distributed throughout the tropics, with concentrations in South America, Australia, and Southeast Asia (Asif, 2015).

Parra-O. (2014) mentions that in Colombia there are 24 genera and 165 species of Myrtaceae, with 52% of the native species of this family distributed between 0 and 1,000 m above sea level (m a.s.l.) and only 10% between 2,000 and 3,500 m a.s.l. From a commercial perspective, there are some species and varieties with fruits useful for human consumption, others with antioxidant and fungicidal properties derived from extracts of their leaves and branches, and others with use as rootstocks for commercial varieties (Trujillo *et al.*, 2018).

As well as the four species mentioned in table 1, there are other known Myrtaceae fruits in the country. These are not commercialized crops and are often used for traditional medicine purposes, for example camu-camu (*Myrciaria dubia*), pitanga (*Eugenia uniflora*), jaboticaba (*Myrciaria jaboticaba*), and pomarrosa (*Syzygium jambos*).

Asrey *et al.* (2018) note that the physiological behavior, as well as the quality and perishability of the fruits, depends on the individual characteristics of each fruit, in addition to environmental conditions, crop management, and post-harvest treatments. Wills and Golding (2016) define quality as the desired attributes of products being marketed, including appearance, texture, flavor (aroma), and nutritional

value of the fruits. The attributes that define the quality of the fruit depend on the evaluator; thus, for the marketer, appearance, firmness, and post-harvest shelf life are the most important, while for the consumer, good taste and nutritional value are key, among other factors.

The quality characteristics of fruits at harvest and post-harvest are determined largely by factors relevant to the cultivation stage, since post-harvest technologies can only maintain quality, not improve it (Yahia, 2019). In many cases, post-harvest studies have not sufficiently considered the influence of factors during cultivation, such as climate conditions and management practices, on fruit quality (Barman *et al.*, 2015). Due to this situation, the production of high-quality Myrtaceae fruits requires the right variety, suitable environmental conditions, and appropriate crop management practices (Fischer *et al.*, 2018). Therefore, the aim of this review is to provide information on the conditions that facilitate the production of high-quality Myrtaceae fruits that are important in Colombia, namely: guava, feijoa, arazá, and champa.

## DEVELOPMENT OF FRUIT QUALITY DURING CULTIVATION

As previously indicated, decisive factors for the development of fruit quality during cultivation are the environmental conditions, plantation management, the genetics of the variety, and the interactions between these factors (Fischer *et al.*, 2018).

### Environmental factors and fruit quality

In many cases, as Raza *et al.* (2020) state, fruit trees are grown in unsuitable conditions that do not allow them to reach their maximum potential. These sub-optimal environmental conditions result in yields far lower than the reported maximum. Environmental factors greatly affect the quality and nutritional value of the fruit (Yahia *et al.*, 2019a), but these conditions are difficult to control in open fields. Additionally, fruit trees are among the species most affected by climate change, as global warming leads to reduced yields and fruit quality, especially in tropical and subtropical regions (Shukla *et al.*, 2019). The environmental conditions of the planting site are crucial for fruit quality formation and form the basis for the production of commercial crops in a given region or

country (Fischer and Orduz-Rodríguez, 2012; Fischer *et al.*, 2018).

Ladaniya (2008) specifies that the cultivation environment influences processes such as photosynthesis, respiration, transpiration, translocation of photoassimilates, and overall plant metabolism. Consequently, these processes are essential for the development of both external and internal fruit quality and their post-harvest behavior. Therefore, ecophysiology studies are of the utmost importance in ensuring that the full potential of a variety in a given location is reached. According to Lambers and Oliveira (2019), plant ecophysiology studies the physiological mechanisms resulting from ecological observations, with a focus on the growth, physiology, reproduction, and survival of plants, as these processes depend on the interactions between plants and their physical, chemical, and biotic environments.

In Colombia, a tropical country with significant mountainous areas, Myrtaceae are cultivated at different altitudes, ranging from 0 to 2,700 m a.s.l. (Tab. 2). It is important to note that, with every 100 m of elevation gain, the temperature decreases by 0.6 to 0.7°C (Benavides *et al.*, 2017; Fischer *et al.*, 2022a). Similarly, atmospheric pressure and the partial pressures of O<sub>2</sub>, CO<sub>2</sub>, and N<sub>2</sub> decrease by 11% (at 20°C) for every 1,000 m increase in altitude (Körner, 2007). In contrast, with a 1,000 m increase in altitude, UV-B radiation increases by 10-12% (Benavides *et al.*, 2017).

This information on the changes in climatic effects with altitude is key to the crops' optimal cultivation due to their temperature requirements. Only feijoa can withstand cold conditions above 2,000 m a.s.l. (Tab. 2). The fruits can be affected by sunburn due to the increase in UV-B radiation (Fischer *et al.*, 2022b),

especially during dry seasons and when there is insufficient canopy shading over the fruits. Due to the high sun exposure susceptibility of arazá, it is recommended that this crop be integrated into an agroforestry system that provides moderate shade, such as with *Cordia alliodora* or *Hevea brasiliensis* (Van Kanten and Beer, 2005; Fernández-Trujillo *et al.*, 2011). Sunburn has not been reported as a limiting factor in champa, possibly due to the tree's abundant foliage.

However, within certain ranges, exposure of fruits to direct sunlight favors the fruit's protection system by increasing the production of antioxidants (especially phenols) in their epidermis, which also enhances the nutritional and medicinal values of this edible organ (Fischer *et al.*, 2016). In cases of excessive and prolonged solar radiation, the temperature of the epidermal tissues increases, which can cause necrosis, fruit cracking, and other problems (Fischer *et al.*, 2021).

On the other hand, if crops are planted at higher altitudes, it may be possible to offset the detrimental effects of heat, with these tropical elevations being considered "escape zones from global warming" given the temperature increase due to climate change (Fischer *et al.*, 2022a). Thus, Duarte and Paull (2015) recommend planting arazá at even higher elevations than those indicated in table 2, specifically below 700-800 m a.s.l. and preferably in warm, humid tropics.

Due to the colder environments at higher altitudes, production cycles start later and fruit development is prolonged (Fischer *et al.*, 2024). Parra-Coronado *et al.* (2015a, 2015b) observed the growth of feijoa at two altitudes in Cundinamarca. They found that fruits grown at 2,580 m a.s.l. (in Tenjo township, average temperature 12.3°C) developed over 180 d and had higher concentrations of sucrose (Parra-Coronado *et*

**Table 2. Recommended climatic and altitude conditions for the production of four Myrtaceae fruits in Colombia.**

Climatic factor	Common guava	Feijoa	Arazá	Champa
Altitude (m a.s.l.)	0-2,000	1,800-2,700	0-650	800-1,600
Temperature (°C)	15-30	13-21	18-30	22-30
Light/solar radiation	≤ 2,000 μmol photons m <sup>-2</sup> s <sup>-1</sup>	≥ 1,500 h sunlight brightness/year	1,200-2,000 h sunlight brightness /year	~1,500 h sunlight brightness /year*
Precipitation (mm year <sup>1</sup> )	1,000-2,000	700-1,200	2,500-4,000	>1,500
References	Solarte <i>et al.</i> , 2014; Fischer and Melgarejo, 2021	Fischer and Parra-Coronado, 2020	Escobar <i>et al.</i> , 1999; Barrera <i>et al.</i> , 2012	Balaguera-López <i>et al.</i> , 2022

\* The requirement for the species is not known; it was estimated using the values from the production zone.

*al.*, 2022) and total soluble solids (Parra-Coronado *et al.*, 2015a) than fruit grown in San Francisco de Sales township (1,800 m a.s.l., 18.5°C), which took only 149 d to develop. According to Parra-Coronado *et al.* (2015a), this improved quality is due to higher accumulated solar radiation at the higher elevation site. Furthermore, prediction models and regression analyses confirmed that altitude, accumulated precipitation, and growing degree days (GDD) had the greatest impact on physicochemical characteristics during fruit development (Parra-Coronado *et al.*, 2016), especially the weight and size of mature feijoa fruits.

Champa has one harvest per year, with peak production in September (López and Rodríguez, 1995). However, harvesting in lower-altitude zones in the same region can begin much earlier, even as early as May, indicating the role of temperature in accelerating the phenology of this species. At 1,432 m a.s.l., with an average temperature of 22.3°C, Balaguera-López *et al.* (2012) estimated that the duration from flowering to fruit harvest of champa was 145 d, corresponding to an accumulation of 1,422.8 GDD. The duration of fruit development can vary due to several factors, with another report estimating the duration at 160 d (Balaguera *et al.*, 2009).

Regarding the effect of CO<sub>2</sub>, which increases due to climate change but decreases with increasing altitude, these fruit trees are not likely to be affected. Higher CO<sub>2</sub> levels promote photosynthesis, biomass production (Lambers and Oliveira, 2019; Fischer *et al.*, 2022c), and in some cases, fruit quality (Moretti *et al.*, 2010). Also, elevated CO<sub>2</sub> concentrations will lead to more efficient water use (Fischer *et al.*, 2022c). However, there is much uncertainty due to increasing temperatures and extreme changes in humidity. There is still a lack of research on this topic in fruit trees, with no studies at all for most commercial Myrtaceae species (Fischer *et al.*, 2024).

Furthermore, in fruit trees, it is possible that the number of leaf stomata increases with increasing altitude to counteract the lower partial pressure of CO<sub>2</sub> at high altitudes, as found by Fischer and Melgarejo (2020) in cape gooseberry at 2,690 m a.s.l. This effect has not yet been investigated in most fruit species.

However, guava, arazá, and champa thrive in temperatures of up to 30°C (Tab. 2). Increases in temperature due to global warming can affect the growth and development of plant organs, causing morphological,

anatomical, physiological, and biochemical changes that drastically affect the commercial yield of crops (Moretti *et al.*, 2010). In guava fruits, very high temperatures, such as in the summers of subtropical regions, decrease sugar and organic acid levels, which are used in respiration (Solarte *et al.*, 2014). Similarly, in feijoa, global warming will not only reduce the time for fruit development but also increase sugar levels at the expense of acids (Ubeda *et al.*, 2020), resulting in fruits with an undesirably high sugar/acid ratio.

Knowledge of the base temperature (minimum for growth) or the temperature required for a specific phenological phase of the fruit tree is very useful when choosing a site for planting. Parra-Coronado *et al.* (2015b) calculated the base temperature for feijoa fruit development as 1.76°C and for flowering as 3.04°C. Similarly, Ferreira *et al.* (2019) calculated the minimum temperature for guava plant growth as 10.9°C, while Insuasty *et al.* (2007) observed that guava fruits do not ripen at temperatures as low as 3°C. For champa, the base temperature has not yet been identified, although GDD have been determined (Balaguera-López *et al.*, 2012).

Due to feijoa's adaptation to lower temperatures, it can also be grown in temperate zones, producing large fruits with higher yields in locations with moderately mild winter temperatures (Morley-Bunker, 2010). In this context, Duarte and Paull (2015) noted that warmer temperatures accelerate the phenological stages of flowering and fruit ripening of feijoa, advancing them by up to 8 weeks compared to colder climate zones.

In feijoa, as mentioned earlier, higher accumulated solar radiation increases the sugar content (total soluble solids [TSS] and sucrose) in the fruit. For arazá, Hernández *et al.* (2006) reported that plants grown in shaded habitats do not achieve very high photosynthetic rates but are still efficient at these low light intensities.

Due to the relative uniformity of temperature and photoperiod in the tropics throughout the year, rainfall has a greater impact on the growth, production, and quality of fruit trees (Ramírez *et al.*, 2021). Prolonged periods of drought, which have become increasingly common due to global warming, are the most prevalent abiotic stressors globally, greatly limiting the growth and productivity of fruit trees (Taiwo *et al.*, 2020). Low ambient humidity and drought

during the flowering stage severely affect fruit set, leading to fruit drop as reported by Paull and Duarte (2012) for guavas. In more advanced stages of guava development, Mercado-Silva *et al.* (1998) found that water scarcity promotes an increase in sugar concentration due to a concentration effect, with fruits only reaching a medium or small size under severe drought conditions (Lozano *et al.*, 2002). Balerdi *et al.* (2003) classified guava as moderately tolerant to drought conditions. In feijoa, a rather dry climate promotes flowering (Quintero, 2012); however, a long dry season can cause the dropping of flowers, fruits, and leaves and prolong fruit ripening (Fischer and Parra-Coronado, 2020).

Interestingly, guava also tolerates waterlogging (Balerdi *et al.*, 2003). However, crops in areas with abundant rains make them more susceptible to cracking (Fischer and Melgarejo, 2021). Additionally, prolonged rainy seasons result in watery fruits with low contents of ascorbic acid, titratable acidity, and sugars (Souza *et al.*, 2010). Furthermore, many of these fruits fall due to the increased incidence of diseases in very humid conditions (Solarte *et al.*, 2010). In addition, in feijoa, very humid conditions during flowering decrease the number of fruit sets due to the incidence of *Botrytis cinerea* in flowers and the difficulty of pollination because pollinating birds do not fly in the rain, resulting in fruits formed under these conditions of low caliber and asymmetric (Quintero,



**Figure 2. Champa fruit with cracking symptoms. Photo: A.L. Balaguera.**

2012). For arazá, Fernández-Trujillo *et al.* (2011) report large fruits with good color ( $h^* 83$  to  $88^\circ$ ,  $C^* 49$  to  $54$  units) under rainfall between 200 and 300 mm per month, while Duarte and Paull (2015) mention that arazá adapts to diverse rainfall conditions, from 1,500 to 4,000 mm per year. Moreover, for champa, planting is generally recommended in areas with rainfall exceeding 1,500 mm per year (Tab. 2). In this fruit, cracking also occurs because of irregular water supply (Fig. 2).

### Cultural practices and fruit quality

Proper crop management increases the productive potential of the species and variety, as well as their quality at harvest and post-harvest (Fischer *et al.*, 2018; Fallik and Ilic, 2018). This proper management involves understanding the implications of factors such as pruning, irrigation, fertilization, and pollination, among others. Below are some considerations for managing the Myrtaceae species of interest.

**Pruning.** Many tropical fruit species have a natural tendency to develop suitably; however, they often need assistance to form the desired canopy (Paull and Duarte, 2012). As a general rule, to avoid sunburn, Myrtaceae fruit trees need leaves above their fruits to reduce the intensity of direct sunlight, especially UV in high-altitude areas; this can be achieved by pruning and proper training (Lal and Sahu, 2017; Fischer *et al.*, 2022b). It is important that trees maintain a physiological balance between vegetative and reproductive branches, which is achieved by pruning after harvest and/or by removing some unwanted branches during fruit development, such as suckers and non-fruiting parallel branches. Additionally, tipping very long branches helps remove overly vegetative branches that compete for assimilation with developing fruits (Casierra-Posada and Fischer, 2012).

Excellent results have been achieved with the formation of more open canopies for guava. For this, the single-trunk tree should branch out at a height of about 50 cm, or the central axis should be tipped to encourage the insertion of branches in a more horizontal position (Fischer *et al.*, 2012).

Technified feijoa crops require pruning due to its effects on floral induction, improvement of productivity, and quality of production, as well as to support phytosanitary controls (Quintero, 2012). For feijoa, highly productive trees with a central leader and more horizontal lateral branches (up to a maximum

of 90°) are preferred. This structure reduces vegetative growth in favor of fruiting and ensures good fruit size (Quintero, 2003). In feijoa pruning, very thin and short branches (about 15 to 30 cm, mostly hanging inside the canopy) should not be removed, as these are very fruitful (Duarte and Paull, 2015). A more intense pruning in feijoa, thinning out branches with low production or overly vigorous branches within the canopy, reduces the leaf area and the number of fruits but favors the size of the remaining fruits (Sánchez-Mora *et al.*, 2017). In feijoa trees, Quintero (2003) observed that pruning in the reproductive state (with floral buds, flowers, or newly set fruits) induces new branches with more floral buds, unlike pruning in a state of “infertility.”

For arazá, Reyes (2012) recommends forming plants with three or four thick primary branches, and then, during production, applying only maintenance and sanitary pruning.

For champa, no established pruning systems exist due to the low cultivation technification. The plant grows while maintaining its natural architecture and can reach up to 10 m in height, with a strong main stem and a densely branched canopy (Balaguera, 2011; Nates-Parra *et al.*, 2016). This creates difficulties in management, mainly in harvesting, which is why fruits are commonly collected from the ground after they detach from the tree (Villachica *et al.*, 1996; Balaguera-López *et al.*, 2012). Such collection practices can cause mechanical damage that further limits their short post-harvest life. The high density of the canopy can also generate fruit quality problems by limiting the entry of light for photosynthesis and fruit ripening, creating a microclimate with higher humidity that can increase disease problems. The champa tree is similar to the guava tree, so initially, the pruning recommendations for guava can be followed (Fischer *et al.*, 2012), while establishing a specific pruning protocol for champa.

**Nutrient application and plant hormones.** The nutrition of fruit trees greatly influences the production and quality of their fruits, with proper nutrient management being vital for tree growth and development (Buitrago *et al.*, 2021). Proper nutrient management in fruit trees also helps better control diseases that can affect fruit quality, reducing the use of pesticides to ensure higher sustainability in production systems (Bautista-Montealegre *et al.*, 2022). Fertilization decisions for commercial crops depend on soil and foliar sampling results (Fischer *et al.*, 2012).

In guava, Lozano *et al.* (2002) reported that excessive nitrogen fertilization during flowering induces floral abortion, while near harvest, it restricts post-harvest life. To increase average yields of guava fruit by 45%, as well as the content of TSS, sugars, and ascorbic acid in the fruit, Paull and Duarte (2012) recommend applying urea and phosphate to the leaves at the pre-flowering stage. They also point out that Ca deficiency can cause blossom-end rot in fruits, leading to their abscission.

Due to the effect of potassium on the yield and quality of fleshy fruits (Rengel *et al.*, 2023), trials with foliar application of  $K_2SO_4$  (2%) or  $KNO_3$  (2%) in guava (‘Sardar’) resulted in high-quality physical and chemical fruit parameters (Ritthe *et al.*, 2023). The best results were found when applying 2%  $KNO_3$  in the ‘Allahabad Safeda’ variety (Shukla and Bisen, 2021).

On the other hand, Sau *et al.* (2018) suggest foliar fertilization, combining boric acid with zinc sulfate ( $0.2\% H_3BO_3 + 0.5\% ZnSO_4$ ), which increased the weight, volume, total soluble solids, and ascorbic acid of ‘Allahabad Safeda’ guava fruit compared to the control. Meanwhile, Kumar *et al.* (2017) found higher TSS, ascorbic acid, and fruit firmness, as well as lower acidity, in ‘Taiwan Pink’ guava when applying 3% potassium phosphate via foliar pathway, compared to treatment with zinc sulfate (0.2-0.4%) or urea (2-4%). These results on fruit quality, which are sometimes contradictory, indicate the significant influence of soil and leaf nutritional status, variety, plant age, and climatic zone of cultivation.

Regarding the application of plant hormones in guava, Tiwari *et al.* (2024) applied 200 mg L<sup>-1</sup> of naphthalene acetic acid (NAA) in the “marble” stage of ‘L-49’ guava fruit, with a second application 15 d later. They found this had a very beneficial effect, increasing physical characteristics, yield, and fruit quality (TSS and ascorbic acid) compared to benzyl adenine (BA) and different combinations of the two hormones.

Fischer *et al.* (2020) reported for feijoa that soils with a Ca/Mg ratio  $\geq 10$  develop fruits that are brown, chlorotic, cracked, and have a short shelf life (<3 d post-harvest), which can be controlled with dolomitic lime (3 kg/plant-year) (Quintero, 2003). Also, feijoa plants in soils with pH <5.0 can develop chlorotic fruits, especially in combination with nitrogen deficiencies; for this reason Quintero (2014) recommends

amending with dolomitic lime (3 kg/plant-year) and applying nitrogen fertilizers (urea, 17-6-18-6, or 18-18-18), 500 g every 4 months.

Rupavatharam *et al.* (2016) applied aminoethoxyvinylglycine (AVG), an ethylene synthesis inhibitor, 4 weeks before commercial harvest in 'Unique' feijoa and observed a delay in maturity and a lower ethylene production during storage. However, these fruits increased their titratable acidity content while decreasing soluble solids, compared to fruits not treated with AVG, affecting their maturity ratio.

Arazá performs well with N applications in conditions of poor soil, as well as with P and N in acidic tropical soils, and overall, K appears to be an effective fertilizer for this crop, according to Duarte and Paull (2015). Good results in fruit production have been achieved by applying organic matter in a fractionated form, around 8 kg/plant-year, or by applying 1 kg of chicken manure per plant every three months, increasing the amount every year by 1 kg (Reyes, 2012).

Regarding champa, no fertilization studies have been conducted; there is an urgent need to determine at least the nutritional requirements and main deficiency symptoms. This would provide basic information to develop appropriate fertilization plans for the species. Villachica *et al.* (1996) mention that, for plantings of 6×6 m, it is recommended to apply 10 kg of organic fertilizer and 100 g of triple superphosphate at each site. Champa fruit is highly perishable, and one of the causes of this is its low firmness (Balaguera-López *et al.*, 2022). In this regard, special attention is recommended through fertilization with calcium and boron.

**Irrigation.** It is well known that, in fruit plantations, regular water supply is key to meeting the trees' needs for optimal vegetative and reproductive growth. For feijoa, Duarte and Paull (2015) note that two harvests per year are possible where a bimodal rainfall regime exists.

In these tropical and subtropical fruits, different phenological stages have their own water requirements. Moderate humidity periods promote floral induction, while sufficient soil moisture is required for full flowering, fruit setting, and fruit filling to produce a good number of fruits with adequate size for national and international markets (Fischer and Melgarejo, 2021). These authors also point out that excessive rainfall or over-irrigation during fruit development can make

the fruits watery, with low firmness and low content of sugars, titratable acidity, and ascorbic acid.

In guava, Salazar *et al.* (2006) reported that the trees require a water application of approximately 1,000 to 2,000 m<sup>3</sup> ha<sup>-1</sup> per year. However, Aguilera-Arango *et al.* (2020) observed good crop development and production in areas with a bimodal rainfall pattern, where annual precipitation ranges from 800 to 1,300 mm and is well-distributed. For the arazá crop, approximately 2,500-4,000 mm of precipitation per year (Tab. 1) should be supplied. If rainfall is insufficient, an irrigation system should be used, as a water deficit affects flowering and fructification (Hernández *et al.*, 2006). It has been found that the formation of flower buds is possibly stimulated by rainfall (Hernández *et al.*, 2006). The champa production area has a monomodal rainfall distribution. The tree naturally blooms once a year when the rainy season begins between March and April (Rodríguez *et al.*, 2015), after a prolonged dry period. This is a general indication that a water deficit, followed by a good water supply, is necessary to induce flowering. Some farmers who are able to do so provide irrigation to the trees in the dry season after the rest period because it is a deciduous tropical species. In this way, they have managed to advance flowering and harvest.

**Pollination.** Guava develops bisexual flowers with a 60 to 75% self-pollination rate and a 35% cross-pollination rate, with few problems in fruit set in most clones. If triploid cultivars are to be cultivated, Paull and Duarte (2012) advise establishing them together with diploid clones as pollen donors.

In the case of feijoa, the pollination process is a key reproductive event for the fruit set (Ramírez and Kallarackal, 2017). It is important to note that, besides some self-fertile cultivars (autogamy), others require cross-pollination (allogamy), mainly by birds (e.g., blackbirds) and some insects like bees or hoverflies in commercial plantations (Santos *et al.*, 2022). The first flowers are allogamous and the later ones are autogamous, with cross-pollination resulting in the highest percentage of fruit set, between 80 and 90%, and larger harvested fruits (Quintero, 2012). In Colombia, for establishing a feijoa plantation, Quintero (2014) recommends using cultivars from the CENAF selection: 41, 8-4, 15-1, UN, and K3, planting more than one cultivar in the plantation.

In arazá, after self-pollination (2%), the best pollination is done by bees such as *Apis mellifera* (L.),

*Eulaema mocsaryi* (Friese), *Eulaema bombiformis* (Packard), *Melipona lateralis* (Erichson), *Megalopta* sp., and *Melipona pseudocentris* (Cockerell), ensuring a 25% fruit set (Reyes, 2012).

Champa has white flowers with numerous stamens. The floral characteristics facilitate self-pollination, but cross-pollination is required for successful seed and fruit formation (Nates-Parra *et al.*, 2016). Interestingly, pollen from the same plant can initiate fruit formation, but then abortion occurs, indicating that it is an obligate xenogamous species and requires pollinators (Rodríguez, 2014; Rodríguez *et al.*, 2015). Nates-Parra *et al.* (2016) report that anthesis is diurnal, occurring between 5:30 and 8:00 am and lasting around 10 h, with peak pollination in the morning. The flower is highly aromatic but does not produce nectar, so the only reward for pollinators is pollen. The species has several insect visitors, but the main ones are bees of the *A. mellifera* species and various species of the *Melipona* genus (Calderón-Acero and Nates-Parra, 2013; Rodríguez, 2014). Interestingly, multiple visits from the same species or combined visits from two or more species are required for successful fruit formation (Nates-Parra *et al.*, 2016).

**Phyosanitary status.** Due to climate change and climate variability, uncertainties exist regarding the impacts of some pests and diseases (Tito *et al.*, 2018), which can influence quality and affect food security. Additionally, when grown outside their optimal altitudinal range, crops may suffer from a higher incidence of pests and diseases (Fischer *et al.*, 2024).

The pests that affect the quality of guava fruit are mainly the fruit fly species *Anastrepha striata* (Schiner) and *A. fraterculus* (Wiedemann). To protect improved varieties from these pests or from sunburn, fruits in Colombia are bagged, using polyethylene PE bags with a thickness between 0.5 and 3 mm, measuring 20 cm long by 15 cm wide. These bags are placed on healthy and clean fruits with one month of development (Fischer *et al.*, 2012). This bagging practice is very common in the largest guava-producing country, India, where non-woven polypropylene bags are used, thus controlling pests and diseases and improving quality, especially during the rainy season (Sharma *et al.*, 2020). The most limiting diseases of guava fruit are fruit rot (*Pestalotia versicolor* [Spegazzini] Steyaert) and anthracnose (*Colletotrichum gloeosporioides* or *C. psidii*) (Fischer *et al.*, 2012).

For feijoa, as for guava, the pests that most affect the fruit are the fruit fly (*A. fraterculus*) and lepidopterans

that oviposit on the fruits, known as the “pink worm” (Quintero, 2012). Regarding diseases, *Botrytis* affects the petals and, in the case of intense rainfall, can cause the total loss of flowers and fruits (Quintero, 2012). The blackbird (*Turdus fuscater* Orbigny and Lafresnaye), one of the main pollinating agents, eats the sweet petals of the feijoa, including those affected by *Botrytis*, thus controlling the disease, especially during drier weather conditions (Perea *et al.*, 2010).

Also, in arazá, the fruit fly (*Anastrepha obliqua* [Macquart] and *A. striata*) affects the fruit, as do the weevil *Conotrachelus* sp. and the black bee *Trigona branneri* (Cockerell). The primary diseases of this fruit are anthracnose (*C. gloeosporioides*), brown spot (*Cylindrocladium scoparium* [(Ellis and Everhart) Rossman *et al.*]), and rust *Puccinia psidii* ([G. Winter] Beenken) (Fernández-Trujillo *et al.*, 2011; Reyes, 2012).

In champa, the main pests are *A. striata*, which parasitizes fruits at rates up to 39% (Carrejo and González, 1999), and the coleopteran *Costalimaita ferruginea* (Fabricius) (Villachica *et al.*, 1996).

## GENETIC MATERIAL AND QUALITY

The development of new varieties is essential for fruit trees to maintain fruit production and quality amidst extreme climatic events (Balfagón *et al.*, 2022). In this regard, due to the potential of Myrtaceae crops for producers and national and international markets, as well as their high phyto-genetic value, a country-wide program to find genotypes superior to current ones, in terms of resistance to combined abiotic and biotic stress along with high fruit quality, would greatly contribute to the resistance of these crops against climate change (Valdés-Infante *et al.*, 2012; Fischer and Melgarejo, 2021).

In Colombia consumers prefer large guava fruits with red pulp and oval and oblong shapes that show suitable postharvest behavior (Fischer *et al.*, 2012). The varieties selected as outstanding by the Colombian Corporation for Agricultural Research (Agrosavia) include ‘Palmira ICA-1’ (sweet, known as ‘Pera’), ‘Roja ICA-2’, and more recently, ‘Corpoica Carmín 0328’ and ‘Corpoica Rosa-C’, among others. These two newer varieties, originating from the Guava Germplasm Bank of the Palmira Research Center, are notable for their high yield (>20 t ha<sup>-1</sup>), high vitamin C content (≥75 mg/100 g pulp), and agro-industrial value (>10.4 °Brix, acidity <0.7% citric acid, and

maturity ratio >11.7) (Carabalí *et al.*, 2019). In addition to these selected varieties, the Thai hybrid 'Manzana' meets the preferences of consumers in the country (Fischer *et al.*, 2012). However, no information is currently available on how these varieties behave under conditions of climate change. Additionally, Lozano *et al.* (2002) warn of possible genetic problems in plants propagated from seed, such as early maturity and poor fruit quality.

The CENAF farm (National Feijoa Center) near La Vega township (Cundinamarca) maintains a collection of more than 1,500 accessions of feijoa, from which five cultivars for technified crops were selected: 'Clone 41' (Quimba), '8-4', '15-1', 'UN', and 'K3'. These cultivars produce fruits >60 g and yield >20 kg/plant per year, have smooth skin—especially 'Quimba'—and have a maximum of only 20% of their production classified as inferior quality (industrial) (Quintero, 2012). In order to preserve the quality of feijoa fruit in regions with higher temperatures, particularly to avoid an undesirable increase in the sugar/acidity ratio, Parra-Coronado and Fischer (2013) recommend selecting genotypes that do not exhibit this trait. Likewise, there is a need to develop new feijoa varieties with a reduced content of the unpleasant soluble oxalate (Zhu, 2018).

In arazá, no varieties have been developed, but two subspecies have been recognized: *Eugenia stipitata* subsp. *stipitata* and *E. stipitata* subsp. *Sororia*. The latter is considered the cultivated type (Reyes, 2012) and exhibits habits akin to a shrub (Duarte and Paull, 2015).

For champa, there are no reports of varieties; the cultivated species is *Campomanesia lineatifolia* Ruiz & Pavon. However, the heterogeneity in the size and organoleptic quality of the fruit suggests that, in addition to environmental and management conditions, there could be genetic variability.

## FRUIT GROWTH, YIELD, HARVEST AND QUALITY

The four Myrtaceae species in this review are climacteric fruits, meaning that their growth and development can continue when they are attached to the plant or after harvest, depending on their stage of development (Fischer *et al.*, 2018). The optimal maturity stage at harvest depends on the destination of the fruit and greatly affects its post-harvest life and commercialization (Parra-Coronado, 2014).

As previously mentioned, guava shows high variation among its varieties in terms of growth, physicochemical composition, and fruit yield (Fischer *et al.*, 2012). Depending on the cultivar, TSS can increase from 3% in green fruits to over 10% in mature ones, and total titratable acidity from 0.2 to 1.5% (Paull and Duarte, 2012), with large differences between varieties. Due to the decrease in temperature with altitude, the content of organic acids increases in several guava varieties (Solarte *et al.*, 2014), while TSS increases with the average temperature of the site (Chiveu *et al.*, 2019).

Paull and Duarte (2012) report average guava yields in Hawaii of 26.9 t ha<sup>-1</sup>, while in Colombia, yields only reach half that, averaging 13.3 t ha<sup>-1</sup> (Tab. 1) (MinAgricultura, 2024). This disparity indicates an urgent need for improvements in Colombian guava cultivation. Guava fruit development follows a simple sigmoid curve that can last between 120 and over 220 d depending on the temperature of the plantation site, with differences between varieties of up to 60 d to reach the maturity period (Paull and Duarte, 2012). Harvesting later than the optimal maturity index indicated in table 3 carries the risk of fruit fly stings and subsequent larval development in the pulp (Paull and Duarte, 2012). Additionally, bioactive compounds and antioxidant capacity in guava vary according to

**Table 3. Recommended harvest index for the four Myrtaceae fruits.**

Specie	Maturity index of harvest <sup>1</sup>	Author
Guava	Color changes from green to yellow with initial softening of the pulp	Paull and Duarte, 2012
Feijoa	Fruit detaches from the peduncle; lower consistency in the equatorial zone of the fruit	Schotsmans <i>et al.</i> , 2011
Arazá	Skin color "hue" value (h*) of about 110° (dull green), pulp firmness of 30 N, with a titratable acidity (TTA) of 300 mmol L <sup>-1</sup> of H <sup>+</sup>	Fernández-Trujillo <i>et al.</i> , 2011
Champa	Color changes from green to yellow. Fruits that are 100% yellow (L*: 76.2, a*: -3.4, b*: 51.3) exhibit optimal organoleptic characteristics but have a short postharvest life	Balaguera-López and Herrera, 2012

<sup>1</sup>The index can vary depending on the destination of the fruits and particular export requirements.

the developmental stage and variety. While Shukla *et al.* (2018) observed a decline in bioactive constituents and antioxidant capacity during fruit development, except for vitamin C, which increases with ripening, Araújo *et al.* (2015) detected the opposite, i.e., a decrease in ascorbic acid content and an increase in flavonoids with fruit maturity.

Commercial production of feijoa begins in the sixth year (Quintero, 2014). At full production (from the 6th year onwards), a feijoa orchard can yield between 20 and 25 t ha<sup>-1</sup> (30-40 kg/tree) (Thorp, 2008). However, the national average yield is 9.2 t ha<sup>-1</sup> (Tab. 1) (MinAgricultura, 2024), which Quintero (2014) attributes to the planting of unimproved genetic material. Fruit development, as observed by its weight and diameter, follows a simple sigmoidal curve, similar to guava (Galvis, 2003). According to Quintero (2012), feijoa fruit takes between 120 and 150 d to reach harvest maturity, depending on the variety and cultivation conditions. However, Parra-Coronado *et al.* (2015a) reported waiting up to 180 d for the Quimba variety in Tenjo (Cundinamarca). Parra-Coronado *et al.* (2016) developed a logistic sigmoidal growth model for feijoa fruit weight as a function of thermal time and elevation of the production area. Since feijoa is a green fruit, determining harvest maturity requires significant experience. Indicators include peduncle detachment, fruit firmness (Tab. 3), fruit shape and size, and shade of green (Parra-Coronado and Fischer, 2013). In optimal conditions with very abundant feijoa production, Duarte and Paull (2015) suggest thinning out unsuitable fruits (very small or deformed) at their early stage of development to promote the size and quality of the remaining fruits.

Significant yields in arazá begin in the third year, and by the fifth year, arazá production reaches peak yields, with an adult tree producing between 10 and 35 kg of fruit per year, throughout the year, if soil moisture and temperatures are optimal (Duarte and Paull, 2015). The arazá fruit growth behavior pattern follows a sigmoidal curve fitted to a logistic model. The period between fruit set and full ripening of fruit grown in the Colombian Amazonia was 55±5 d (Hernández *et al.*, 2007). Fruits destined for the fresh market should be harvested when they are green and beginning to turn yellow (breaker), following the indications given by Fernández-Trujillo *et al.* (2011; Tab. 3). Fruits harvested when fully green do not ripen later (Galvis and Hernández, 1993), and fruits harvested later than the breaker stage are only suitable for processing. Fruits harvested at the breaker stage

ripen in 2-3 d to a fully yellow and very soft texture, requiring daily harvesting (Duarte and Paull, 2015).

Currently, champa is propagated sexually through seeds (Porras *et al.*, 2020), mainly due to a lack of knowledge about more appropriate methods. This results in a delay in the onset of production of around 5 years and generates variability in quality. Harvesting of this species is annual, with a harvest period of 80 to 90 d per year and a peak production in September (López and Rodríguez, 1995). This limited harvest period reduces market availability, limiting its popularity to production areas (Villachica *et al.*, 1996). Champa tree production can range from 5 kg for young trees to 500 kg for adult trees, and a tree can remain productive for over 20 years (López and Rodríguez, 1995; Álvarez-Herrera *et al.*, 2009). Yield estimates for champa are very general; statistical figures from MinAgricultura (2024) indicate a yield of 11.07 t ha<sup>-1</sup> (Tab. 1). Harvesting is done every third day, and up to 75 kg per tree can be collected in each harvesting session (Álvarez-Herrera *et al.*, 2009). The maturity index used by producers for harvesting is from green to yellow (Tab. 3), although fruits are most commonly collected directly from the ground (Nates-Parra *et al.*, 2016).

As mentioned earlier, harvesting can be done between 145 and 160 d after full bloom (Balaguera *et al.*, 2009; Balaguera-López *et al.*, 2012). Champa exhibits a sigmoidal pattern of development (Balaguera *et al.*, 2009; Balaguera-López *et al.*, 2012), and is a climacteric fruit, undergoing rapid softening during ripening. This process is influenced in part by polygalacturonase activity, a high sugar content, and a high acid content, which, along with volatile compounds, give it an exquisite flavor and aroma. The predominant sugar is sucrose, and the most concentrated acid is citric acid (Balaguera-López *et al.*, 2022). All these production and quality characteristics should be studied in more detail, as the pre-harvest factors affecting them are not yet fully understood.

### Preharvest conditions and phytochemical fruit quality

Tropical and subtropical fruits, including those of the Myrtaceae family, contain a wide range of bioactive compounds, antioxidants, and free radical scavenging properties which may provide potential health benefits for humans (Fernández-Trujillo *et al.*, 2011). Antioxidants in the fruit, particularly phenolic

compounds, act as reducing agents against reactive oxygen species (ROS) (Amarante *et al.*, 2017).

The qualitative and quantitative content of phytochemicals can be affected by various conditions that may negatively alter the nutraceutical value of these fruits (Yahia, 2017). Climate conditions, particularly changes in climate, affect fruit quality components and their physiological behavior, influencing the production of secondary metabolites and their functional properties (Ali *et al.*, 2021). Pre-harvest conditions, such as climate, soil, or crop management, influence the development of important phytochemicals in the fruit (Yahia *et al.*, 2019a), and when these conditions closely align with the crop's needs, its genetic potential can be maximized (Pérez and Melgarejo, 2015).

To increase the content of phytochemical compounds in horticultural products, Schreiner (2005) suggests various cultural practices, including species and variety selection, nutrition, water management, and selection of production season harvest time, with prerequisite research into the interactions between genotype, eco-physiological effects, and phytochemical formation in the fruit. Yahia (2017) notes a general lack of information from the tropical and subtropical regions on the influence of crop management (fertilization, soil, irrigation, pruning, plant hormones, protected cultivation, among others) on these bioactive compounds. Furthermore, environmental conditions and physiological factors can modify the expression of phytochemical compounds; however the genetic aspect of the variety is the most determining factor (Schreiner, 2005).

As phytochemicals are substances that protect plants against different types of stress, their concentration can increase under conditions such as drier soil conditions or high solar radiation (Schreiner, 2005; Yahia *et al.*, 2019a). As UV radiation increases in plantations with higher elevation, the concentration of antioxidants in the fruit increases (Fischer *et al.*, 2022a). In particular, carotenoids are pigments that play a crucial role in adaptation to high solar radiation (Yahia *et al.*, 2019b). Light is a determining factor in the accumulation of carotenoid and anthocyanin pigments in fruits, as it affects the expression of genes related to pigment synthesis in the fruit (Benkeblia *et al.*, 2011). Carotenoids protect chlorophylls from light damage (Yahia *et al.*, 2019b). Similarly, Zoratti *et al.* (2014) indicate that the intensity of radiation influences flavonoid metabolism, increasing their concentration in plant tissues exposed to full sunlight.

Muñoz-Ordoñez *et al.* (2023) found that lower radiation due to increased rainfall negatively impacted passion fruit, decreasing antioxidant capacity and ascorbic acid in the fruit compared to the previous harvest cycle with drier weather and good solar radiation.

As shown in table 4, guava has a higher content of ascorbic acid, total phenols, antioxidant activity and carotenoids than the other three Myrtaceae studied (lycopene) (Prado *et al.*, 2017). Some researchers found that varieties with red pulp have lower phytochemical content than white ones (Singh, 2011); however, the 'Regional Roja' variety tended to have higher concentrations of bioactive compounds than the 'Regional Blanca' in Santander (Colombia) (Rojas-Barquera and Narváez-Cuenca, 2009). Espinal *et al.* (2012) found that the Regional Roja and Palmira ICA varieties showed lipophilic antioxidant activity significantly higher than the Regional Blanca variety, with the lipophilic antioxidant activity of the Regional Roja variety strongly influenced by  $\beta$ -carotene. Additionally, Olaya and Restrepo (2012) report that higher concentrations of vitamin C and phenols have been found in the guava fruit epidermis than in the pulp, possibly to better protect against diseases and pests and especially, against UV radiation, thus avoiding damage to the fruit's internal tissues.

Paull and Duarte (2012) indicated that the concentration of ascorbic acid increases with increasing solar radiation in guava; however, there may be limits to the levels tolerated by this species, as Solarte *et al.* (2014) observed a decrease in vitamin C with radiation exceeding  $2,000 \mu\text{mol photons m}^{-2} \text{s}^{-1}$ .

Regarding feijoa, Zhu *et al.* (2018) highlight the high content of phenolic compounds that provide this fruit with excellent antioxidant properties (Tab. 4). Fourteen genotypes from Uruguay showed phenol content in the pulp, containing catechin, quercetin, ellagic acid, gallic acid, rutin, syringic acid, pyrocatechol, eriodictyol, and eriocitrin (Monforte *et al.*, 2014), in addition to a level of vitamin C and bioflavonoids (Pasquariello *et al.*, 2015). Several feijoa varieties have a higher concentrations of antioxidants in the fruit skin than in the pulp, as found by Amarante *et al.* (2017) in the Mattos, Nonante, and Helena varieties, for total phenols and total antioxidant activity (ABTS method), making the fruit skin an important source of nutrients and bioactive compounds in this species.

**Table 4. Important bioactive substances and antioxidant activity determined in the pulp of mature Myrtaceae fruits.**

Species, variety	Antioxidants <sup>1</sup>	Reference
Guava, var. Regional Roja	Ascorbic acid: 206.6 mg 100 g <sup>-1</sup> Total phenols: 508 mg AG 100 g <sup>-1</sup> Antioxidant activity ABTS: 107.3 Antioxidant activity FRAP: 77.0 Antioxidant activity DPPH: 26.1	Rojas-Barquera and Narváez-Cuenca, 2009
Feijoa, var. Triumph	Ascorbic acid: 38.5 mg 100 g <sup>-1</sup> Total phenols: 178.5 mg AG 100 g <sup>-1</sup> Total flavonoids: 28.8 mg CE 100 g <sup>-1</sup> Antioxidant activity DPPH: 2.1	Pasquariello <i>et al.</i> , 2015
Arazá	Ascorbic acid: 8.9 mg 100 g <sup>-1</sup> Total phenols: 111 mg AG 100 g <sup>-1</sup> Antioxidant activity ABTS: 20.2 Antioxidant activity FRAP: 11.4	Contreras-Calderón <i>et al.</i> , 2011
Champa (fruit) Champa (dry pulp)	Ascorbic acid: 74.44 mg 100 g <sup>-1</sup> Total phenols: 229.37 mg AG 100 g <sup>-1</sup> Antioxidant activity ABTS: 14.54 Antioxidant activity FRAP: 31.44 mg of trolox g <sup>-1</sup> dry pulp Antioxidant activity DPPH: 11.36 mg of trolox g <sup>-1</sup> dry pulp	Lima <i>et al.</i> , 2016; Otalvaro-Álvarez <i>et al.</i> , 2017

<sup>1</sup>All measurements related to fresh weight. GA: gallic acid; ABTS: 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid); FRAP: ferric reducing antioxidant power; DPPH: 1,1-diphenyl-2-picrylhydrazyl; CE: catechin equivalent. Antioxidant activity is expressed in  $\mu\text{mol Trolox equivalents/g}$  fresh weight.

Also, the content of these bioactive substances can be much higher in the seeds than in the pulp (Tab. 4), as found by Contreras-Calderón *et al.* (2011) in arazá, where the antioxidant activity in the seeds, according to the FRAP and ABTS methods, was 258 and 440, respectively, and total phenols were 1,624 mg GAE 100 g<sup>-1</sup>. Acosta-Vega *et al.* (2024) reported that arazá fruit is rich in bioactive compounds in its three fractions (seed, pulp, and peel), such as ascorbic acid, phenolic compounds (and their derivatives), and carotenoids.

As mentioned above, the genetic aspect of the variety is the most determining factor in the quality and quantity of phytochemical compounds; all studies have shown marked differences between varieties, as found by Pasquariello *et al.* (2015) with 12 feijoa varieties in Brazil, determining total phenols, ascorbic acid, total flavonoids, and antioxidant activity.

The champa fruit has a significant content of ascorbic acid, which is even higher than that of feijoa and arazá, with moderate antioxidant activity (Tab. 4), making it suitable for regular consumption. Otalvaro-Álvarez *et al.* (2017) indicate that this fruit is an important source of phenolic compounds with antioxidant activity useful for the agrifood industry, for example, as natural additives to extend the shelf life of different products.

To improve the study of the functional properties of fruits, it is highly recommended to expand the monitoring of pre- and post-harvest influences on the content of these phytochemicals (Schreiner, 2005).

## CONCLUSIONS

The fruits of the Myrtaceae family stand out for their good nutritional, bioactive, and other promising characteristics. Among these myrtaceous plants, the most commercially cultivated in Colombia are guava, feijoa, arazá, and champa.

Each of these species and varieties thrives in its own specific soil, climate, and altitude range, which define its quality. Additionally, specific cultural practices are needed to maximize their genetic potential. The fruits of guavas and feijoas stand out for their high content of phytochemicals (phenols, ascorbic acid, carotenoids, and antioxidant activity), which not only help the plant defend against stress conditions but also offers benefits to human consumers by counteracting chronic diseases.

Unfortunately, there is a lack of studies on these crops, for example, regarding the most suitable cultural practices to increase these bioactive compounds

in the fruit. More research is needed in the country to improve the quality and production of these fruits, especially champa, which is mainly cultivated in Boyacá and is the least studied.

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