

Physical-morphological characterization of the mangosteen fruit *Garcinia mangostana* L. cultivated in Tuxtla Chico, Chiapas, México

Caracterización físico-morfológico del fruto de mangostán *Garcinia mangostana* L. cultivados en Tuxtla Chico, Chiapas, México

Martínez-Rodríguez, A.E.¹, Villarreal-Fuentes, J.M.^{1*}, Alia-Tejacal, I.²,
Guevara-Hernández, F.¹

¹ Facultad de Ciencias Agronómicas, Campus V. Universidad Autónoma de Chiapas. Carretera Ocozocoautla-Villaflores, km 84.5, Apartado postal #78. 30470, Villaflores, Chiapas, México.

² Facultad de Ciencias Agropecuarias. Universidad Autónoma del Estado de Morelos. Av. Universidad, 1001, Col Chamilpa. 62209, Cuernavaca, Morelos, México.



Please cite this article as/Como citar este artículo: Martínez-Rodríguez, A.E., Villarreal-Fuentes, J.M., Alia-Tejacal, I., Guevara-Hernández, F. (2025). Physical-morphological characterization of the mangosteen fruit *Garcinia mangostana* L. cultivated in Tuxtla Chico, Chiapas, México. *Revista Bio Ciencias*, 13, e1858. <https://doi.org/10.15741/revbio.13.e1858>.

Article Info/Información del artículo

Received/Recibido: December 17, 2024.

Accepted/Aceptado: November 21, 2025.

Available online/Publicado: December 15, 2025.

ABSTRACT

There is a growing interest in the food industry in mangosteen fruits, and the cultivated area in the Soconusco region of Chiapas has increased. However, no studies have been conducted on the physical-morphological characteristics of fruits produced in the region. This study describes the physical and morphological traits of fruits from 10 mangosteen genotypes cultivated in Tuxtla Chico, Chiapas. Using descriptive analysis, cluster analysis, and canonical discriminant analysis, promising materials were identified for future breeding programs. Fruits were stored at 23 °C and 70 % RH, and were analyzed in a completely randomized design at 0, 3, 6, 9, and 12 days after harvest. Fruit mass ranged from 66 to 85 g, and diameter from 6 to 8 cm; pulp and peel firmness increased during postharvest from 1.3 to 2.4 N and 14.5 to 35 N, respectively. During ripening, fruit color shifted between red and purple ($h = 15-26$), with low lightness ($L^* = 24-32$) and low chroma ($C^* = 3-16$). Cluster analysis grouped trees into three categories with 3, 5, and 2 members, mainly based on fruit mass and diameter, peel thickness and weight, and seed width and weight. Groups 1 and 3 exhibited the best quality traits, indicating their potential for genetic improvement.

KEY WORDS: Morphological characterization, *Garcinia mangostana*, firmness, color, fruit.

*Corresponding Author:

Juan Manuel Villarreal-Fuentes. Facultad de Ciencias Agronómicas, Campus V. Universidad Autónoma de Chiapas. Carretera Ocozocoautla-Villaflores, km 84.5, Apartado postal #78. 30470, Villaflores, Chiapas, México. Teléfono: (+52) 962 121 8564.
E-mail: jmfv@unach.mx

RESUMEN

Hay un creciente interés en la industria alimentaria por los frutos de mangostán y la superficie cultivada en la región del Soconusco, Chiapas, ha aumentado, sin embargo, no se ha realizado ningún estudio sobre las características físico-morfológicas de los frutos producidos en la región. El presente estudio describe características físicas-morfológicas del fruto de 10 genotipos de mangostán cultivados en Tuxtla Chico, Chiapas y utilizando análisis descriptivo, conglomerados y discriminante canónico se definieron materiales promisorios para futuros programas de mejoramiento genético. Los frutos fueron almacenados a 23 °C, 70 % H.R. y se analizaron completamente al azar a los 0, 3, 6, 9 y 12 días después de su cosecha. La masa del fruto varió de 66 a 85 g, el diámetro fue de 6 a 8 cm; la firmeza en pulpa y cáscara incrementó durante la poscosecha de 1.3 a 2.4 N y 14.5 a 35 N respectivamente; durante la maduración, el color de los frutos mostró tendencia entre rojo y morado ($h = 15$ y 26) con baja luminosidad (L^* entre 24 y 32) y opacos (C^* entre 3 y 16). Se formaron tres grupos de árboles con 3, 5 y 2 integrantes, de acuerdo con el análisis de agrupamiento, basado principalmente en la masa y diámetro de fruto, grosor de cáscara, peso de cáscara y ancho y peso de semilla. Los grupos 1 y 3 presentaron las mejores características de calidad por lo que muestran potencial para su mejoramiento genético.

PALABRAS CLAVE: Caracterización morfológica, *Garcinia mangostana*, firmeza, color, fruto.

Introduction

The mangosteen fruit (*G. mangostana*) is a climacteric tropical species cultivated in Southeast Asia (Rizaldy *et al.*, 2022). Globally known varieties include the standard 'Mangosteen' and several local types such as 'Mangosteen Malaccensis' in Malaysia, 'Mangosteen Thai' in Thailand, and 'Mangosteen Borneo' in Indonesia (Bohra, 2024). In Central and South America, including Mexico, Colombia, Brazil, Costa Rica, and Panama, commercial plantations are scarce due to the species' late onset of production, with the first harvest occurring after 8 to 10 years (Díaz *et al.*, 2011). Nevertheless, due to its excellent quality and high antioxidant capacity (Nawawi *et al.*, 2023), there is an increasing demand in both domestic and international markets (FAO, 2024). Historically, the fruit has been highly esteemed; Queen Victoria of England reportedly declared that anyone who brought her mangosteen fruits (*Garcinia mangostana*) would immediately be granted knighthood. For this reason, mangosteen is often referred to as the "queen of fruits" or the "fruit of the gods" (Ketsa & Paull, 2011). Mangosteen cultivation was introduced to Mexico in the 1960s through the Experimental Field "El Palmar" of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) (Díaz & Picón, 2007). Research activities on

mangosteen began in the 1990s, as it was considered a highly profitable alternative crop for the country's humid tropical regions. These expectations have proven valid, as mangosteen cultivation has expanded to the states of Chiapas, Veracruz, and Jalisco in recent years (Rueda *et al.*, 2014), covering approximately 840 ha with a tendency to increase (Díaz & Díaz, 2011). In the Soconusco region of Chiapas, new plantations established between 2013 and 2017 account for 98 % of the national cultivated area. These plantations began production between 2019 and 2023 (Díaz *et al.*, 2019). At the Rosario Izapa Experimental Field in Tuxtla Chico, Chiapas, 25,226 fruits were harvested in the fourth production cycle, with an average of 146 fruits per tree. Yields in Tuxtla Chico are reported to be comparable to, and in some cases higher than, those of major mangosteen-producing countries in Southeast Asia, such as Indonesia and the Philippines (Díaz *et al.*, 2019), giving Mexico a high level of competitiveness in international mangosteen markets.

G. mangostana is an apomictic species; however, it has been shown to exhibit high genetic variability (Matra *et al.*, 2016). Additionally, conventional vegetative propagation methods have proven challenging, so the species is typically propagated by seed (Hapsari *et al.*, 2018). This could result in considerable genetic variability among cultivated trees in the Soconusco region of Chiapas.

Mangosteen is considered a crop of the future due to its superior flavor, high nutraceutical value, long shelf life, low incidence of pests and diseases, excellent processing potential, and, most importantly, strong consumer acceptance. Therefore, the development of desirable mangosteen genotypes could support the expansion of cultivation into non-traditional areas (Bohra, 2024). In this context, it is necessary to characterize the morphology of mangosteen fruits produced in Mexico to develop strategies for future breeding programs, preserve germplasm, and assess the extent of genetic diversity.

In this study, we analyzed the postharvest physical-morphological characteristics of fruits from 10 mangosteen genotypes collected in Tuxtla Chico, Chiapas, Mexico, to evaluate morphological similarity and variability, as well as fruit quality. The results are expected to provide superior materials for the food industry, consumers, and future genetic improvement programs.

Materials and Methods

Fruits were harvested from the Rosario Izapa Experimental Field of the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), located in the municipality of Tuxtla Chico, Chiapas, at latitude 14°56' N and longitude 92°16' W. The region has an altitude of 320 m, with an annual mean temperature of 25.5 °C and precipitation ranging from 3544.5 to 5000 mm (INEGI, 2010).

Ten trees considered superior were selected for postharvest evaluation (105, 122, 133, 198, 212, 217, 218, 219, 277, and 286) within a two-hectare plot during the fruiting period. From each tree, 25 fruits were collected at stage six of ripening (Palapol *et al.*, 2009), corresponding to a purple-black color. The experimental unit consisted of a single fruit, with five replicates arranged

in a completely randomized design. Laboratory analyses were carried out at the Agricultural Production Laboratory of the Faculty of Agricultural Sciences, Universidad Autónoma de Chiapas. Fruits were stored at 23 ± 2 °C and 70 % relative humidity. Duplicate analyses were performed at 0, 3, 6, 9, and 12 days after harvest to evaluate morphological and physical variables.

Morphological analysis

The mass of the fruit component was determined using a digital balance (ScoutPro SP 4001, OHAUS) with a minimum resolution of 0.1 g and a maximum capacity of 4 kg. Each harvested fruit was weighed to obtain fruit mass, then carefully dissected to determine the mass of the pedicel, peel, pulp, and seeds. The number of seeds per fruit was also recorded. Length and diameters were measured using a Vernier caliper and measuring tape, including fruit length and diameter, peel diameter, and seed length and diameter.

Physical analysis

Pericarp and mesocarp firmness were measured using a universal texture analyzer (FORCE FME), which recorded penetration force in Newtons (N). For pericarp firmness, measurements were taken on both sides of the equatorial region of an intact fruit. In contrast, for pulp firmness, the complete aril was removed and measured on both sides of the equatorial region.

Fruit epidermis color was determined with a spectrophotometer (X-Rite, model 3290, USA). Lightness (L^*), chroma (C^*), and hue (h) values were obtained from readings taken at three different positions on each fruit (Maldonado-Astudillo *et al.*, 2023).

Statistical analysis

Data were analyzed using descriptive statistics (Castillo, 2011). Cluster analysis was performed using Euclidean distances and Ward's (1963) minimum variance method, followed by canonical discriminant analysis of the resulting groups, as described by Johnson (1998), Núñez-Colín & Escobedo-López (2014), and Cruz-Castillo *et al.* (1994).

All statistical analyses were conducted with SAS v. 9.0. Graphs were prepared with SigmaPlot® v. 12, showing mean values and their standard errors.

Results and Discussion

Fruit weight showed a low coefficient of variation (7.7 %), with an average of 75.40 g and a maximum of 85.14 g (Table 1). Mulyono *et al.* (2021) reported fruits weighing 25.31-57.31 g in Indonesia. Díaz *et al.* (2019), working at the same Rosario Izapa Experimental Field where the fruits for this study were collected, recorded a harvest of 25,226 fruits per hectare, of which 61.7% weighed 60-80 g, 7.2 % weighed 80-100 g, and 31 % weighed less than 60 g. However, Tac-an *et al.* (2021) reported fruit weights exceeding 100 g. According to ASEAN (Association of Southeast

Asian Nations), fruits weighing more than 100 g are classified as extra quality. The results reported by Díaz *et al.* (2019) and those obtained in the present study on fruit weight reflect a typical productive pattern observed in many fruit crops. For mangosteen, this has been highlighted by Sdoodee *et al.* (2008), who noted an adverse effect of heavy fruiting on fruit size.

The average fruit diameter was 7.53 cm. Díaz *et al.* (2011) reported an average mangosteen fruit diameter of 5.8 cm, with a variation range of 4.2-8.4 cm, while Morton (1987) noted a range of 3.4-7.5 cm. More recently, dimensions of 3.6-4.57 cm were reported in Indonesia (Mulyono *et al.*, 2021). Therefore, the results obtained in this study fall within the range established by Díaz *et al.* (2011), but are larger than those documented in some major mangosteen-producing countries such as Indonesia.

Peel weight ranged from 34.03 g to 49.84 g, with an average of 40.28 g. Pulp weight ranged from 26.58 to 32.71 g, averaging 29.5 g, while seeds weighed between 1.09 and 1.42 g (Table 1). Based on these data, the proportions of pulp, peel, and seed per fruit were 41.5 %, 56 %, and 2.5 %, respectively. Díaz *et al.* (2011) reported that pulp accounts for approximately 20 % of the total fruit weight. In contrast, studies in Brazil (Muller *et al.*, 1995) compared the composition of mangosteen fruit and found that fruits with weights similar to those reported in the present study (51-75 g) had pulp, seed, and peel proportions of 20.4 %, 3.0 %, and 76.6 %, respectively. Thus, the results of this research stand out by showing nearly twice the pulp proportion, while peel was about 20 % lower, and seed proportions were similar. Similarly, Hidayat *et al.* (2020) reported 65.27 % peel in fruits from Indonesia. These findings suggest that in Tuxtla Chico, Chiapas, mangosteen fruits may have a higher pulp percentage compared to those produced in other regions of the world.

Regarding seeds, the average number was 1.44 per fruit, with minimum and maximum weights of 1.09 and 1.42 g, averaging 1.26 g (Table 1). Seed length ranged from 1.49 to 1.80 cm, with an average of 1.66 cm, while width varied between 1.07 and 1.30 cm, averaging 1.2 cm. Díaz *et al.* (2011) reported that seed size in fruits produced in Tuxtla Chico, Chiapas, varied between 1.5 and 2.5 cm in length and 1.0-1.5 cm in width, with an average weight of 1-2 g. These values corroborate those obtained in the present study. By contrast, in Malaysia, seeds with an average length and width of 1.39 and 1.17 cm, respectively, and an average weight of 0.7 g have been reported (Tsan, 2022), which are below the values observed in this study and the ranges established by Díaz *et al.* (2011).

Table 1. Descriptive statistics of the variables evaluated in fruits of 10 mangosteen genotypes cultivated in Tuxtla Chico, Chiapas, México.

Variable	Mean	Range	Minimum	Maximum	CV (%)
Fruit mass (g)	75.40	18.89	66.25	85.17	7.7
Fruit Length (cm)	5.22	0.34	5.08	5.42	2.23
Fruit diameter (cm)	7.53	2.31	6.18	8.49	9.60
Petiole mass (g)	2.62	0.63	2.29	2.92	8.61
Pericarp thickness (cm)	0.65	0.21	0.57	0.78	11.81
Pericarp mass (g)	40.28	15.81	34.03	49.84	12.19
Pulp mass (g)	29.5	6.13	26.58	32.71	6.66
Seeds (numbers)	1.44	0.72	0.96	1.68	14.40
Seed length (cm)	1.66	0.31	1.49	1.80	6.84
Seed width (cm)	1.2	0.23	1.07	1.30	6.54
Seed mass (g)	1.26	0.33	1.09	1.42	9.87

Cluster analysis

The dendrogram was divided into three groups (Figure 1), identified as Groups 1, 2, and 3, respectively. These groups were separated based on variability in fruit characteristics. Group 1 consisted of five genotypes: trees 198, 277, 217, 122, and 286. Group 2 comprised trees 105 and 218, while Group 3 included trees 219, 212, and 133. Although it has been demonstrated that cross-pollination is only possible between mangosteen and the wild *G. mangostana* var. *malaccensis* (Hambali & Natawijaya, 2016), genetic flow in this case would be unidirectional, from the wild *malaccensis* variety to cultivated mangosteen, with variation contributed only by pollen donors. However, Sinaga *et al.* (2010), working in different localities in Indonesia, identified five groups in cluster analysis, with isoenzyme polymorphism levels reaching 88 %. These results, together with the findings of the present study, suggest that there is high genetic flow despite *G. mangostana* being an asexually reproducing species through apomixis (Yao *et al.*, 2023). Plants produced from apomictic seeds typically retain the characteristics of the parent tree from which the fruit and seeds were derived, which would be expected to reduce variability. Nevertheless, wide genetic variation in *G. mangostana* has been demonstrated, as it is a polyploid species. In fact, mangosteen exhibits moderate genetic variation within a single population, as confirmed in this study. Even though samples were collected from a two-hectare area under uniform agronomic management and environmental conditions, considerable variability was observed.

Genetic variation in mangosteen may be attributed to natural hybridization with multiple ancestors such as *G. malaccensis*, *G. hombroniana* Pierre, and *G. venulosa*, or to genomic instability resulting from polyploidy and genome asynchrony (Matra *et al.*, 2016).

Genetic variation, as a source of genetic resources, forms the basis of any program aimed at expanding cultivation areas, since it allows the identification of genotypes adapted to new environments. In Mexico, related species such as *Garcinia humilis* (achachairú) (Sanchez *et al.*, 2024) and *G. intermedia* (known locally as limoncillo or toronjil) are found. The latter is native to the American tropics and is semi-cultivated in home gardens in Santiago Acahuato, Apatzingán, Michoacán, Mexico (Agustín *et al.*, 2022). The diversity available within species and among wild taxa contributes significantly to the development of new varieties, potential rootstocks, and even the domestication of candidate species (Bohra, 2024).

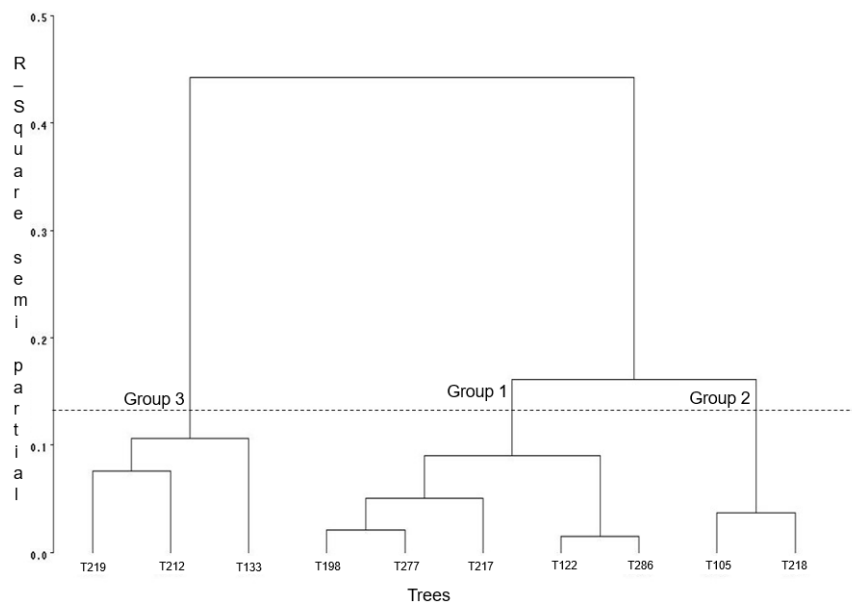


Figure 1. Dendrogram of 10 mangosteen genotypes (*Garcinia mangostana* L.) cultivated in Tuxtla Chico, Chiapas, México, constructed by the Ward method from 11 morphological fruit variables.

Canonical discriminant analysis

Two canonical roots explained total variance. The first function (CAN 1) accounted for 72 % of the variance, while the second (CAN 2) explained 28 %. CAN 1 was associated with fruit mass, fruit diameter, peel thickness, and peel weight (Table 2). CAN 2 was related to two seed descriptors: width and weight (Table 2). Canonical discriminant analysis simultaneously examines differences across all variables, which, unlike other eigenanalysis-based methods, highlights the variables that actually distinguish between predefined groups, rather than those showing the most significant variation (Cruz-Castillo *et al.*, 1994; Núñez-Colín & Escobedo-López, 2014). These

results indicate that seed width, seed weight, fruit mass, fruit diameter, peel thickness, and peel weight are significantly different among the groups.

Fruits from Group 3 exhibited higher proportions in several traits, including fruit weight, pulp weight, greater length and diameter, as well as increased peel thickness and peel weight (Table 3). However, the average number of seeds was the lowest among the three groups. Group 1, represented by the most significant number of trees, showed higher values for seed number, length, width, and weight (Table 3). Group 2, consisting of trees 105 and 218, displayed intermediate results for most variables (except for pedicel weight) compared with Groups 1 and 3. The high genetic variation observed indicates considerable potential for the development of high-quality plants. This can be achieved through mass selection in certain trees to generate new varieties, particularly those from Groups 1 and 3, as they displayed the most favorable fruit quality traits. Additionally, trees in Group 3 exhibited superior peel-related characteristics. It is worth noting the growing interest of the pharmaceutical industry in mangosteen pericarp, as this tissue is well known to be rich in nutraceutical compounds, including anthocyanins, phenols, and xanthenes (Andayani *et al.*, 2020). These compounds have been associated with anticancer properties by providing protective effects against degenerative processes (Nardini & Garaguso, 2020), as well as with the prevention of cardiovascular disease (Sari *et al.*, 2020), diabetes (Yani *et al.*, 2021), and potential roles in mitigating memory loss and neurodegenerative disorders (Tiang *et al.*, 2020).

Table 2. Total canonical structure of 11 variables in the two canonical functions of 10 mangosteen genotypes cultivated in Tuxtla Chico, Chiapas, México.

Variable	CAN1	CAN2
Fruit mass	0.8795	0
Fruit Length	0.7040	0.2804
Fruit diameter	0.8489	0.1804
Petiole mass	0.3196	-0.5015
Pericarp thickness	0.9124	0.1217
Pericarp mass	0.8407	0.0783
Pulp mass	0.4294	0.3662
Seeds number	-0.5853	0.3168
Seed length	-0.5846	0.5300
Seed width	-0.4288	0.6946
Seed mass	-0.5295	0.6536
% Variability	72	28

Table 3. Average of 11 variables of the groups formed at cluster analysis of 10 mangosteen genotypes cultivated in Tuxtla Chico, Chiapas, México.

Variable	Group 1	Group 2	Group 3
Fruit mass (g)	71.82	73.62	82.73*
Fruit Length (cm)	5.18	5.14	5.35
Fruit diameter (cm)	7.14	7.4	8.36*
Petiole mass (g)	2.56	2.81	2.70
Pericarp thickness (cm)	0.60	0.63	0.76*
Pericarp mass (g)	37.35	38.12	46.29*
Pulp mass (g)	28.90	27.53	30.50
Seeds number (number)	1.55	1.36	1.28
Seed length (cm)	1.71	1.57	1.58
Seed width (cm)	1.23*	1.11	1.16
Seed mass (g)	1.32*	1.14	1.19

*Important values in fruit quality selection (high mass and diameter fruit; high thickness and pericarp mass) based on Can 1. *Important values in quality fruit selection (high width and seed mass) based on Can 2.

Pulp and peel firmness during the ripening process

Pulp firmness showed a consistent decreasing trend in all cases without exception. Initially, pulp firmness fluctuated between 1.5 and 2.4 N, reaching values of 1.3 to 1.5 N by day 12 after harvest (Figure 2). The highest value was recorded in tree 198 on day 3, with a value of 2.7 N, while the lowest value reached 1 N on day 9; this occurred in 8 of the 10 trees studied: 198, 122, 212, 286, 105, 218, 217, and 277 (Figure 2). In Indonesia, Suriati (2023) reported that fruits harvested at stage 3 of ripening had pulp firmness of 4.1 N, which decreased to 0.6 N after 9 days of storage. Similarly, Noichinda *et al.* (2007) in Thailand reported that fruits harvested at stage 6 (dark purple) had a pulp firmness of 0.4 N, which decreased to 0.2 N after 10 days of storage. These findings support the trends observed in the present study, suggesting that pulp firmness decreases as a result of reduced insoluble pectin content. According to Noichinda *et al.* (2007), low storage temperatures (13 °C) delay the activity of enzymes involved in protopectin degradation. Thus, changes in cell wall solubilization associated with the activities of pectin methyl esterase and polygalacturonase may be responsible for pulp softening during ripening. In contrast to the pulp, peel firmness showed an increasing trend in all selections studied. At day 0, no significant differences were observed among the genotypes, with mean values ranging from 14.5 to 15 N. Subsequently, trees 196, 286, 105, 218, and 277 exhibited a rapid increase from day 9 to day 12 (Figure 2). However, no significant differences were detected when compared with the other

selections; by day 12, peel firmness ranged from 22 to 35 N, with tree 122 showing the lowest firmness. Several authors have also reported this behavior. For example, Palapol *et al.* (2009) in Thailand found values similar to those in our study for fruits at stage 6 (dark purple), with peel firmness ranging from 42.9 to 47.9 N. Likewise, Castro *et al.* (2012) in Brazil reported that fruits at stage 6 of ripening reached peel firmness of 40 to 47 N at 12 days after harvest, which further increased up to 140 N by day 18 of storage. The lignification process serves a structural role in plants. It often occurs as a metabolic response to stress imposed on plant tissues by harvest and postharvest handling, ethylene exposure, temperature changes, water loss, gas composition and exchange, mechanical injury, and senescence (Siegel, 1993; Chitarra & Chitarra, 2005). This suggests that the observed increase in peel firmness is due to peel lignification, a process associated with mangosteen fruit senescence

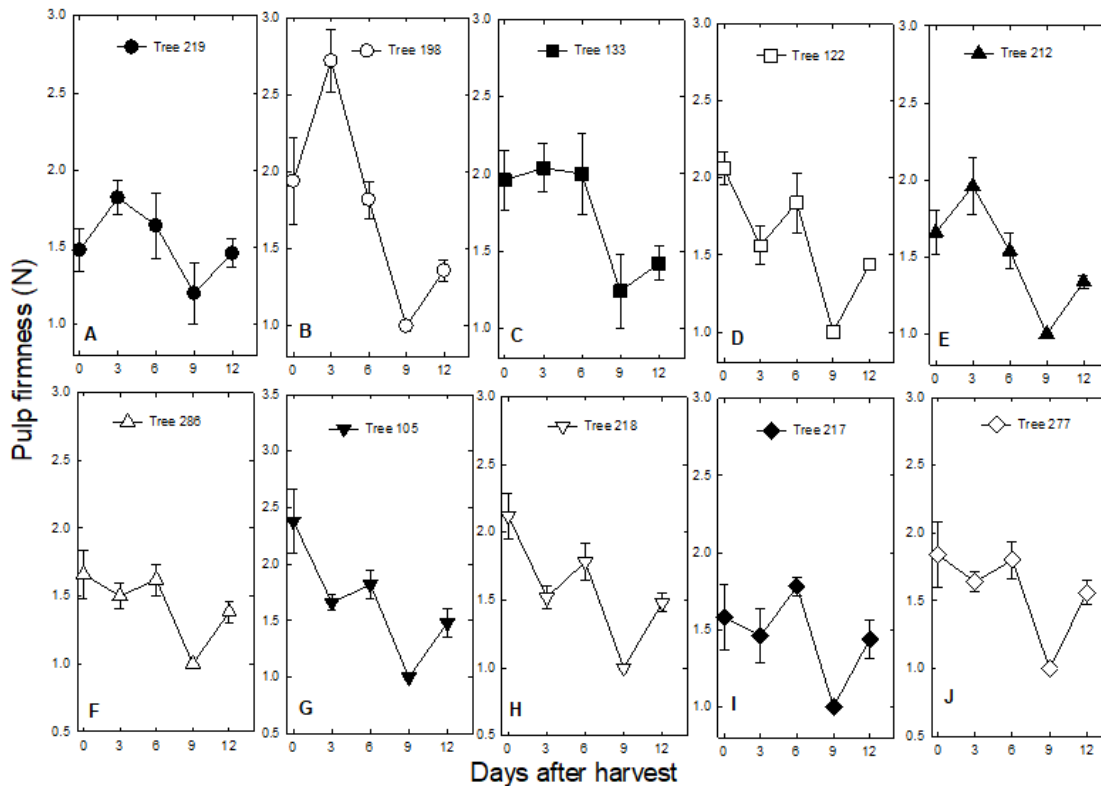


Figure 2. Pulp firmness in fruit of 10 mangosteen *Garcinia mangostana* genotype (A-J) cultivated in Tuxtla Chico, Chiapas, México.

Each point represents the mean of five observations and its standar error.

Color development

Fruit luminosity (L^*) values and trends were similar across the ten selections evaluated. At the beginning of the analysis, L^* values ranged from 28 to 32 (Figure 4), followed by a considerable decrease over the subsequent days, reaching minimum values of 24 to 25 on day 9 after harvest (Figure 4). A subsequent increase was observed on day 12, with values ranging from 26 to 28. Comparable results have been reported in Indonesia. Herawati *et al.* (2019) documented L^* values in mangosteen fruit ranging from 25 to 27.9, while Hidayat *et al.* (2020) reported an average luminosity of 22.73 for fruits harvested at stage 6 of ripening (dark purple).

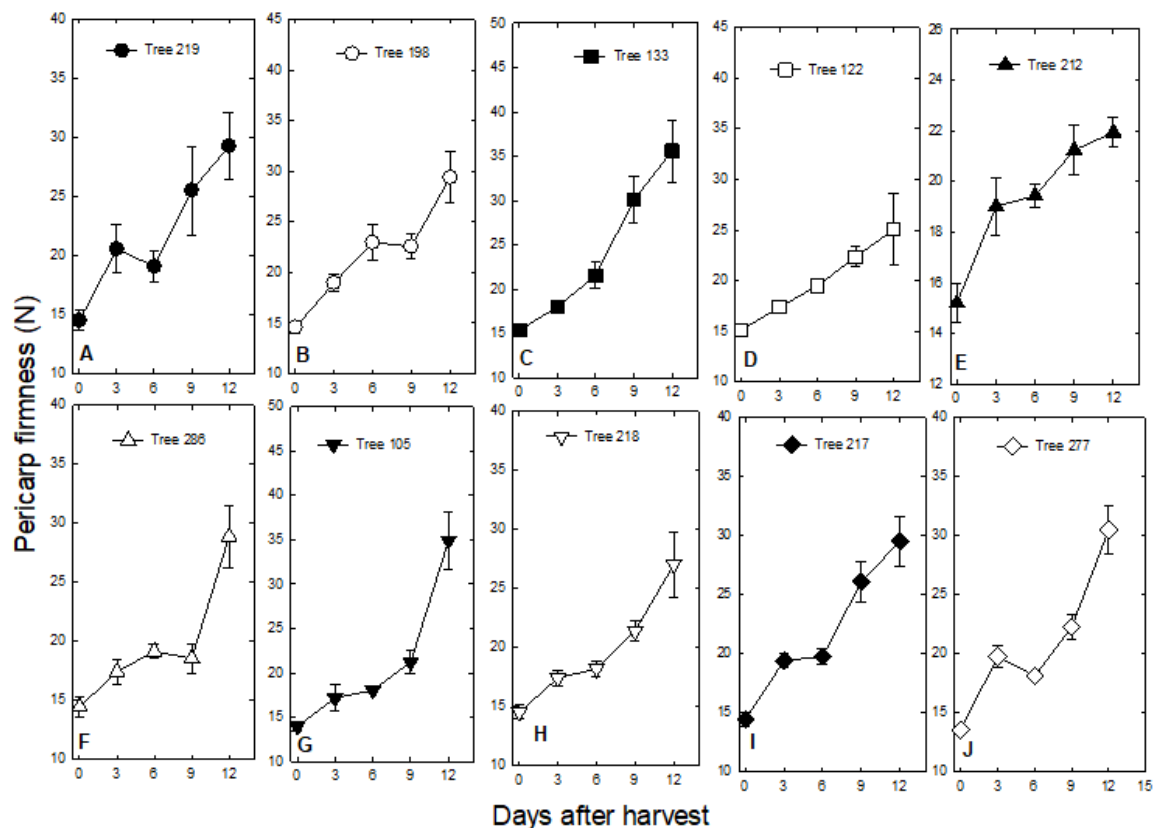


Figure 3. Pericarp firmness in fruits of 10 mangosteen *Garcinia mangostana* genotypes (A-J) cultivated in Tuxtla Chico, Chiapas, México.

Each point represents the mean of five observations, along with its standard error.

Regarding chromaticity (C^*), which refers to color saturation, where high values indicate vivid colors and low values indicate dull or muted colors, initial values ranged from 9 to 16. The chromaticity dynamics (C^*) across all trees were similar (except for tree 219), showing a decreasing trend and reaching values of 3 to 6 by day 12 (Figure 5). Tree 219 exhibited the lowest initial value at 7, similar to the values observed on day 12 in the other fruits (Figure 5). Subsequently, C^* decreased to 6 and remained at this level until the last day of analysis (Figure 5), suggesting that fruits from tree 219 were slightly more advanced in ripening. Based on these values, the peel color can be considered dull or opaque. Hidayat *et al.* (2020) in Indonesia reported similar chromaticity values for dark purple *G. mangostana* fruits, with an average of 9.36 ± 2.14 .

Regarding hue or hue angle (h), it is visually evident that *G. mangostana* fruits at stage 6 are dark purple. This observation is supported by the data obtained in the present study, which ranged between red and purple, with values of 15-26 (Figure 8). Other authors have reported values ranging from 20 to 0 (Palapol *et al.*, 2009; Piriyaivinit *et al.*, 2011; Hidayat *et al.*, 2020). Specifically, Palapol *et al.* (2009) noted that fruits at stage 5 of ripening (dark purple) had an h value of 16. This contrasts with the values obtained in the present work, as the fruits analyzed had already reached a dark purple color. In summary, the color of *G. mangostana* fruits showed a trend between red and purple ($h = 15-26$), with low luminosity (L^* between 24 and 32) and dull chromaticity (C^* between 3 and 16). During mangosteen fruit ripening, brightness tends to decrease, and the peel color shifts from pale yellowish-green (stage 0) to dark purple (stage 6). This epidermal discoloration can serve as a harvest index and is caused by the degradation of chlorophyll and the synthesis of anthocyanin pigments (Tadmor *et al.*, 2010).

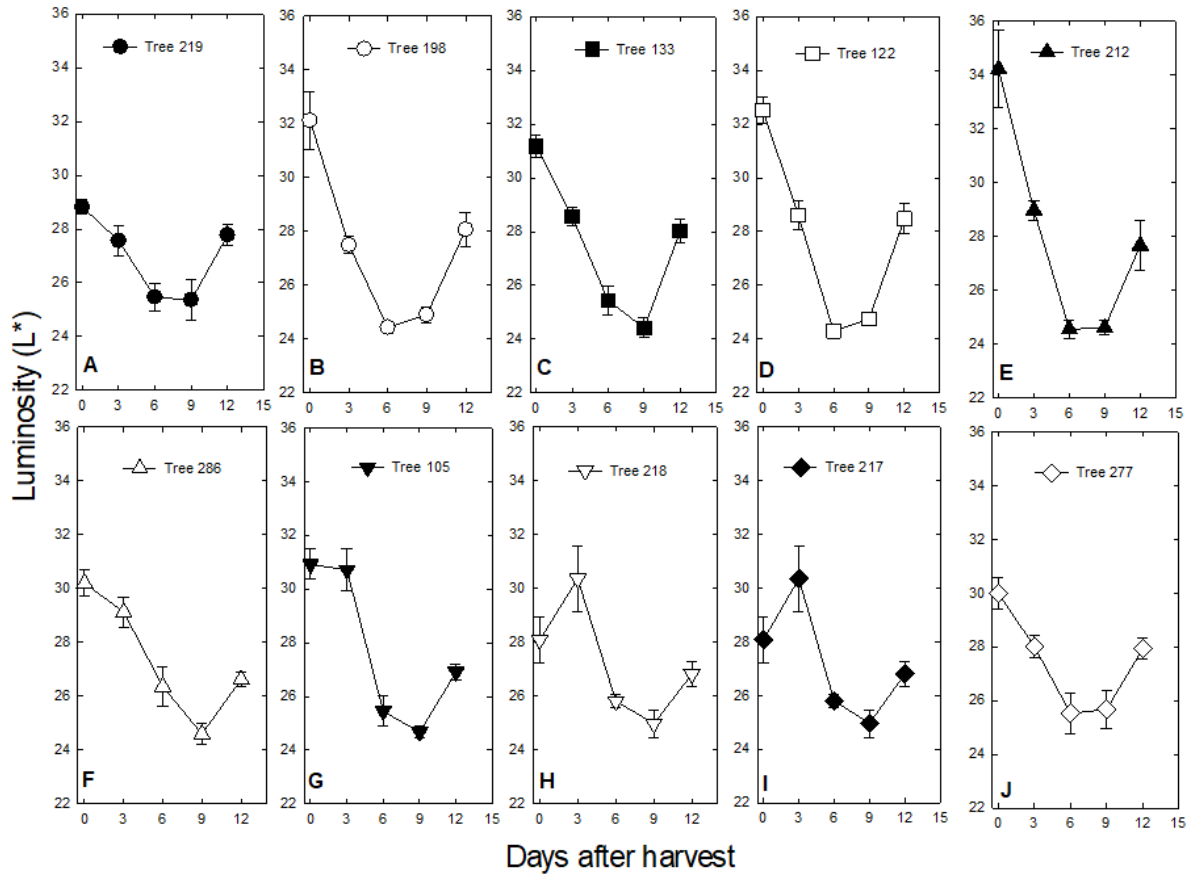


Figure 4. Pericarp luminosity in fruits of 10 mangosteen *Garcinia mangostana* genotypes (A-J) cultivated in Tuxtla Chico, Chiapas, México.

Each point represents the mean of five observations, along with its standard error.

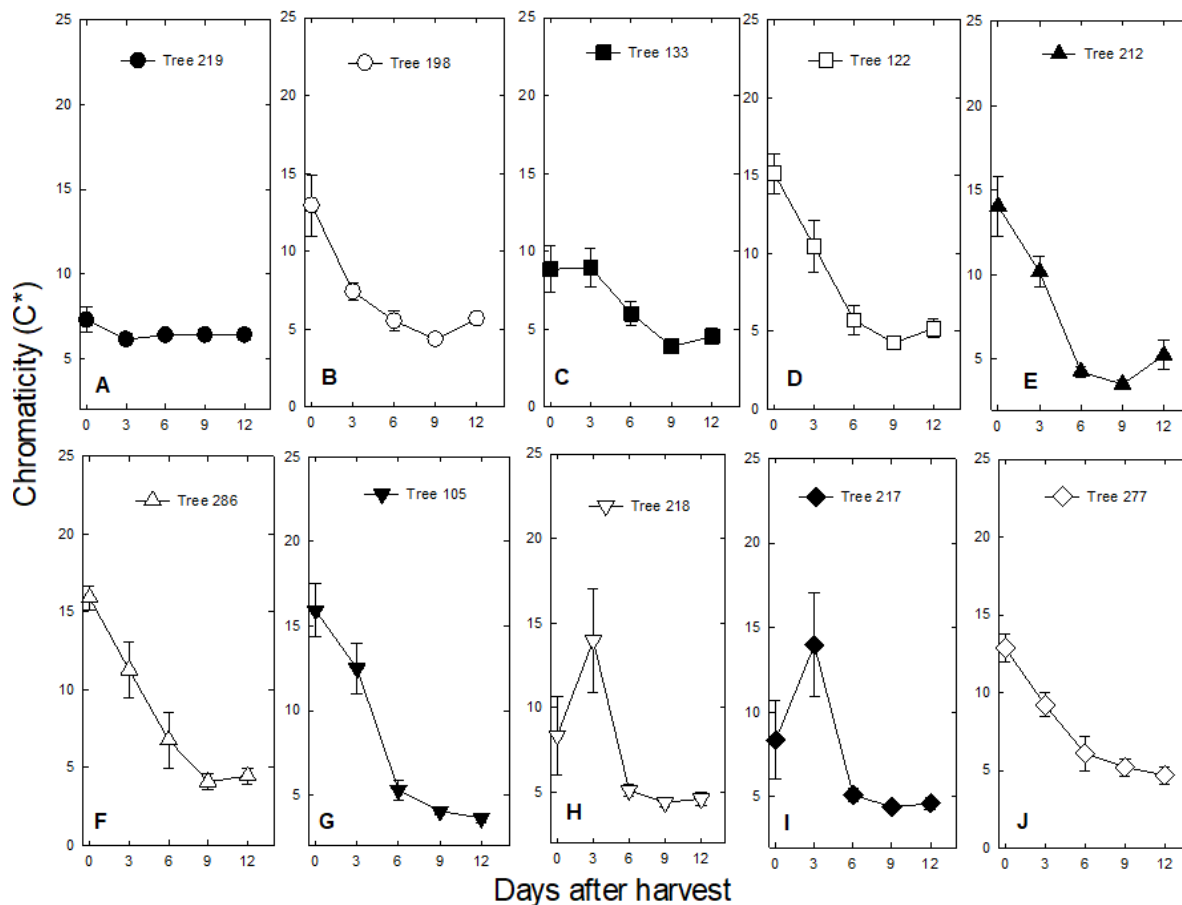


Figure 5. Pericarp chromaticity in fruits of 10 mangosteen *Garcinia mangostana* genotypes (A-J) cultivated in Tuxtla Chico, Chiapas, México.

Each point represents the mean of five observations, along with its standard error.

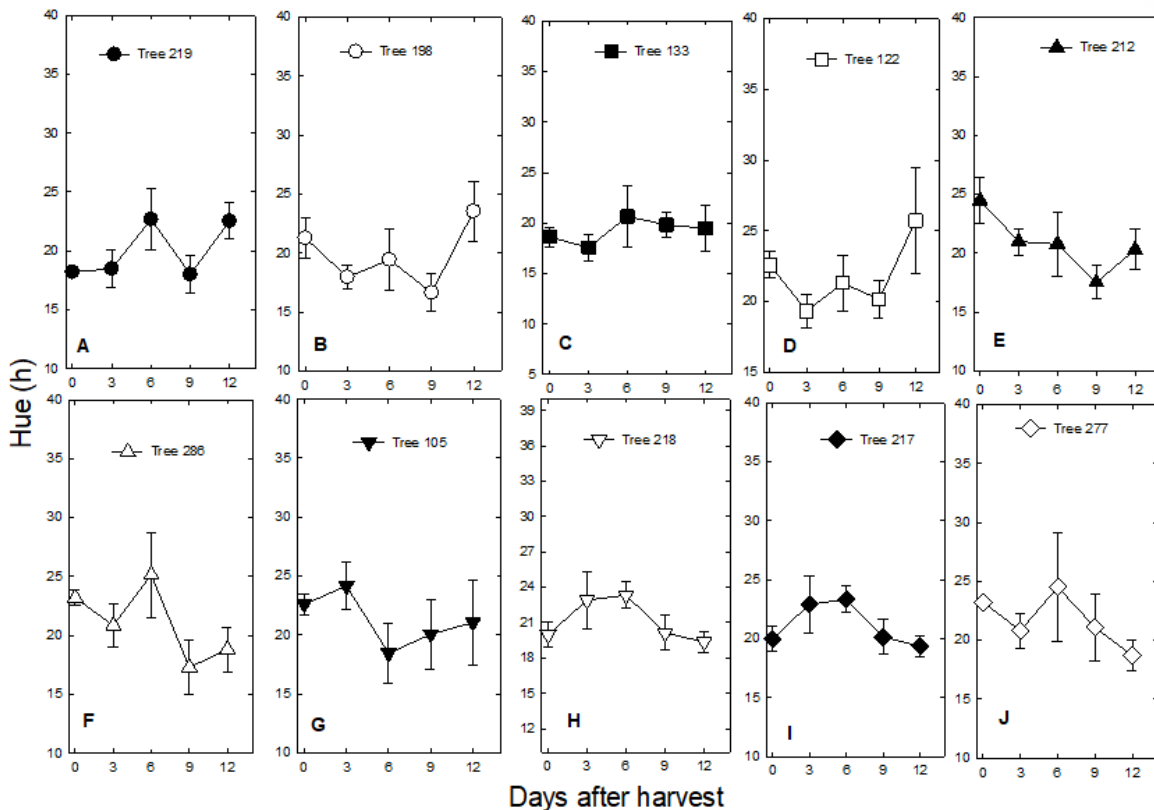


Figure 6. Pericarp hue in fruits of 10 mangosteen *Garcinia mangostana* genotypes (A-J) cultivated in Tuxtla Chico, Chiapas, México.

Each point represents the mean of five observations, along with its standard error.

Conclusions

The fruits produced in Tuxtla Chico, Chiapas, Mexico, demonstrated the quality required for the food industry in both national and export markets.

High variability was observed within the *Garcinia mangostana* population, indicating considerable potential for producing high-quality plants. Fruits from Groups 1 and 3 exhibited the best quality characteristics, and it is suggested that these be utilized in future mangosteen breeding programs in Soconusco, Chiapas.

Author contributions

Work conceptualization: AEMR, JMVf, IAT, and FGH; Methodology development: AEMR; Software management: IAT, AEMR; Experimental validation: JMVf, IAT; Data analysis: AEMR, JMVf, IAT; Data curation: AEMR, IAT; Writing-original draft preparation: AEMR; Writing-review and editing: AEMR, JMVf, IAT, and FGH; Project administration.

All authors have read and approved the published version of this manuscript.

Funding

This research received no external funding.

Acknowledgments

We thank CONAHCYT for support through the national master's scholarship (1200341) awarded to Alexis Eduardo Martínez Rodríguez, and the National Institute of Forestry, Agricultural, and Livestock Research (INIFAP) for providing the fruits.

Conflict of interest

The authors declare no conflict of interest.

Referencias

- Agustín, J.A., Cruz-Castillo, J.G., & Bautista Villegas, J.C. (2022). *Garcinia intermedia*, a neglected fruit tree in the tropics of America. *Revista Chapingo Serie Horticultura*, 28(1), 5-15. <https://doi.org/10.5154/r.rchsh.2021.03.005>
- Andayani, R., Armin, F., & Mardiyah, A. (2020). Determination of the total phenolics and antioxidant activity in the rind extracts of *Garcinia mangostana* L. *Garcinia cowa* Roxb., and *Garcinia atroviridis* Griff. EX T. Anders. *Asian Journal of Pharmaceutical and Clinical Research*, 13, 149–152. <https://doi.org/10.22159/ajpcr.2020.v13i8.36525>
- Bohra, P. (2024). Mangosteen (*Garcinia mangostana* L.). In Rajasekharan, P.E. & Ramanatha-Rao, V. Handbooks of Crop Diversity: Conservation and Use of Plant Genetic Resources, Fruit and Nut Crops. (pp. 426-443). Ed. Springer Nature Singapore Pte Ltd. <https://doi.org/10.1007/978-981-99-5348-6>
- Castillo, M.L.E. (2011). Introducción al SAS® para Windows. Universidad Autónoma Chapingo. Chapingo, Estado de México, México. 295 p.
- Castro, M.F.P.P.M., Anjos, V.D. de A., Rezende, A.C.B., Benato, E.A., & Valentini, S.R. de T.

- (2012). Postharvest technologies for mangosteen (*Garcinia mangostana* L.) conservation. *Food Science and Technology*, 32(4), 668–672. <https://doi.org/10.1590/S0101-20612012005000103>
- Chitarra, A.B., & M.I.F. Chitarra. (2005). Pós-colheita de frutas e hortaliças: fisiologia e manuseio. 2. ed. Lavras: UFLA. 785 p.
- Cruz-Castillo, J.G., Ganeshanandam, S., MacKay, B.R., Lawes, G.S., Lawoko, C.R.O., & Woolley, D.J. (1994). Applications of Canonical Discriminant Analysis in Horticultural Research. *HortScience*, 29(10), 1115-1119.
- Díaz, A.M., & Picón, R.L. (2007). Influencia de los factores climáticos en la fenología del mangostán (*Garcinia mangostana* L.) en la zona centro del estado de Veracruz, México. En Memoria del II simposio Internacional de Fruticultura tropical y subtropical. p. 98.
- Díaz, F.V.H., & Díaz, H.B.G. (2011). El mangostán (*Garcinia mangostana* L.): Una alternativa para la reconversión productiva en la región tropical húmeda de México. In López, G.G., Iracheta, D.J. & Avendaño, A.C.H. Tecnologías de producción para el trópico. 65 aniversario del Campo Experimental Rosario Izapa. INIFAP. Campo Experimental Rosario Izapa, Libro Técnico No 7. (pp. 74–78). Ed. INIFAP. Tuxtla Chico, Chiapas, México.
- Díaz, F.V.H., Díaz, H.B.G., Ruíz, C.P.A., Mariles, F.V., Cano, G.M.A., & Gálvez, M.L.A. (2011). El mangostán *Garcinia mangostana* L. Libro Técnico No 8. INIFAP. Tuxtla Chico, Chiapas, México.
- Díaz Fuentes, V. H., Ruíz-Cruz, P.A., Nájera-Domínguez, W., Iracheta-Donjuán, L., & Gálvez-Marroquín, L.A. (2019). Comportamiento productivo inicial del mangostán (*Garcinia mangostana* L.) en el Soconusco, Chiapas, México. *Agro Productividad*, 12(3), 17–22. <https://doi.org/10.32854/agrop.v0i0.1321>
- Food and Agriculture Organization of the United Nations [FAO]. (2024). Major Tropical Fruits Market Review 2023. Rome. https://agfstorage.blob.core.windows.net/misc/FP_com/2024/08/20/Ado.pdf.
- Hambali, G.G., & Natawijaya, A. (2016). A preliminary study of *Garcinia malaccensis* collection in Taman Buah Mekarsari, Cileungsi, Bogor, Indonesia. In Proceedings of the SABRAO 13th Congress and International Conference. Contribution of Breeding Research for Sustainable Agricultural Production Under Changing Environment for Food Security in Asia and Oceania. Bogor: Society for the Advancement of Breeding Research in Asia and Oceania, 14-16 September 2015. (pp. 31-36).
- Hapsari, D.P., Poerwanto, R., Sopandie, D., & Santosa, E. (2018). Partial root-zone irrigation effects on growth, metabolism and calcium status of Mangosteen seedling (*Garcinia mangostana* L.). *Adv. Hort. Sci.*, 32(1), 49-59. <https://doi.org/10.13128/ahs-21360>
- Herawati, H., Winarti, C, Setyabudi, D.A., & Wahyuningsih, K. (2019). Effect of Hormone Treatment, Coating Material and Ethylene Absorber on the Shelf Life of Mangosteen. *IOP Conference Series: Earth and Environmental Science*, 309, article 012019. <https://doi.org/10.1088/1755-1315/309/1/012019>
- Hidayat, D.D., Andriansyah, R.C.E. Indriati, A. Surahman, D.N., & Luthfiyanti, R. (2020). Studies on geometrical, physical, mechanical and colour properties of mangosteen fruits. *IOP Conference series: Earth and Environmental Science*, 462, article 012045. <https://doi.org/10.1088/1755-1315/462/1/012045>
- Instituto Nacional de Estadística y Geografía [INEGI]. (2010). Compendio de información

- geográfica municipal 2010 Tuxtla Chico Chiapas. https://www.inegi.org.mx/contenidos/app/mexicocifras/datos_geograficos/07/07102.pdf. Fecha de consulta: 07 de abril de 2024.
- Johnson, D.E. (1998). Métodos Multivariados Aplicados al Análisis de Datos. International Thomson Editores, Ciudad de México, México. 566 p.
- Ketsa, S., & Paull, R.E. (2011). Mangosteen (*Garcinia mangostana* L.). In Yahia, E.M. Postharvest Biology and Technology of Tropical and Subtropical Fruits. (pp. 1–30). Ed. Woodhead Publishing. https://www.researchgate.net/publication/277891434_Postharvest_biology_and_technology_of_tropical_and_subtropical_fruits_Volume_4_Mangosteen_to_sapote
- Maldonado-Astudillo, Y.I., Alia-Tejacal, I., Jiménez-Hernández, J., & Núñez-Colín, C.A. (2023). Postharvest quality and physiological changes in five ecotypes of *Spondias purpurea* L. harvested at three distinct maturity stages. *Revista Brasileira de Fruticultura*, 45, article e-607. <https://dx.doi.org/10.1590/0100-29452023607>
- Matra, D.D., Poerwanto, R., Santosa, E., Sobir, S., Higashio, H., Anzai, H., & Inoue, E.. (2016). Analysis of Allelic Diversity and Genetic Relationships Among Cultivated Mangosteen (*Garcinia mangostana* L.) in Java, Indonesia Using Microsatellite Markers and Morphological Characters. *Tropical Plant Biology*, 9(1), 29-41. <https://doi.org/10.1007/s12042-016-9161-8>
- Morton, J.F. (1987). Mangosteen. In Morton, J.f. Fruits of warm climates. Miami, Florida. pp 301 – 304. https://books.google.com.mx/books/about/Fruits_of_Warm_Climates.html?id=MjJunQEACAAJ&redir_esc=y
- Muller, C.H., Figueiredo F.J.C., & Muler, N.R.M. (1995). Armazenamento de sementes de mangostao. Circular Técnica 58. EMBRAPA-CPATU. Belém, Brasil. 15 pp.
- Mulyono, D., Irawati, Y., & Syah, M.J.A. (2021). Identification morphological variability of six mangosteen (*Garcinia mangostana* L.) As a conservation strategy for local varieties. *IOP Conference Series: Earth and Environmental Science*, 739(1), article 012076. <https://doi.org/10.1088/1755-1315/739/1/012076>
- Nardini, M., & Garaguso, I. (2020). Characterization of bioactive compounds and antioxidant activity of fruit beers. *Food Chemistry*, 305, article 125437. <https://doi.org/10.1016/j.foodchem.2019.125437>
- Nawawi, N., Ijod, G., Abas, F., Ramli, N., Mohd Adzahan, N., & Mohamad Azman, E. (2023). Influence of Different Drying Methods on Anthocyanins Composition and Antioxidant Activities of Mangosteen (*Garcinia mangostana* L.) Pericarps and LC-MS Analysis of the Active Extract. *Foods*, 12(12), article 2351. <https://doi.org/10.3390/foods12122351>
- Noichinda, S., Bodhipadma, K., & Singkhornart, S. (2007). Changes in pectic substances and cell wall hydrolase enzymes of mangosteen (*Garcinia mangostana*) fruit during storage. *New Zealand Journal of Crop and Horticultural Science*, 35, 229-233. <https://doi.org/10.1080/01140670709510189>
- Núñez-Colín, C.A., & Escobedo-López, D. (2014). Caracterización de germoplasma vegetal: la piedra angular en el estudio de los recursos fitogenéticos. *Acta Agríc. Pec*, 1, 1-6. <https://aap.uaem.mx/index.php/aap/article/view/1>
- Palapol, Y., Ketsa, S., Stevenson, D., Cooney, J.M., Allan, A.C., & Ferguson, I.B. (2009). Colour development and quality of mangosteen (*Garcinia mangostana* L.) fruit during ripening and after harvest. *Postharvest Biology and Technology*, 51(3), 349–353. <https://doi.org/10.1016/j.postharvbio.2008.08.003>
- Piriyavinit, P., Ketsa, S., & van Doorn, W.G. (2011). 1-MCP extends the storage and shelf life of

- mangosteen (*Garcinia mangostana* L.) fruit. *Postharvest Biology and Technology*, 61(1), 15-20. <https://doi.org/10.1016/j.postharvbio.2011.02.007>
- Rizaldy, D., Hartati, R., Nadhifa, T., & Fidrianny, I. (2022). Chemical Compounds and Pharmacological Activities of Mangosteen (*Garcinia mangostana* L.) – Updated Review. *Biointerface Research in Applied Chemistry*, 12(2), 2503–2516. <https://doi.org/10.33263/BRIAC122.25032516>
- Rueda, S.A., Pérez, D.J.F., & Ireta, M.J. (2014). El cultivo del mangostán (*Garcinia mangostana*) como nueva alternativa de producción en el estado de Jalisco.
- Sanchez, F.W., Crane, J.H., Bayabil, H., Sarkhosh, A., & Schaffer, B. (2024). Achachairú (*Garcinia humilis*) Fruit Trees: Botany and Commercial Cultivation in South Florida. *UF IFAS Extension University of Florida*, HS1480. <https://doi.org/10.32473/edis-HS1480-2024>
- Sari, N., Katanasaka, Y., Sugiyama, Y., Miyazaki, Y., Sunagawa, Y., Funamoto, M., Shimizu, K., Shimizu, S., Hasegawa, K., & Morimoto, T. (2021). Alpha Mangostin Derived from *Garcinia mangostana* Linn Ameliorates Cardiomyocyte Hypertrophy and Fibroblast Phenotypes in Vitro. *Biological and Pharmaceutical Bulletin*, 44(10), 1465–1472. <https://doi.org/10.1248/bpb.b21-00294>
- Sdoodee, S. Phonrong, K., & Ruongying, Y. (2008). Mangosteen crop load affects physiological responses, fruit yield and fruit quality. *Acta Hort.*, 773, 187–194. <https://doi.org/10.17660/ActaHortic.2008.773.27>
- Siegel, B.Z. (1993). Plant peroxidases –an organismic perspective. *Plant Growth Regulation*, 12, 303-312. <http://dx.doi.org/10.1007/BF00027212>
- Sinaga, S., Sobir, S., Poerwanto, R., Aswidinnor, H., & Dedy Duryadi, D. (2010). Genetic Diversity and The Relationship Between The Indonesian Mangosteen (*Garcinia mangostana*) and The Related Species Using Isozyme Markers. *Jurnal Natur Indonesia*, 13(1), 53-58. <http://dx.doi.org/10.31258/jnat.13.1.53-58>
- Suriati, L. (2023). Evaluation of the Quality of Fresh-Cut Mango, Mangosteen and Rambutan Under Cold Storage. *Journal of Agriculture and Crops*, 9(1), 62-69. <https://doi.org/10.32861/jac.91.62.69>
- Tac-an, A.M.I., Lacap, A.T., Bayogan, E.R.V., & Lubaton, C.D.S. (2021). Postharvest Quality of Two Mangosteen (*Garcinia mangostana* L.) Fruit Maturities Held in Ambient and CoolBot-equipped Cold Storage. *Journal of Science, Engineering and Technology (JSET)*, 9(1), 48–60. <https://doi.org/10.61569/n49qq233>
- Tadmor, Y., Burger, J., Yaakov, I., Feder, A., Libhaber, S.E., Portnoy, V., Meir, A., Tzuri, G., Sa'ar, U., & Rogachev, I. (2010). Genetics of flavonoid, carotenoid, and chlorophyll pigments in melon fruit rinds. *J. Agric. Food Chemical*, 58(19), 10722–62810728. <https://doi.org/10.1021/jf1021797>
- Terán -Erazo, B., Alia-Tejagal, I., Balois-Morales, R., Juárez-López, P., López-Guzmán, G.G., Pérez-Arias, G.A., & Núñez-Colín, C.A. (2019). Caraterización física, química y morfológica de frutos de guanábana (*Annona muricata* L.). *Agrociencia*, 53(7), 1013-1027. <https://www.agrociencia-colpos.org/index.php/agrociencia/article/view/1860>
- Tiang, N., Ahad, M.A., Murugaiyah, V., & Hassan, Z. (2020). Xanthone-enriched fraction of *Garcinia mangostana* and α -mangostin improve the spatial learning and memory of chronic cerebral hypoperfusion rats. *Journal of Pharmacy and Pharmacology*, 72(11), 1629–1644. <https://doi.org/10.1111/jphp.13345>

- Tsan, F.Y. (2022). Regeneration of *Garcinia mangostana* L. with Cut Seeds. In Che-Husin, N.M., Mohd-Roseli, A.N., Sekeli, R., Othman, R., Osman, N., Aishah-Hassan, S. Plant Resilience and Productivity in New Environmental Era. (pp.149-154). Ed. Trans. Malaysian Soc. Plant Physiol.
- Ward, J.H. Jr. (1963). Hierarchical grouping to optimize an objective function. *J. American Stat. Assoc.*, 58, 236-244 pp. <https://doi.org/10.2307/2282967>
- Yani, F., Bellastasié, R., & Fauziah, F. (2021). Antidiabetic Potential of *Garcinia mangostana* Extract and α -Mangostin Compounds from Mangosteen (*Garcinia mangostana* Linn.). *EAS Journal of Pharmacy and Pharmacology*. 3(5), 95–105. <https://doi.org/10.36349/easjpp.2021.v03i05.001>
- Yao, T.L., Nazre, M., McKey, D., Jalonen, R., & Duminil, J. (2023). The origin of cultivated mangosteen (*Garcinia mangostana* L. var. *mangostana*): Crucial assessments and an evolutionary-ecological perspective. *Ecology and Evolution*, 13(3), article e9792. <https://doi.org/10.1002/ece3.9792>