

Ecophysiological aspects of guava (*Psidium guajava* L.). A review

Aspectos de la ecofisiología de la guayaba (*Psidium guajava* L.). Una revisión



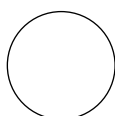
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Fruiting guava plant.

Photo: G. Fischer

ABSTRACT

Guava, because of its ability to grow in tropical and subtropical climates, has been introduced to some 60 low-latitude countries. It is adapted to a temperature range between 15 and 30°C. Outside this range, the effect of lower or higher temperatures reduces fruit set, while night temperatures of 5 to 7°C stop growth. Additionally, low temperatures hinder production, causing flowers to fall or increasing the fruit development cycle, up to 220 days. When estimating the cardinal temperatures of development, the minimum threshold temperature was 10.9°C, the optimum temperature was 17.3°C, and the maximum threshold temperature was 51.2°C. The guava tree adapts well to altitudes between 0 and 2,000 m a.s.l. in Colombia; however, there is a high genotype×environment interaction for production and quality characteristics in fruits with respect to the orchard elevation. Radiation >2,000 $\mu\text{mol photons m}^{-2} \text{s}^{-1}$ decreased the fruit ascorbic acid content. An important ecophysiological factor in guava is water, and crops require between 1,000 to 2,000 mm year⁻¹. It withstands waterlogging for several days, but excess precipitation and atmospheric humidity decrease fruit quality considerably. However, this tree is classified as moderately drought-tolerant to stress from water deficits, affecting flowering and fruit set. It is also moderately tolerant to salinity, depending on the variety, supporting electrical conductivities up to 1.5-1.8 dS m⁻¹. Generally, guava can be cultivated in a wide range of tropical and subtropical areas, where it is preferred because of its high nutritional and medicinal contents and its aptitude for transport and handling.



Additional keywords: temperature; altitude; humidity; fruit quality; salinity.

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RESUMEN

La guayaba, debido a su habilidad de crecer en climas tropicales y subtropicales, ha sido introducida en unos 60 países de las latitudes bajas. Se adapta a rangos de temperatura entre los 15 y 30°C. Fuera de este rango, el efecto de temperaturas inferiores o superiores reducen, en primer lugar, el cuajamiento de los frutos, y temperaturas nocturnas de 5 a 7°C detienen el crecimiento. Adicionalmente, las temperaturas bajas dificultan la producción generando caída de flores o aumentando el ciclo de desarrollo del fruto hasta unos 220 días. En una estimación de las temperaturas cardinales de desarrollo se encontraron como temperatura umbral mínima 10,9°C, temperatura óptima 17,3°C y temperatura umbral máxima 51,2°C. El árbol de guayaba se adapta bien a altitudes entre 0 y 2.000 msnm en Colombia; sin embargo, existe alta interacción genotipo (variedad)×ambiente referente a las características de producción y calidad del fruto con respecto a la elevación del sitio. Radiaciones >2.000 $\mu\text{mol fotones m}^{-2} \text{ s}^{-1}$ disminuyeron el contenido del ácido ascórbico en el fruto. Un factor ecofisiológico importante en la guayaba es el agua ya que los cultivos exigen entre unos 1.000 a 2.000 mm año⁻¹. Soportan el anegamiento de varios días; pero mucha precipitación y humedad atmosférica disminuyen la calidad del fruto considerablemente. No obstante, este árbol está clasificado como moderadamente tolerante a la sequía, el estrés por déficit hídrico afecta la floración y el cuajamiento de los frutos. Es también moderadamente tolerante a la salinidad, dependiendo de la variedad, con conductividades eléctricas hasta máximo 1,5-1,8 dS m⁻¹. En general, se puede concluir que la guayaba se puede cultivar en una amplia gama de áreas tropicales y subtropicales donde es preferida por su alto contenido nutricional y medicinal y su aptitud para el transporte y manejo.

Palabras clave adicionales: temperatura; altitud; humedad; calidad fruto; salinidad.

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INTRODUCTION

Because of the continuous production and supply of tropical fruits, it is possible to increase cultivation and export (Blancke, 2016). This opens a world of possibilities for improving local and global consumption with healthy foods (Viera *et al.*, 2019). Most of the so-called “exotic fruits” are important functional foods (Moreno *et al.*, 2014; Campos *et al.*, 2018) and are highly valued, not only in tropical and subtropical countries but also by consumers in higher latitudes (Ramadan, 2011). This trend has greatly benefited Andean countries with increasing export volumes since the beginning of the 21st century (Moreno-Miranda *et al.*, 2019).

Plants require an abiotic environment to develop (Jalil and Ansari, 2020). Thus, ecophysiological studies are of utmost importance for the physical and biotic factors of the environment in terms of physiological processes in plants and interaction mechanisms that affect growth and development (Lambers *et al.*, 2008; Fischer *et al.*, 2016). Environmental conditions must be as close to optimal as possible for a plantation to achieve the highest crop production and quality, which are determined by the genetic potential (Pérez and Melgarejo, 2015). Most of the time, plants

are grown under conditions that are not suitable for maximum development, with yields that are much lower than the maximum recorded for the species as a consequence of suboptimal environmental conditions (Raza *et al.*, 2020). Thus, ecophysiology is closely related to environmental conditions that affect plants when conditions are not optimal for growth and development. Very small changes in abiotic factors, far from the optimum for the species, can manifest as stress for plants and have considerable effects on production (Jalil and Ansari, 2020).

Climatic factors, such as temperature, relative humidity, vapor pressure deficit, solar radiation, rain and wind, in addition to altitude, affect the ecophysiology of cultivated plants the most (Restrepo-Díaz and Sánchez-Reinoso, 2020). At low latitudes, the inner tropics lack pronounced temperature seasons, similar to temperate climate zones; consequently, the rainy and dry seasons determine to which the plant physiology reacts and adapts (Fischer and Parra-Coronado, 2020).

Several abiotic factors always act simultaneously on plants, with little research (Raza *et al.*, 2020); unlike

studies in controlled environments that allow only one or very few factors to vary, but which do not agree with the multidimensionality (Mittler, 2006) in which all factors occur under field conditions. For this reason, more ecophysiological studies on crops are required because climate change requires the re-evaluation of previous results (Restrepo-Díaz and Sánchez-Reinoso, 2020).

According to Marengo *et al.* (2011), climate change will not affect low areas in the tropics as much. However, the Andean areas will increase rainfall by 20 to 25%. This phenomenon will consequently accelerate events such as “La Niña”, causing prolonged flooding, accompanied by less solar radiation (Ramírez and Kallarackal, 2018; Sánchez-Reinoso *et al.*, 2019; Arteaga and Burbano, 2018). Furthermore, climate change increases warming more in higher regions of the tropics than in valleys (Marengo *et al.*, 2011).

Shukla *et al.* (2019) classified fruits and vegetables within the species most affected by climate change, where yield and quality tend to decrease as warming increases, mainly in tropical and subtropical areas. Also, Haokip *et al.* (2020) attributed the fact that fruit trees have a higher incidence of physiological disorders, problems in pollination and changes in phenology to climate change. In addition, there are many uncertainties in terms of the impacts of pests and diseases in a changing climate (Tito *et al.*, 2018), which influence fruit quality and food security.

However, Devenish and Gianella (2012) and Raza *et al.* (2020) stated that atmospheric warming can increase fruit production for trees in a given site. In addition, in the Andean region, there are suitable plots at higher altitudes that have the optimum temperature of this crop (Tito *et al.*, 2018) and optimal physiological or ecological conditions. Likewise, DaMatta *et al.* (2010) concluded that C3 plants, which are almost all fruit trees, could produce higher yields as the result of increased atmospheric CO₂ and use less water if no other stress conditions arise because of altered regional patterns of precipitation and temperature.

Guava (*Psidium guajava* L.) is an evergreen tree that is native to Mesoamerica and South America (Solarte *et al.*, 2014), possibly from Mexico to Peru (Menzel, 1985) or from Central America and southern Mexico (Blancke, 2016). Paull and Duarte (2012) and Bandera and Pérez (2015) observed the origin as “simply” being the tropical region of the Americas. Thanks to its ability to grow in tropical and subtropical climates, it

has been introduced in many low-latitude countries (Singh *et al.*, 2019). It has its highest production in India, Brazil and Mexico (Mishra *et al.*, 2014) and on the continents South America, Asia and Australia (Singh *et al.*, 2019). It is important for the domestic economy of more than 60 countries in the tropics (Bandera and Pérez, 2015).

The popularity of guava arises from its availability throughout the year, affordable price, high nutritional and medicinal contents, aptitude for transport and handling, and consumer preference (Methela *et al.*, 2019).

In Colombia, Agronet (2020) reported a production of 80,814.7 t for 2018, harvested on 7,628.2 ha, mainly in the departments Boyaca (2,351.0 ha), Santander (1,790.6 ha), Tolima (841.0 ha) and Valle del Cauca (693.6 ha). 69% is for fresh consumption, and the rest is used for making sweets, known as bocadillo (López-Santos *et al.*, 2017).

The guava plant belongs to the myrtaceae family, known for its botanical richness and very high agro-industrial potential with 121 genera and 5,800 species of aromatic fruits, classified by Farias *et al.* (2020) as one of the more important commercial families globally.

Some 150 species belong to the genus *Psidium* (Ligarreto, 2012), and most of the cultivars are *P. guajava*. However, there are other species of *Psidium* known as *P. cattleianum*, *P. molle*, *P. guineense*, *P. friedrichsthalianum*, and *P. montanum*, among others (Rai and Jaiswal, 2020). *P. guajava* is the most cultivated in the world (Aguilera-Arango *et al.*, 2020). Most of the species of the genus *Psidium* are native fruit trees from the tropical and subtropical Americas (Fischer *et al.*, 2012).

The fruits have high levels of ascorbic acid (0.6-6.0 g kg⁻¹ edible fruit), vitamin A, calcium, phosphorus, potassium and dietary fiber (Paull and Duarte, 2012; Prado *et al.*, 2017). In addition, they are used because of their antimicrobial, anti-inflammatory, antigenotoxic, and hepatoprotective properties and for the treatment of diabetes and diarrhea (Pérez-Gutiérrez *et al.*, 2008). Its consumption reduces triglycerides, cholesterol and blood pressure (Singh, 2007). Its flavor is bittersweet, combined with a pleasant aroma, and it is consumed fresh or processed into products such as freshly cut salads, juice, nectar, cake, puree, concentrates, jam, and gelatin, among others (Singh, 2011).

Paull and Duarte (2012) characterized guava as a shrub, which, under good humidity conditions, can grow up to 6 to 9 m in height, forming trunks up to 30 cm or more in diameter. By pruning and training, only one stem is developed, with a height of up to 3 or 4 m with flexible branches and young square twigs that become rounded with age. Yadava (1996) described the guava tree as having undemanding growth with a symmetrical and pyramidal shape. It forms bisexual flowers that are 2.5-3.0 cm in diameter, with autogamous reproduction, considerable self-pollination (60-75%) and 35% cross-pollination (Fischer *et al.*, 2012; Menzel, 1985).

The fruit contains many seeds and is botanically a berry with spherical ovoid or pyriform shapes depending on the variety, with diameters that vary between 2.5 and 10.0 cm, skin colors between light green and yellow and white to red pulps (Parra-Coronado, 2014). There are about 400 varieties in the world (Bandera and Pérez, 2015). Paull and Duarte (2012) reported that this short-cycle fruit tree begins to produce one year after planting, with maximum production at three or four years.

Because these promising crops have great potential for producers and international markets, ecophysiological impacts on quality and production characteristics (Mayorga *et al.*, 2020) must be elucidated for the development of guava crops. Therefore, the objective of this review was to reveal climatic demands and their effects on the physiology of plants, providing the basis of processes that have taken place for the adaptation and diffusion of the species and useful information for management and breeding programs.

ECOPHYSIOLOGICAL FACTORS AND THEIR INFLUENCE ON GUAYABA

There are diverse semi-wild and commercial forms, with very diverse morphological and nutritional characteristics (Solarte *et al.*, 2014); however, plant breeding programs must develop cultivars with increasingly superior fruit qualities and resistance to abiotic and biotic stress (Thaipong and Boonprakob, 2005). The guava tree blooms and produces at different times depending on the site, climatic characteristics, soil and crop management (Bandera and Pérez, 2015), as well as the genotype and the climatic conditions, which affect the growth cycle (Salazar *et al.*, 2006). Singh (2011) confirmed that flowering and

fruiting occur continuously throughout the year in tropical and mild subtropical climates.

Temperature

According to Gómez and Rebolledo-Podleski (2006) and Salazar *et al.* (2006), the temperature range for the cultivation of guava is between 18 and 28°C and between 15 and 30°C, respectively; while Paull and Duarte (2012) concentrated this range from 23 to 28°C for optimal tree performance. Temperatures lower and higher than this range reduce fruit setting, and very low night temperatures (5-7°C) paralyze growth and turn leaves purple (Nakasone and Paull, 1998). If temperatures drop to 3°C, the fruit no longer ripens (Insuasty *et al.*, 2007). Sentelhas *et al.* (1996) found the lethal temperature for guava was -4°C and rated it as not very tolerant to low temperatures. Paull and Duarte (2012) reported that prolonged low temperatures of -2°C burn young plants.

Ferreira *et al.* (2019) estimated the cardinal development temperatures for guava seedlings, applying 12 different models with methodologies based on the standard deviation of the accumulated degree days of growth, calculating the base (minimum) temperature as 10.9°C, the optimum as 17.3°C and the maximum as 51.2°C. There is little information on cardinal temperatures in fruit species, which are very useful for studies on adaptation to different microclimates (Souza and Martins, 2014).

Fruits react to unfavorable conditions for their development and quality. It has been observed that, at elevated temperatures, they are more aqueous, with low sugar and ascorbic acid contents (Souza *et al.*, 2010). In addition, under conditions of high temperatures and humidity during the development of the fruit, they become very susceptible to attacks by fruit flies (Haokip *et al.*, 2020).

Low temperatures, such as during the winter months in the subtropics, make commercial production very difficult, increasing the time of fruit development to about 220 days (Paull and Duarte, 2012), and, if the cold season is also dry, these combined stress factors lead to natural defoliation and flowering will begin as soon as temperatures rise and rain induces a new flow of growth and fruit set (Nakasone and Paull, 1998). Haokip *et al.* (2020) stated that flower drop occurs in guava when low temperatures prevail during flowering. Floral opening depends on the daytime temperature (Bandera and Pérez, 2015).

In subtropical areas, very high summer temperatures can impair the content of sugars and organic acids in fruits, which are used in respiratory processes (Solarte *et al.*, 2014). In comparison, these authors found an increase in ascorbic acid with increasing temperature and relative humidity at tropical altitudes between 1,570 and 1,890 m a.s.l.

Salazar *et al.* (2006) measured the phenological stages of guava by also calculating the degree days of growth, adding the differences between the mean daytime temperatures and the base temperature of 12.0°C, which was recorded when the development of the flower bud began, comparing the development of the plant between the different years and geographical sites.

Radiation

Paull and Duarte (2012) found that a greater number of hours of sunlight leads to greater growth of the branches. Also, the concentration of ascorbic acid increases with increasing light intensities; however, Solarte *et al.* (2014) recorded a decrease in this acid with radiation $>2,000 \mu\text{mol photons m}^{-2} \text{s}^{-1}$.

Altitude

According to Solarte *et al.* (2014), the ecophysiological effect of altitude on the guava plant depends mostly on the variety but the concept of multidimensionality of Mittler (2006) must be considered because increasing altitudes decrease the temperature (about 0.6°C/100 m), the partial pressure of the air (O_2 , CO_2 and N_2) and the relative humidity, while radiation (visible, UV and infrared), rain (from 1,300-1,500 m a.s.l.) and wind increase (Fischer and Orduz-Rodríguez, 2012).

However, since guava is a native species of the tropics, adaptation to these ranges of altitude (Tab. 1) has

allowed it to be distributed in the subtropics and numerous countries of the world (Natale *et al.*, 2008).

Solarte *et al.* (2014) studied the effect of three altitudes (1,570; 1,720 and 1,890 m a.s.l.) on fruit quality in four guava genotypes grown in a traditional semi-wild system in the Department of Santander, Colombia with a bimodal rainfall regime (average rainfall/year of 1,780 mm and temperature of 20°C). In this study, the environmental factors that were associated with altitude and resulted in differences in fruit quality between the genotypes included the vapor pressure deficit (VPD), the maximum photosynthetic photon flux density (PPFD_{max}) and the temperature difference between day and night (ΔT°). It was observed that, at low altitudes (with higher temperature and solar radiation), the fruits had a higher fresh weight and changed faster from green to yellow; while, in general, the content of organic acids increased with increasing altitude. Likewise, the higher altitude conditions promoted efficiency in the accumulation of the monosaccharides fructose and glucose, but only in two of the four genotypes. Solarte *et al.* (2014) stated that there was a genotype $\times$ environment interaction effect on all variables because not all genotypes reacted uniformly.

Musyarofah *et al.* (2020) evaluated 'Kristal' guavas from low (200 m a.s.l.) and middle (550 m a.s.l.) altitudes in Indonesia and found that fruits from the low elevation were heavier and bigger, with a higher vitamin E-content than in those grown in the middle altitude farm, with fruits that were crispier and not as soft as the low elevation ones.

Water

Water is essential for all reproductive phases of guava (Fischer *et al.*, 2012). In a high Andean phenological study on the agrometeorological influences on the reproductive phase of plants, Mendoza *et al.* (2017)

Table 1. Recommended altitudes for growing guava.

Altitude (m a.s.l.)	Annotation	Author
0 – 2,300	Ecuador	Morton (1987)
0 – 2,000	Grows in a wide range of altitudes	Solarte <i>et al.</i> (2014)
0 – 1,800	Venezuela	Hoyos (1989)
0 – 1,700	This range favors the distribution	Natale <i>et al.</i> (2008)
0 – 1,500	In frost-free places	Paull and Duarte (2012)

found that rain is the climatic factor that most promotes this reproductive phase (73.4%), when compared to temperature (19.3%), followed by solar radiation or the photoperiod (3.2%).

Salazar *et al.* (2006) reported that guava trees need a water supply of about 1,000 to 2,000 m³ ha⁻¹ year⁻¹, but Aguilar-Arango *et al.* (2020), in areas with a bi-modal system, annual rainfall of 800 to 1,300 mm that is well-distributed, saw good development and production of the crop. On the other hand, Natale *et al.* (2008) stated that the ideal range of rainfall is 1,000 to 1,600 mm, well-distributed throughout the year, but it should not be less than 600 mm year⁻¹. In turn, because of the relative tolerance of guava to waterlogging (Crane *et al.*, 2019), Hoyos (1989) reported that these plants can be grown in regions with rainfall between 1,000 and 3,000 mm per year; however, the same author reported that periods of excessive rains during the development of the fruit can cause cracking and harvest losses.

Excessive rains during fruit development make them more watery, with less firmness and reduced contents of sugars, titratable acidity and ascorbic acid. According to Souza *et al.* (2010), the values varied depending on the precipitation volumes and the ripening stages of the fruits. Menzel (1985) confirmed that excess water during the fruiting period increases the cracking and fall of fruits, similar to those of cape gooseberry (Fischer and Melgarejo, 2020). Sharma *et al.* (2020) reported that, in India, many crops in the summer rainy season are discarded because of poor commercial quality and found that bagging fruits with polypropylene non-woven bags is very beneficial for controlling pests and diseases and improving the harvest quality during the rainy season.

The favorable contribution of water in guava is not only essential for full vegetative growth but also in the beginning of the reproductive phase, in flowering, and in the setting and filling of fruits; therefore, in nature, flowering begins with the rainy season (Fischer *et al.*, 2012; Paull and Duarte, 2012). The sprouting of the terminal branches that will carry the flowers requires an optimal supply of humidity (Mata and Rodríguez, 2000). These same authors reported that a minimum rainfall of 127 to 178 mm per month is required in Hawaii and that irrigation is applied to advance flowering, which also allows scheduling the harvest (Aguilar-Arango *et al.*, 2020).

To replace the evaporated water in a guava plantation (25-50 mm/week), Nakasone and Paull (1998)

suggested drip irrigation. In larger plantations that receive irrigation by sectors, they recommend sprinkler or microjet systems that, additionally, provide the nutrients quickly to the plant. Likewise, to guarantee the economic sustainability of a crop, Aguilar-Arango *et al.* (2020) suggested the application of irrigation, modification of the pruning season, and scheduling the main harvest taking into account the fact that pruned plant needs enough water for the development of new shoots.

Crane *et al.* (2019) classified the guava tree as tolerant to waterlogging, while Morton (1987) categorized it as moderately tolerant to waterlogging. Kongsri *et al.* (2020) observed that guava trees propagated by seedlings were more tolerant than those propagated by shoot layering under flooding conditions. Solarte *et al.* (2010) reported that prolonged rainfall can cause alterations in the normal production cycle in the Suarez river basin (Department of Santander, Colombia), which shorten harvest times. On the other hand, these authors observed an increase in the foliar anthocyanin pigments that decrease the photosynthetic capacity and thus the production of guava. In addition, very humid conditions increase diseases and pests (Singh, 2011), causing the abortion of a large number of fruits (Solarte *et al.*, 2010). Likewise, environments with prolonged high relative humidity damage the quality of guavas (Fischer *et al.*, 2012).

Taiwo *et al.* (2020) pointed out that drought is the most prevalent abiotic stress in the world, which limits the productivity of plantations. Therefore, in the dry tropics, the flowering of the guava is highly influenced by the availability of water (Paull and Duarte, 2012). Interestingly, guava is not only classified as tolerant to waterlogging but also moderately tolerant to droughts (Crane *et al.*, 2019). Alix *et al.* (cited by Paull and Duarte, 2012) mentioned that this plant can withstand a dry period of about 6 months. This tolerance is surprising because of the superficial root system (Menzel, 1985). This tolerance is favored by the large number and extension of the roots that exceed the diameter of the crown (Bandera and Pérez, 2015). As previously mentioned, dry seasons combined with cold temperatures usually induce defoliation of the tree, which recovers fully if these conditions change (Nakasone and Paull, 1998). Furthermore, as Fischer *et al.* (2012) mentioned, low humid periods promote flower induction; while, on the contrary, dry conditions can induce the abortion of already formed flowers.

Irrigation is necessary in regions with long dry seasons, which is why Paull and Duarte (2012) emphasized that the ideal pattern for guava is alternating conditions of dry and humid seasons since drought and low ambient humidity during flowering can seriously reduce fruit set and cause abscission of recently set fruit. Likewise, these authors stated that, when trees that suffer from water stress abort the fruits of 1-2 cm in diameter after intense irrigation or heavy rain, these trees resume vegetative growth. In addition, low humidity during fruit filling reduces size and causes a recollection of the pulp from the epidermis (Paull and Duarte, 2012).

As reported by Souza *et al.* (2010), the hydric conditions in guava promote optimum fruit quality, and excess water during fruit filling reduces the soluble solids content; while the sugar concentration is favored by water scarcity as a concentration effect (Mercado-Silva *et al.*, 1998).

In drier environments, Solarte *et al.* (2014) found that, as the air vapor pressure deficit (DPV) and the maximum photonic flux density ($PPFD_{max}$) increased, the concentrations of citric and succinic acid decreased in guava. The DPV and $PPFD_{max}$ can influence the water status in fruits (Genard *et al.*, 2009) and thus reduce the transpiration and photosynthesis rates of green fruits, affecting the primary metabolism of this organ.

Salinity

Jalil and Ansari (2020) reported that salinity occurs in areas with little rainfall and high temperatures, which promote high transpiration rates and affect the normal development of plants because of the use of saline water for irrigation, where excess sodium and chlorine ions cause toxicity and hinder the absorption of essential elements and water from the soil.

The guava tree shows moderate tolerance to salinity (Morton, 1987), and applications of calcium nitrate, $Ca(NO_3)_2$ of 10 mM, alleviated reductions in growth of seedlings induced by NaCl through an increase in the concentration of foliar chlorophyll and higher photosynthetic rates (Ebert *et al.*, 2002).

Many studies on salinity in guava were carried out in Brazil, especially in arid and semi-arid areas, where the scarcity of good quality water and the occurrence of low fertility soils are limiting factors in irrigated agriculture, which led to the use of salt water and

nitrogen fertilizers as alternatives for agricultural production in these regions (Souza *et al.*, 2017).

Salinity, especially at levels greater than 1.8 dS m^{-1} , affects the emergence of seedlings, as well as growth and biomass accumulation in guava. The cultivar 'Crioula' is more tolerant to salinity than 'Paluma' and 'Ogawa' and is recommended as a rootstock (Sá *et al.*, 2016). Cavalcante *et al.* (2005) found that four guava varieties with seedlings irrigated with an EC_w greater than 1.5 dS m^{-1} , 180 d after sowing, did not have the agronomic quality for transplanting; while Ramírez *et al.* (2017) observed, in the germination, longitudinal root and stem growth of the variety 'Criolla Roja', a slight tolerance up to a concentration of 2.5 dS m^{-1} of NaCl. Souza *et al.* (2020) found that *P. cattleianum* is not very suitable as a rootstock in saline areas because of its greater absorption of Na^+ , which leads to high levels of Na^+ in the leaves of the scion and, thus, lower tolerance to saline stress.

In the Paluma variety, increases in irrigation water salinity from 0.3 dS m^{-1} produced reductions in stomatal conductance, internal CO_2 concentration, CO_2 assimilation rate, transpiration, and efficiency in the instantaneous use of water, in addition to reducing the number of leaves and branches, the diameter of the stem and the absolute and relative growth rates (Bezerra *et al.*, 2018a). However, in this study, the growth of 'Paluma' was affected by increases in the water salinity, and these plants could be irrigated with water of up to 1.42 dS m^{-1} , causing an acceptable reduction of 10% in growth variables.

Cavalcante *et al.* (2010) managed to relieve the effects of salinity with the application of liquid bovine manure, but potassium applications failed to do so (Bonifácio *et al.*, 2018). Applications of N above 70% of the recommended dose ($378.7 \text{ mg N dm}^{-3}$ soil) did not mitigate the detrimental effect of saline stress on plants (Bezerra *et al.*, 2018b).

Winds

Paull and Duarte (2012) recommended windbreaks for guava, especially for high-quality dessert-type fruits produced for the fresh market. In addition, these authors reported that plants grafted on clonal rootstocks are very susceptible to wind speeds between 65 and 80 km h^{-1} during the first three years of cultivation; while trees exposed to winds between 16 and 32 km h^{-1} have branches that gradually develop out of the direction of the wind.

On the contrary, Bandera and Pérez (2015) reported that, despite the fact that the root system of guava is superficial, it resists strong winds and storms thanks to the extension and number of large roots that exceed the width of the canopy of the crown, allowing this species to develop in a large number of different soils.

CONCLUSIONS

Guava, thanks to its ability to grow in tropical and subtropical climates, has been introduced to many low-latitude countries.

This crop grows in temperature ranges between 15 and 30°C. Lower and higher temperatures reduce fruit set. Low temperatures make production difficult, causing flower drop or extending the fruit development phase. However, guava adapts well up to altitudes of 2,000 m a.s.l. Colombia has a high genotype×environment interaction in the production characteristics and fruit quality with respect to the elevation of the orchard.

An important ecophysiological factor in guava is water since crops require between 1,000 to 2,000 mm year⁻¹ and endure waterlogging for several days; however, a lot of precipitation and environmental humidity decrease fruit quality considerably. On the other hand, since this tree is classified as moderately drought tolerant, this adversity greatly affects flowering and fruit set. In addition, since it has moderate tolerance to salinity, it supports irrigation water with up to an EC of 1.5 to 1.8 dS m⁻¹ depending on the variety.

Guava should be researched under conditions of elevated CO₂ concentrations, along with interactions with nitrogen fertilization.

Conflict of interests: The manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts at risk the validity of the presented results.

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