

Fruit productivity and quality in yellow passion fruit orchards with different trellis systems and planting density in the Colombian low tropics

Productividad y calidad de la fruta en huertos de maracuyá con diferentes sistemas de tutorado y densidad en el trópico bajo colombiano



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Comparative advantage of the single trellis (or espalier) system: mechanized phytosanitary management.

Photo: J.A. Cleves-Leguízamo

ABSTRACT

In the last two decades, the cultivation of passion fruit has gained significant importance, as evidenced by the sustained increase in planting area, productivity growth, technological advancements, and the creation of numerous jobs. The trellising system, also known as the support system, is closely linked to the productivity and quality of the fruit, yet information on this topic is not available for the Colombian Orinoquia. In the municipalities of Granada and Lejanias, yellow passion fruit (*Passiflora edulis* f. *flavicarpa* Deg.) orchards with different trellising systems were identified: simple trellis (ES), T or horizontal trellis (T), and total trellis or barbecue (ET). Based on the Colombian technical standard (NTC 1279), weekly records of production volume were taken once production began, considering the quality grades: first, second, and industrial. The variables analyzed were planting distance, planting density (plants/ha), production cycle duration (months), productivity (kg ha⁻¹), and fruit quality (%). The study found that the simple trellis system (ES) presented significant comparative advantages, such as higher productivity (30.5 t ha⁻¹) with 73% first-quality fruit, followed by the T or horizontal trellis system with 22.8 t ha⁻¹ and 55% first-quality fruit, and finally the total trellis system (ET) with 19 t ha⁻¹ and 39.7% first-quality fruit. Regarding the duration of the crop cycle, no significant differences were found. It was confirmed that the simple trellis system offers the greatest and best competitive advantages, allowing for higher planting density, increased crop ventilation, reduced self-shading, higher photosynthetic efficiency, lower incidence and severity of pests and diseases, and facilitating practices such as mechanization, assisted pollination, pruning, more efficient phytosanitary controls, and a lower requirement for synthetic chemical inputs.

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Additional keywords: *Passiflora edulis* f. *flavicarpa* Deg.; support system; trellising system; productivity; fruit quality.

RESUMEN

En las últimas dos décadas, el cultivo de maracuyá ha ganado significativa importancia, como lo demuestra el aumento sostenido de la superficie de siembra, el crecimiento de la productividad, los avances tecnológicos y la generación de numerosos empleos. El sistema de tutorado, también llamado de soporte, está íntimamente ligado a la productividad y calidad del fruto, sin embargo no se dispone de información sobre este tema para la Orinoquía colombiana. En los municipios de Granada y Lejanías se identificaron huertos de maracuyá (*Passiflora edulis* f. *flavicarpa* Deg.) con diferentes sistemas de tutorado: espaldera simple (ES), espaldera en T o mantel (T), y espaldera total o barbaoca (ET). Con base en la norma técnica colombiana (NTC 1279), se tomaron registros semanales del volumen de producción una vez iniciada la producción, considerando los grados de calidad: primera, segunda e industrial. Las variables analizadas fueron distancia de siembra, densidad de siembra (plantas/ha), duración del ciclo de producción (meses), productividad (kg ha⁻¹) y calidad del fruto (%). El estudio encontró que el sistema de espaldera simple (ES) presentó importantes ventajas comparativas, como mayor productividad (30,5 t ha⁻¹), con un 73% de fruta de primera calidad, seguido del sistema T o mantel con 22,8 t ha⁻¹ y 55% de fruta de primera calidad, y finalmente el sistema en espaldera total (ET) con 19 t ha⁻¹ y 39,7% de fruto de primera calidad. En cuanto a la duración del ciclo del cultivo no se encontraron diferencias significativas. Se confirmó que el sistema de espaldera simple ofrece las mayores y mejores ventajas competitivas, permitiendo mayor densidad de siembra, mayor ventilación del cultivo, reducción del autosombreamiento, mayor eficiencia fotosintética, menor incidencia y severidad de plagas y enfermedades, y facilitando prácticas como la mecanización, polinización asistida, poda, controles fitosanitarios más eficientes y menor requerimiento de insumos de síntesis química.

Palabras clave adicionales: *Passiflora edulis* f. *flavicarpa* Deg.; sistema de soporte; tutorado; productividad; calidad de la fruta.

Received: 24-09-2023 Accepted: 05-03-2024 Published: 30-04-2024

INTRODUCTION

Passion fruit is a tropical plant belonging to the Passifloraceae family (Souza *et al.*, 2018). The most important genus within this family is *Passiflora* L., with about 752 species (GBIF Secretariat, 2023). These species have various uses, including ornamental purposes, industrial food applications, fresh fruit consumption, and as sources for cosmetic and medicinal inputs (therapeutic compounds, psychoactive drugs, and dietary supplements) (Bernacci *et al.*, 2003; Bernacci *et al.*, 2008; Rodríguez-Amaya, 2012; Cerqueira-Silva *et al.*, 2014a; Fernandes *et al.*, 2020). Basso *et al.* (2019) and Rodríguez *et al.* (2020) suggest that South America is the center of diversity for most passion fruits, particularly in the northern region (Colombia, Ecuador, and Venezuela) and the southern region (Bolivia, Brazil, and Peru). Brazil, Colombia, Peru, Ecuador, and Venezuela generate over 80% of the regional production (Souza *et al.*, 2018), with consumption

in various forms such as fresh fruit, juices, concentrates, condiments, pulps, and for medicinal use, though large-scale industrialization processes are still in their early stages (Tigrero *et al.*, 2016). Kawasoe *et al.* (2021) and Xu *et al.* (2023) report that this fruit has nutraceutical properties, which help to boost immunity and prevent disease.

In Colombia, yellow passion fruit (*Passiflora edulis* f. *flavicarpa* Deg.) adapts well and is commercially cultivated across a wide range of altitudinal zones in the low and mid tropics (Delgado-Méndez *et al.*, 2013). Previous research has shown that yield potential and quality are associated with genotype, water resource availability, growing practices (fertilization, artificial pollination), and environmental factors, including the availability of natural pollinators (Martínez *et al.*, 2009).

The use of training systems in the production of passion fruits is intended to regulate the yield (Deshmukh *et al.*, 2017). These systems are similar to those used in the production of grapes, to keep flowers and fruits away from the ground and facilitate harvesting (Stafne and Rezazadeh, 2021). The most used is the 2-arm Kniffin training system due to its cost-benefit ratio (Deshmukh *et al.*, 2017), although the pergola is also used (Stafne and Rezazadeh, 2021).

Passion fruit production systems face the challenge of being competitive and require optimization of the production system (D'abadia *et al.*, 2019). A systematic study by Cleves-Leguízamo (2021) in the central Colombian zone indicates that the choice of the trellis system depends on the target market, planting density, environmental factors and soil fertility level. Silva Filho *et al.* (2019) report higher yield and more fruits per plant when using a staking system in *Pasiflora foetida*, with the horizontal ones being particularly effective. Jesus *et al.* (2020) report a low number of flowers and fruit set as well as greater damage due to bacteriocins in passion fruit without staking and soil mulching (Nóbrega *et al.*, 2022).

Cleves-Leguízamo (2021) consider the single trellis system or simple espalier system (ES) the most used option because it adapts well to a growing cycle of 24 months, allows for greater planting density, is durable and easy to build, has less wind resistance, facilitates crop work, and allows intercropping with other crops. It is ideal for areas of high fertility, warm and humid climates, slopes less than 15%, high productivity with small fruits and optimal °Brix for regional and local markets. The study also notes that other conduction systems require greater economic investment in construction and maintenance, as well as increased phytosanitary and crop management, lower planting density and shorter crop duration. The choice of systems depends on the slope (T or mantel trellis <20%, pergola 30%), wind speed, solar radiation and persistence of cloud cover.

The commercial and intensive cultivation of passion fruit requires the timely availability of support or trellising systems, which can represent up to 70% of the total production costs. There is a significant lack of information regarding the relationship between trellising and productivity in terms of volume and quality of the fruit (first, second and industrial expressed as a percentage). This deficiency is addressed in this document, where the three support systems – single trellis system or simple espalier system, “T”

or “mantel” support system, and total trellising or barbacoa support system – are analyzed in relation to planting density, crop duration, total production, and fruit quality percentage.

MATERIALS AND METHODS

The fieldwork was conducted in yellow passion fruit orchards of the Colombian Orinoquia, specifically in the municipalities of Granada and Lejanias, at 650 m a.s.l., with 3,500 mm year⁻¹ of precipitation, 23°C average annual temperature and 89% RH and 420 m a.s.l., 2,465 mm year⁻¹ of precipitation, 25°C of average annual temperature and 79% RH.

In the aforementioned municipalities, the soils are deep, with high to medium fertility, though they do have some technically manageable chemical limitations. They possess adequate physical properties, with moderate to slight slopes and excellent drainage, and are grouped in agrological classes II and III, which allow the establishment of a wide range of intensive crops. The fertilization and nutrition program was established based on the results obtained from soil analysis. The seedlings were obtained from nurseries registered at the regional level. According to the water balance, the water supply was 70% higher than the required demand; therefore, in all productive units and for all phenological phases of the crop, no supplementary irrigation was required.

Based on a survey of passion fruit producers, a targeted sampling was carried out to select three productive units that used the following trellis systems, single trellis system (ES) or simple espalier system, “T” or “mantel” support system, and total trellising or barbacoa support system for two cycles or consecutive plantings for an approximate period of 3.5 years: once the first production cycle was completed and the plant material was removed, the new planting of the second production cycle begins with soil preparation incorporating different sources of mineralized organic matter. This is followed by minor repairs and adjustments to the support system. This cultural management practice is frequently carried out by farmers in the region, an activity that allows them to significantly reduce total production costs in the second harvest.

The study unit corresponded to 10,000 m² for each trellis system. Information was collected from each unit by engaging with passion fruit producers,

ensuring that planting dates did not differ by more than 30 d between production units to maintain equal environment conditions, specifically the distribution and volume of precipitation (monthly, annual, and decadal levels), a variable considered to have a significant impact on the phenological behavior of cultivars under low tropical conditions. Recent studies by Jiménez-Bohórquez *et al.* (2024) have shown that under water stress conditions, the passion flowers experience significant decrease in plant height, leaf area, fresh and dry matter, and photosynthate accumulation, which can ultimately lead to crop failure.

Starting from the fifth month, the production volume was recorded weekly, categorizing the quality into first, second and third or industrial, also called “juicy”, according to NTC number 1267 (ICONTEC, 2022). The classification was based on fruit weight and size (diameter): first quality at 60 mm and 169 g; second quality at 40 mm and 140 g; and third or industrial quality with lower weight and size, including fruit with mechanical defects. Additionally, data on planting density (plants/ha) and crop duration (months) were collected.

Trellising systems

Single trellis system or simple espalier system (Es): this system consists of a structure incorporating sturdy 3.0 m long wooden posts, buried 50 cm deep and spaced 9.0 m apart. Two bamboo sticks are placed between each wooden post, 3 m apart. Galvanized wire gauge 10 is fixed at a height of 1.85 m using staples. The most commonly used planting distances are 3.0 m between plants and 3.0 m between rows (1,111 plants/ha), although in smaller areas, it can be 3.0 m between plants and 2.5 m between rows (1,333 plants/ha). Regardless of the system, two stakes must be placed, one at the beginning and one at the end of each row (Cleves-Leguízamo *et al.*, 2009).

“T” or “mantel” support system (T): this system is widely used in regions with high relative humidity, high cloud cover, and low wind speed. It is quite similar to the ES system: wooden posts and bamboo sticks are placed at the same distance, with the main difference being that three wires are placed at the top, forming a kind of tunnel or mantel. The distance between plants remains at 3.0 m, but the distance between rows is increased to 4.0 m, allowing for a planting density of 833 plants/ha.

Total trellising support system (babarcoa) or pergola: this system is widely used in regions with high relative humidity, low solar radiation, and high cloud cover. It is used to increase and expose the photosynthetically active area of the crop. Wooden posts, 2.5 m long, are placed around the perimeter of the plot, spaced 9.0 m apart. The posts are secured at a depth of 50 cm, leaving an effective height of 2.0 m. Then, using gauge 12 wire, a square is configured, supported on top of the posts. From this square, a grid is created (1.0 x 1.0 m) using gauge 16 wire. When the crop develops, it forms a foliage canopy that limits pollination, harvesting, and spraying operations (Cleves-Leguízamo, 2021). In this system, the planting distance is increased to 4.0 m between plants and 4.0 m between rows (625 plants/ha). Regardless of the system, two stakes must be placed, one at the beginning and one at the end of each row (Cleves-Leguízamo *et al.*, 2009).

Descriptive statistical parameters were determined including mean, standard deviation and coefficient of variation between the trellis systems evaluated. The program used was R.

RESULTS AND DISCUSSION

Planting density and crop duration

The Colombian Orinoquia region is one of the most important fruit-producing areas in the Meta department, with the largest area of fruit cultivation. Commercial plantings of cocoa (*Theobroma cacao* L.), avocado (*Persea americana* L.), mangosteen (*Garcinia mangostana* L.), and orange var. Valencia (*Citrus sinensis* L. Osbeck var. Valencia), Arrayana mandarin (*Citrus reticulata* L.), Tahiti lemon (*Citrus latifolia* L.), tangelo (*Citrus tangelo* L.) are also prominent in this region (Cleves-Leguízamo, 2022).

Passion fruit producers prefer the simple trellis system because it allows greater planting density and duration of the crop cycle (Tab. 1).

The study found that passion fruit cultivation with a simple trellis had a higher planting density (1,231 plants/ha) and a useful life of the productive system similar to the T-trellis or mantel (17-18 months). The lowest planting density was observed in the total trellis or pergola (617 plants/ha) and the shortest useful life of the plant (13 months).

Table 1. Planting density and crop duration for the three support systems in passion fruit cultivation.

Support system	Planting density (plants/ha)			Crop duration (months)		
	Average	Standard deviation	Variable coefficient (%)	Average	Standard deviation	Variable coefficient (%)
Simple espalier	1,231.3	100.33	8.1	18.8	0.753	3.99
T or mantel	817.7	29.34	3.59	17.3	1.51	8.68
Total trellising	616.7	12.91	2.1	13.5	8.68	9.1

Weber *et al.* (2016), Monzani *et al.* (2018) and Cleves-Leguizamo (2021) consider that several factors must be taken into account when choosing the planting density, topography, trellis system, level of mechanization, plant management, association with other crops, type of pollination, vigor and use of improved cultivars, edaphoclimatic conditions and phytosanitary problems. Various fungi, insects, bacteria, viruses and phytoplasmas affect the cultivation of passion fruit and especially yellow passion fruit. Cerqueira-Silva *et al.* (2014b) and Asande *et al.* (2023) point out that phytosanitary problems, particularly the globally prevalent mosaic virus complex, reduce the useful life of passion fruit to only 1 to 2 years.

Monzani *et al.* (2018) propose the use of pesticides, adequate planting density, resistant cultivars or rootstocks and windbreaks as sanitary management strategies to reduce diseases and guarantee productivity. In this regard, Weber *et al.* (2016) indicate that increasing planting density increases the number of productive branches per area, generating an increase in production and compensating for the lower longevity of the orchards, with earlier production. Likewise, the authors point out that the vertical back is very common in Brazil—a leading country in production—due to its low cost and compatibility with mechanization. However, the reuse of horizontal trellises from other crops is very common, allowing greater exposure to light and a shorter duration of the foliage humidity period, which promotes the development and spread of diseases, and thus increasing crop yield and improving fruit quality.

Productivity

The simple espalier yielded the highest production (30.5 t ha⁻¹), and the total trellising the lowest (19.5 t ha⁻¹) (Tab. 2). The superiority of the simple trellis in terms of duration and production is due to the high planting density (Weber *et al.*, 2016). In addition,

the trellis facilitates better air circulation, greater interception of radiation, and lower pest and disease incidence by reducing relative humidity and thus phytosanitary disturbances. Moreover, it streamlines mechanization processes, assists pollination, enhances input efficiency with more uniform foliar spraying, facilitates pruning, and accelerates harvesting processes. Furthermore, its stable structure limits movement, thus reducing mechanical damage to the root collar (Monzani *et al.*, 2018; Cleves-Leguizamo, 2021).

Table 2. Average fruit productivity in three trellising systems in passion fruit.

Support system	Average (t ha ⁻¹)	Standard deviation	Variable coefficient (%)
Simple espalier	30.5	1.5	4.5
T or mantel support	22.7	1.0	5.0
Total trellising support	19.5	0.8	4.2

Although specialized scientific literature does not report similar work for tropical conditions as the study area, some researchers assert that production volumes and quality percentages in passion fruit cultivation depend on multiple factors, both ecosystemic and crop management (D'abadia *et al.*, 2019). Among the former, water supply emerges as a critical factor in terms of volume and frequency during highly sensitive phenological periods like flowering, fruit set, and fruit filling (Souza *et al.*, 2018), along with soil suitability, species availability, and pollinating entomofauna numbers during the flowering phase (Cleves-Leguizamo, 2021).

Concerning crop management factors, the lack of development and introduction of improved germplasm is notable, with no research and extension work conducted for several decades to evaluate genetic materials in specific environments. This evaluation could provide insight into material adaptability, stability,

and resistance analysis to stress factors, especially biotic ones (Silva *et al.*, 2016; Ajose *et al.*, 2023).

Additionally, the low quality of propagation material available in the region results from institutions failing to enforce current regulations, primarily due to budgetary and logistical constraints. Consequently, nurseries do not adhere to minimum phytosanitary standards. Moreover, the low coverage of government technical assistance creates a void filled by input sellers, often hindering growers' ability to act and leading to excessive application of agrochemical inputs. This practice poses serious environmental risks, particularly to beneficial entomofauna, soil, water, and the health of producers and consumers (Rodríguez *et al.*, 2016).

In tropical conditions, rainfall, relative humidity, sunshine, and cloudiness define harvest cycles. These climatological variables, coupled with technical limitations, affect crop, duration and disease management, particularly bacterial diseases, septoria, scab, anthracnose, and root system diseases (Nóbrega *et al.*, 2022).

Cerqueira-Silva *et al.* (2016) report that the most limiting diseases in passion fruit cultivation affect the vascular system and aerial parts, driven by fungi, bacteria, and viruses in tropical conditions. These pathogens cause premature plant death, defoliation, delayed production, low pulp yield, reduced quality, resulting in economic losses.

Fruit quality

The trellis systems presented marked numerical differences across the three quality categories. The simple trellis system showed the highest proportion of first quality (73%) and the lowest proportion of low-grade fruit compared to the other trellis systems. In contrast, the total trellis or pergola system had a

higher percentage of lower quality fruit (33% 3rd quality) compared to the other trellises. A high percentage of top-quality fruit yields the highest economic reward for the farmer (Tab. 3).

The trellis systems and pruning determine the vegetative and reproductive growth of the plant necessary to obtain the best quality fruit for various tendril crops (Monzani *et al.*, 2018). These observations coincide with the approaches of Weber *et al.* (2016) who suggest that higher planting densities result in increased production and number of fruits from assisted pollination (an increase of 64% compared to natural pollination for the first year). Local studies are necessary to determine the best trellis system and planting density for passion fruit production in the Colombian low tropics, as the simple trellis can yield a high proportion of top-quality fruit.

Cleves-Leguízamo *et al.* (2009; 2012) indicate that the simple espalier system offers greater competitive advantages that are reflected in optimal quality and volume of production. Fischer *et al.* (2018); Ramírez *et al.* (2021); Fischer *et al.* (2022) and Fischer *et al.* (2023) mention that the ecophysiological and climatic requirements of different types of passion fruit are diverse, and in Colombia, these requirements depend on elevation, which is inversely related to temperature. In the study area (low tropics), the temperature is constant most of the year, significantly impacting photosynthesis and respiration processes (Cleves-Leguízamo *et al.*, 2021; Cleves-Leguízamo, 2021).

CONCLUSION

Comparatively, among the three support or trellising systems, the simple trellis system (Es) presented the greatest comparative advantages for the environmental conditions of the Colombian low tropics. This system resulted in higher production volume per

Table 3. Percentage of fruit quality according to the support trellising system in passion fruit cultivation.

Support system	1 st Quality (%)			2 nd Quality (%)			3 rd Quality (%)		
	Average	Standard deviation	Variation coefficient (%)	Average	Standard deviation	Variation coefficient (%)	Average	Standard deviation	Variation coefficient (%)
Simple espalier	73.3	4.27	5.83	15.8	4.21	26.62	12.5	5.92	47.39
T or mantel	55.0	8.69	15.8	21.3	6.15	28.84	23.7	10.28	43.47
Total trellising	39.7	4.97	12.5	27.2	2.14	26.62	33.2	5.04	15.18

hectare and better fruit quality for fresh consumption according to Colombian regulations. This support system facilitates aeration, which reduces pests and diseases and increases the efficiency of assisted pollination, foliar spraying and harvesting. Studies have shown that this system supports a greater leaf area capable of photosynthesis, leading to higher quality and greater income generation. As for the crop duration, there are no significant differences among the three support systems. In tropical conditions, when considering planting density, it is essential to analyze the environmental factors, mainly water supply (volume and distribution), relative humidity, wind speed, radiation, sunshine, land slope, proximity to biological corridors and the feasibility of mechanization.

ACKNOWLEDGMENTS

The author is grateful for the fundamental support received from agricultural engineer A.A. Montaña-Vásquez in the development of the field work with the communities. Additionally, the author thanks Prof. H.E. Balaguera-López for his collaboration in the statistical analysis.

Conflict of interests: The manuscript was prepared and reviewed by the author, who declares that there exists no conflict of interest that puts at risk the validity of the presented results.

BIBLIOGRAPHIC REFERENCES

- Ajose, T.E., J.O. Matthew, O.B. Fajinmi, and O. Arogunda. 2023. Preliminary field evaluation of passion fruit lines for agronomic performance and disease expression. pp. 350-354. In: Proc. 41st Annual Conference of Hortson. Ogbomoso, Nigeria.
- Asande, L.K., O. Ombori, R.O. Oduor, S.B. Nchore, and E.N. Nyaboga. 2023. Occurrence of passion fruit woodiness disease in the coastal lowlands of Kenya and screening of passion fruit genotypes for resistance to passion fruit woodiness disease. *BMC Plant Biol.* 23, 544. Doi: <https://doi.org/10.1186/s12870-023-04546-8>
- Basso, C., C. Rodríguez, G. Rivero, R. León, M. Barrios, and G. Díaz. 2019. Respuesta del cultivo de maracuyá (*Passiflora edulis* Sims L.) a condiciones de estrés por inundación. *Bioagro* 31(3), 185-192.
- Bernacci, L.C., M.D. Soares-Scott, N.T.V. Junqueira, I.R.S. Passos, and L.M.M. Meletti. 2008. Revisão *Passiflora edulis* Sims L.: the correct taxonomic way to cite the yellow passion fruit (and of others colors). *Rev. Bras. Frutic.* 30(2), 566-576. Doi: <https://doi.org/10.1590/S0100-29452008000200053>
- Bernacci, L.C., F.A. Vitta, and Y.V. Bakker. 2003. *Passifloraceae*. pp. 247-274. In: Wanderley, M.G.L., G.J. Shepherd, A.M. Giuletta, and T.S. Melhem (eds.). *Flora fanerogâmica do estado de São Paulo*. RiMa/FAPESP, São Paulo, Brazil.
- Cerqueira-Silva, C.B.M., L.D.H.C.S. Conceição, A.P. Souza, and R.X. Corrêa. 2014b. A history of passion fruit woodiness disease with emphasis on the current situation in Brazil and prospects for Brazilian passion fruit cultivation. *Eur. J. Plant Pathol.* 139, 261-270. Doi: <https://doi.org/10.1007/s10658-014-0391-z>
- Cerqueira-Silva, C., F. Gelape-Faleiro, E. Nunes, L. Santos, and L. Pereira-de Souza. 2016. The genetic diversity, conservation, and use of passion fruit (*Passiflora* spp.). pp. 215-231. In: Ahuja, M.R. and S.M. Jain (eds.) *Genetic diversity and erosion in plants. Sustainable development and biodiversity*. Vol. 8. Springer International Publishing, Cham, Switzerland. Doi: https://doi.org/10.1007/978-3-319-25954-3_5
- Cerqueira-Silva, C.B.M., O.N. Jesús, E.S.L. Santos, R.X. Corrêa, and A.P. Souza. 2014a. Genetic breeding and diversity of the genus *Passiflora*: progress and perspectives in molecular and genetic studies. *Int. J. Mol. Sci.* 15(8), 14122-14152. Doi: <https://doi.org/10.3390/ijms150814122>
- Cleves-Leguizamo, J.-A. 2021. Functional analysis of trellising systems and their impact on quality and productivity in passion fruit (*Passiflora edulis* Sims L. f. *Flavicarpa* and f. *Pupurea*, Degener) cultivars in Colombia. *Rev. Bras. Frutic.* 43(5), e-886. Doi: <https://doi.org/10.1590/0100-29452021886>
- Cleves-Leguizamo, J.A. 2022. Caracterización agroecológica y resiliencia de sistemas citrícolas a la variabilidad climática en el departamento del Meta, Colombia. Colección Techné, Editorial Universidad Nacional de Colombia, Tunja.
- Cleves-Leguizamo, J.A., A.J. Jarma, and J. Fonseca. 2009. Manejo integrado del cultivo de maracuyá (*Passiflora edulis* f. *flavicarpa*). pp. 97-119. In: Miranda, D., G. Fischer, C. Carranza, and F. Casierra (eds.). *Cultivo, postcosecha y comercialización de las pasifloras en Colombia: maracuyá, ganadilla, gulupa y curuba*. Sociedad Colombiana de Ciencias Hortícolas, Bogotá.
- Cleves-Leguizamo, J.A., A.J. Jarma, and G. Puentes. 2012. Maracuyá (*Passiflora edulis* f. *flavicarpa* y f. *purpurea* L.). pp. 682-700. In: Fischer, G. (ed.). *Manual para el cultivo de frutales en el trópico*. Produmedios, Bogotá.
- Cleves-Leguizamo, J.A., L.N. Ramírez-Castaneda, and E.D. Díaz. 2021. Proposal of an empirical model to estimate the productivity of 'Valencia' orange (*Citrus sinensis* L. Osbeck) in the Colombian low tropics. *Rev. Colomb. Cienc. Hortic.* 15(3), e10860. Doi: <https://doi.org/10.17584/rcch.2021v15i3.10860>
- D'abadia, A.C.A., A.M. Costa, F.G. Faleiro, J.V. Malaquias, and F.P. Araújo. 2019. Physical-chemical and chemical characterization of *Passiflora cincinnata* Mast fruits

- conducted in vertical shoot positioned trellis and horizontal trellises system. *Rev. Bras. Frutic.* 41(6), e-452. Doi: <https://doi.org/10.1590/0100-29452019452>
- Delgado-Méndez, C., J. Castaño-Zapata, and B. Villegas-Estrada. 2013. Caracterización del agente causante de la roña del maracuyá (*Passiflora edulis* f. *flavicarpa* DeGENER) en Colombia. *Rev. Acad. Colomb. Cienc. Ex. Fis. Nat.* 37(143), 215-227. Doi: <https://doi.org/10.18257/racefyn.5>
- Deshmukh, N.A., R.K. Patel, S. Okram, H. Rymbai, S.S. Roy, and A.K. Jha. 2017. Passion fruit (*Passiflora* spp.). pp. 979-1005. In: Ghosh, S.N., A. Singh, and A. Thakur (eds.). *Underutilized fruit crops: importance and cultivation*. JAYA publishing, Delhi.
- Fernandes, A.M., E.A. Fortini, L.A.C. Müller, D.S. Batista, L.M. Vieira, P.O. Silva, C.H. Amaral, R.S. Poethig, and W.C. Otoni. 2020. Leaf development stages and ontogenetic changes in passionfruit (*Passiflora edulis* Sims.) are detected by narrowband spectral signal. *J. Photochem. Photobiol. B: Biol.* 209, 111931. Doi: <https://doi.org/10.1016/j.jphotobiol.2020.111931>
- Fischer, G., H.E. Balaguera-López, A. Parra-Coronado, and S. Magnitskiy. 2023. Adaptation of fruit trees to different elevations in the Tropical Andes. In: Tripathi, S. (ed.). *Ecophysiology of tropical plants*. Taylor and Francis Group; University of Delhi, New Delhi. Doi: <https://doi.org/10.1201/9781003335054-22>
- Fischer, G., L. Melgarejo, and J. Cutler. 2018. Pre-harvest factors that influence the quality of passion fruit: A review. *Agron. Colomb.* 36(3), 217-226. Doi: <https://doi.org/10.15446/agron-n.colomb.v36n3.71751>
- Fischer, G., A. Parra-Coronado, and H.E. Balaguera-López. 2022. Altitude as a determinant of fruit quality with emphasis on the Andean tropics of Colombia. A review. *Agron. Colomb.* 40(2), 212-227. Doi: <https://doi.org/10.15446/agron.colomb.v40n2.101854>
- GBIF Secretariat. 2023. *Passiflora* L. GBIF Backbone Taxonomy. Doi: <https://doi.org/10.15468/39omei>
- ICONTEC, Instituto Colombiano de Normas Técnicas. 2022. Norma Técnica Colombiana NTC 1267, Frutas frescas. Maracuyá. Especificaciones. 3rd ed. Bogota.
- Jesus, C.A.S., L.K.S. Lima, E.V. Carvalho, R.C.C. Rosa, O.N. Jesus, and E.A. Girardi. 2020. Optimized cutting of yellow passion fruit and its potential for unstaked or trellised cultivation. *Pesq. Agropec. Bras.* 55, e01563. Doi: <https://doi.org/10.1590/S1678-3921.pab2020.v55.01563>
- Jiménez-Bohórquez, E.F., M.A. Díaz-Arias, and H.E. Balaguera-López. 2024. Exogenous brassinosteroids application in purple passion fruit plants grafted onto a sweet calabash passion fruit rootstock and under water stress. *Rev. Colomb. Cienc. Hortic.* 18(1), e16514. Doi: <https://doi.org/10.17584/rcch.2024v18i1.16514>
- Kawasoe, H., M. Wakamatsu, S. Hamada, Y. Arata, K. Nagayoshi, R. Uchida, R. Yamashita, T. Kishita, H. Yamanouchi, Y. Minami, and K. Kajiya. 2021. Analysis of natural colourant extracted from the pericarp of passion fruit. *Lwt* 136(2), 110412. Doi: <https://doi.org/10.1016/j.lwt.2020.110412>
- Martínez, L., S. García, and R. Sanabria. 2009. Zonificación de las especies pasifloras comerciales en Colombia. pp. 18-44. In: Miranda, D., G. Fischer, C. Carranza, S. Magnitskiy, F. Casierra, W. Piedrahita, and L. Flores (eds.). *Cultivo, poscosecha y comercialización de las pasifloras en Colombia: Maracuyá, granadilla, gulupa y curuba*. Sociedad Colombiana de Ciencias Hortícolas, Bogota.
- Monzani, R.M., H.S.S. Duarte, and L.L.M. Mio. 2018. Yellow passion fruit in overhead trellis system do not differ in diseases intensity and is more productive compared to vertical trellis system. *Rev. Bras. Frutic.* 40(2), e-579. Doi: <https://doi.org/10.1590/0100-29452018579>
- Nóbrega, D.S., J.R. Peixoto, M.S. Vilela, R.S. Mendonça, R.M.D. Sousa, A.P. Oliveira, A.A. Oliveira Júnior, and J.D. Ramos. 2022. Resistance to diseases of sour, sweet and wild passion fruit genotypes. *Biosci. J.* 38, e38030. Doi: <https://doi.org/10.14393/BJ-v38n0a2022-54159>
- Ramírez, L.N., S.L. Cristancho, and J.A. Cleves-Leguizamo. 2021. Modelos de fluctuaciones de precios agrícolas: estudio comparativo de frutas tropicales frescas en Colombia. *Rev. Cienc. Agrar.* 27(Suppl. 4), 197-212. Doi: <https://doi.org/10.31876/rcs.v27i.37002>
- Rodríguez, N., D. Ambachew, L.M. Melgarejo, and M.W. Blair. 2020. Morphological and agronomic variability among cultivars, landraces, and genobank accessions of purple passion fruit, *Passiflora edulis* f. *edulis*. *HortScience* 55(6), 768-777. Doi: <https://doi.org/10.21273/HORTSCI14553-19>
- Rodríguez, M.H., N.E. Niño, J. Cutler, J. Langer, F. Casierra-Posada, D. Miranda, M. Bandte, and C. Büttner. 2016. Certificación de material vegetal sano en Colombia: un análisis crítico de oportunidades y retos para controlar enfermedades ocasionadas por virus. *Rev. Colomb. Cienc. Hortic.* 10(1), 164-175. Doi: <https://doi.org/10.17584/rcch.2016v10i1.4921>
- Rodríguez-Amaya, D.B. 2012. Passion fruit. pp. 321-332. In: Siddiq, M. (ed.). *Tropical and sub-tropical fruits: postharvest physiology, processing and packaging*. Wiley-Blackwell, Oxford, UK. Doi: <https://doi.org/10.1002/9781118324097.ch17>
- Silva, F.H.L., P.R. Muñoz, C.I. Vincent, and A.P. Viana. 2016. Generating relevant information for breeding *Passiflora edulis*: genetic parameters and population structure. *Euphytica* 208(3), 609-619. Doi: <https://doi.org/10.1007/s10681-015-1616-8>
- Silva Filho, D.F., M.R.A. Batista, J.P.L. Aguiar, F.M. Machado, J.N.R. Figueiredo, and C.A. Ticona-Benavente. 2019. *Passiflora foetida* yielding and nutritional

- composition. Rev. Bras. Frutic. 41(3), e-144. Doi: <https://doi.org/10.1590/0100-29452019144>
- Souza, P.U., L.K.S. Lima, T.L. Soares, O.N. Jesus, M.A. Coelho Filho, and E.A. Girardi. 2018. Biometric, physiological and anatomical responses of *Passiflora* spp. to controlled water deficit. Sci. Hortic. 229, 77-90. Doi: <https://doi.org/10.1016/j.scienta.2017.10.019>
- Stafne, E.T. and A. Rezazadeh. 2021. Effect of trellis orientation on *Passiflora incarnata* growth and production. J. Appl. Hort. 23(3), 357-359. Doi: <https://doi.org/10.37855/jah.2021.v23i03.65>
- Tigrero, F., S. Lovato, and F. Quimi. 2016. Estudio de factibilidad de procesadora de derivados de maracuyá. Una alternativa de desarrollo en Santa Elena, Ecuador. Cienc. UNEMI 9(17), 21-35. Doi: <https://doi.org/10.29076/issn.2528-7737vol9iss17.2016pp21-35p>
- Weber, D., J. Eloy, M.A. Giovanaz, J.C. Fachinello, and J.C. Nachtigal. 2016. Densidade de plantio e produção do maracujazeiro-azedo no sul do Brasil. Rev. Bras. Frutic. 38(1), 99-106. Doi: <https://doi.org/10.1590/0100-2945-283/14>
- Xu, H., P. Qiao, J. Pan, Z. Qin, X. Li, H.E. Khoo, and X. Dong. 2023. CaCl₂ treatment effectively delays postharvest senescence of passion fruit. Food Chem. 417, 135786. Doi: <https://doi.org/10.1016/j.foodchem.2023.135786>