

The position in the canopy affects the quality of tropical and subtropical fruits

La posición en el dosel afecta la calidad de frutos tropicales y subtropicales

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ABSTRACT

The position of tropical and subtropical fruits in the canopy is essential for determining their quality, as it is strongly influenced by solar radiation, which acts directly on the outer canopy or indirectly on the inner canopy. The objective of this review was to examine the role of fruit position within the tree canopy on fruit quality, with an emphasis on tropical and subtropical species. In general, fleshy fruits on the outside of the canopy, which are well exposed to sunlight, are distinguished by their greater firmness and content of total soluble solids, sugars, ascorbic acid, antioxidant activity, phenolics, carotenoids, flavonoids, and color, but also by H_2O_2 and O_2^- . Meanwhile, fruits inside the canopy not only accumulate higher amounts of the antioxidants peroxidase (POD), ascorbate peroxidase (APX), superoxide dismutase (SOD), and catalase (CAT), but also acidity. Fruit position also influences disease incidence, mainly due to shade and higher humidity within the canopy. At the same time, physiological disorders such as epidermal discoloration, cracking, or wrinkling are more common in fruits exposed to high radiation. The practices that influence the fruit's exposure to light include pruning, thinning, bagging, and shading nets. Pruning branches and thinning fruits promote light penetration and overall fruit quality. Fruit bagging particularly improves its phytosanitary condition, while shading nets protect the outer fruits from sunburn. The sun-exposed position of the fruits accelerates their ripening, indicating that the canopy position is of great importance in determining the optimal time for harvesting.

Keywords: fruit acidity, antioxidants, physiological disorders, diseases, solar radiation, soluble solids.

RESUMEN

La posición de los frutos tropicales y subtropicales en el dosel es muy importante para la determinación de su calidad, siendo influenciada en alto grado por la radiación solar, ya sea de forma directa, en la parte externa de la copa, o indirecta, en la parte interna del árbol. El objetivo de esta revisión fue estudiar el papel que desempeña la posición del fruto en la copa del árbol sobre la calidad del fruto con énfasis en especies tropicales y subtropicales. En general, los frutos en el exterior de la copa, con buena incidencia de la radiación, se distinguen por su mayor firmeza y contenido de sólidos solubles totales, azúcares, ácido ascórbico, actividad antioxidante, fenoles, carotenos, flavonoides y color, pero también de H_2O_2 y O_2^- . Mientras que los frutos en el interior de la copa no acumulan solamente una mayor cantidad de los antioxidantes peroxidasa (POD), ascorbato peroxidasa (APX), superóxido dismutasa (SOD) y catalasa (CAT), sino también acidez. La posición del fruto influye también en la presencia de enfermedades especialmente por la sombra y mayor humedad en el interior de la copa, mientras que fisiopatías como decoloración, rajado o arrugamiento de la epidermis se observan más en frutos expuestos a alta radiación. Los manejos que influyen en la exposición del fruto a la luz son especialmente la poda, el raleo y el embolsado del fruto, además del sombrero del árbol. La poda de ramas y el raleo de frutos fomentan la entrada de la luz y la calidad en general. El embolsado del fruto mejora especialmente su estado fitosanitario, mientras las polisombras protegen los frutos externos de las quemaduras del sol. La posición soleada del fruto adelanta su maduración, lo que significa que la posición del fruto tiene una gran importancia en la elección del momento óptimo para la cosecha.

Palabras clave: acidez del fruto, antioxidantes, desórdenes fisiológicos, enfermedades, radiación solar, sólidos solubles.

Introduction

Fruits significantly contribute to a healthy diet, with the microclimate they are exposed to being a key factor affecting their production and quality (Fischer *et al.*, 2022). Beyond the environment where fruits grow, Khandaker *et al.* (2017) emphasize tree management as an essential factor

influencing both internal and external fruit characteristics. In tree species, a crucial factor is fruit position within the canopy, which can be altered through agronomic practices such as pruning, training the central axis, branch bending, and fruit thinning (Casierra-Posada & Fischer, 2012). However, in intensive cropping systems, tree canopy design is adjusted to ensure uniform fruit quality, which also

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impacts fruit ripening and final quality (Serna-Escolano *et al.*, 2024). In this context, Olarewaju *et al.* (2018) find that fruit position within the canopy and its exposure to sunlight are among the most essential preharvest factors influencing postharvest fruit quality.

Several studies have demonstrated that fruit quality and postharvest shelf life depend on preharvest factors such as fruit position and crop load (Olaewaju *et al.*, 2018), as well as exposure to light and temperature (Léchaudel *et al.*, 2013). The quality of the fruits depends significantly on its exposure to the sun, especially in fruits not covered by leaves (Ullah & Joyce, 2024), as shown by Gasparin *et al.* (2017) in orange fruits with a higher concentration of ascorbic acid in those exposed to the morning sun in an easterly direction in Spain (northern hemisphere); in the southern hemisphere, in South Africa, Satsuma, and Clementine citrus fruits remain greener in the north section of the canopy (Verreynne *et al.*, 2004).

Similarly, fruit diameter is influenced by internal factors such as genotype, competition among developing organs, and fruit position within the canopy (Neves *et al.*, 2018). The presence of fruits in the canopy can enhance photosynthesis, delay leaf senescence, and improve water and nutrient transport to the fruits (Singh *et al.*, 2024).

Léchaudel and Joas (2007) describe fruit quality based on intrinsic attributes such as aroma, acidity, sweetness, texture, nutritional value, and shelf life, as well as extrinsic attributes such as size and color. Neves *et al.* (2018) highlight that environmental and genetic factors, either alone or through their interaction, are crucial in shaping the organoleptic quality of fruits. Similarly, tree management practices—including rootstock selection (Aregay *et al.*, 2021), pruning and canopy training (Joas *et al.*, 2013), mineral nutrition (Ullah & Joyce, 2024), irrigation (Álvarez-Herrera *et al.*, 2024), fruit thinning (Paull & Duarte, 2012), phytohormone application (Gutiérrez-Villamil *et al.*, 2024), planting design, and intercropping systems (Miranda, 2012)—can markedly affect fruit quality.

Under climate change scenarios characterized by increased temperatures, solar radiation, and drought, trees with denser and shorter canopies, especially dwarf cultivars (López *et al.*, 2021), show better adaptation since their smaller leaves transpire less. Their canopies are less exposed to excessive solar radiation than those of large-canopy varieties (Abobatta, 2021). Only optimal climatic conditions affecting the canopy can support the development of maximum fruit quality at harvest and during postharvest (Balaguera-López

et al., 2024), by influencing photosynthesis, transpiration, carbohydrate translocation, and other metabolic processes of this organ (Ladaniya, 2008). Additionally, fruit position also plays an essential role in the application of (semi)automated harvesting techniques, such as vibrational harvest of litchi (Wang *et al.*, 2022), as well as in predictive models for estimating fruit quantity and yield (Anderson *et al.*, 2021). However, this subject is not yet fully understood and requires further in-depth research.

The goal of this study was to provide a comprehensive review of how the fruit position within the tree canopy affects fruit quality, focusing on tropical and subtropical species, to support decision-making in tree management and serve as a foundation for future research.

Methodology

Following the PRISMA guidelines, research articles, review articles, and book chapters were selected from six databases using a modified analytical method from Page *et al.* (2021). The keyword “fruit position” was used to identify documents published between 2004 and 2025, resulting in 3,740 articles on Google Scholar, of which 43 were relevant to tropical and subtropical fruits. ScienceDirect yielded 452 articles, of which 27 were suitable for this review, while Scopus provided 148 results, with 29 selected. From the SciELO and Redalyc databases, 3 articles each matched the objectives of this review. Semantic Scholar retrieved 711 articles, of which 40 fit this survey. Of the 142 articles considered appropriate, 78 were discarded as duplicates across these databases.

Fruit position in the canopy

In several fruit crops, fruit position within the canopy is closely linked to fruit quality, *e.g.*, in mandarins (Olaewaju *et al.*, 2022). Likewise, Serna-Escolano *et al.* (2024) highlight how factors of temperature, solar radiation, and air humidity influence the canopy microclimate. Additionally, depending on their location within the canopy, fruits develop resistance to environmental stress by upregulating gene expression and enhancing biochemical pathways that provide tolerance to various types of stress (Olaewaju *et al.*, 2022).

The position of the fruiting branch and the fruit itself in the canopy determines light exposure and can cause high variability due to the large number of fruits per tree (Fischer & Parra-Coronado, 2020; Léchaudel & Joas, 2007; Nordey *et al.*, 2014). Fruits directly exposed to sunlight have higher surface temperatures than those protected by leaves (Ullah

& Joyce, 2024). Fruits in unprotected canopy areas exposed to excessive solar radiation may develop photooxidative bleaching, browning, and necrosis, which significantly harm their quality (Racsko & Schrader, 2012), especially under conditions of low humidity and at high-altitude orchards with increased UV radiation (Fischer *et al.*, 2022; Fischer, Balaguera-López, Parra-Coronado *et al.*, 2024). In addition to sunburn, excessive radiation exposure of fleshy fruits can significantly heat epidermal cells, leading to fruit cracking and pathogen infections in these tissues, which lowers their commercial quality (Fischer *et al.*, 2021).

Fruit position within the canopy influences the level of exposure to solar radiation (Nordey *et al.*, 2014). Reduced light exposure directly impacts fruit development, photosynthesis, and dry matter (DM) accumulation, leading to lower sugar levels, nutrient content, and pigment concentration, and may increase fruit acidity (Santos Neto *et al.*, 2018). Regarding fruit size, Singh *et al.* (2025) note that, besides fruit position within the canopy and along the branch, other key factors include the leaf-to-fruit ratio, tree age, seed number, climate, water and nutrient availability, and genetic background.

When comparing light penetration in tree canopies, in lemon (*Citrus x limon* 'Limoneira 8A'), as studied by Interdonato *et al.* (2011) in Tucumán (Argentina) and also in feijoa (*Acca sellowiana* 'Quimba') in the northern hemisphere in Colombia, as reported by Martínez-Vega *et al.* (2008), it was found that internal fruits, under both cloudy and sunny conditions, received significantly less radiation than fruits on the outer canopy. In lemon trees, the internal canopy experience reductions of up to 67% in PAR (photosynthetically active radiation) and 76% in UV-B radiation on sunny days (Interdonato *et al.*, 2011), while in feijoa trees, PAR is reduced by 65% at the base and 30% in the inner middle canopy (Martínez-Vega *et al.*, 2008). Similarly, in both fruit species, the reduction of PAR within the inner canopy is proportionally lower under cloudy conditions.

Citrus

In citrus fruits, Aregay *et al.* (2021) report that fruit size increases with tree age, which is due to the larger canopy providing more leaf area, thus boosting photosynthesis and increasing the supply of assimilates. As shown in Table 1, across different citrus accessions, there is a general trend for fruits in the outer canopy (upper layers or sun-exposed

TABLE 1. Impact of fruit position within the canopy on citrus fruit quality.

Species, variety	Research	Effect on quality	Authors
Orange 'Mahali'	Fruits harvested from different canopy positions in Southern Iraq	Fruits from the internal southern position show the highest values for TSS, TA, maturity index, juice ratio in fruits, and carotenoid content in the skin.	Al-Douri <i>et al.</i> (2021)
Blood Orange 'Sanguinelli'	Fruits harvested from different canopy positions in Spain	Fruits in the upper canopy stratum have the highest TSS and external color, while those that grew in clusters show greater weight, internal color, and maturity index; in turn, individually grown fruits have higher TA.	Serna-Escolano <i>et al.</i> (2024)
Grapefruit 'Marsh'	Comparison of fruit quality according to canopy position and province (KwaZulu-Natal or Mpumalanga) in South Africa	The values of TA and fruit lightness at inner and outer canopy positions differ between orchards in the two provinces. Still, they do not affect quality during cold storage.	Olarewaju <i>et al.</i> (2018)
Grapefruit (<i>C. paradisi</i> Macf) 'Duncan' y 'Paraná.'	Comparison of TSS according to canopy position in Paraguay	TSS in fruits from the outer canopy, with 8.76 °Brix, are higher than those from the inner canopy with 7.85 °Brix.	Wlosek-Stafigret <i>et al.</i> (2016)
'Pontianak' <i>C. nobilis</i>	Comparison of fruit quality according to canopy position in 4-year-old trees in Indonesia	Fruit diameter, weight, total acid and sugar content, and pulp weight show no differences despite originating from different canopy positions (interior or exterior).	Sakhidin <i>et al.</i> (2018)
Mandarin (<i>C. reticulata</i>) Blanco	Comparison of fruit quality according to canopy position in Nepal	TSS (15.0) and pH (3.41) are higher on the south side of the canopy, while TSS/TA (21.13) is higher on the east side, and TA (0.91%) and ascorbic acid (37.54 mg 100 g ⁻¹) are higher on the west side of the canopy.	Timilsina and Tripathi (2019)
Mandarin 'Shogun'	Comparison of fruit quality according to canopy position in Thailand	TSS, appearance, yellow color, and chroma are higher in fruits from the upper canopy layer. In contrast, TA is similar across the different canopy positions.	Youryon and Supapvanich (2019)
Satsuma 'Mihowase' and Clementine 'Nules' and Tangor 'Fairchild' and 'Temple'	Comparison of fruit quality according to tree position (4 orientations and 3 subsectors) in Citrusdal, South Africa	'Fairchild' is the most colorful, with fruits on the north side (warmer) being greener. For Clementines, Satsumas, and 'Temple', fruits in the upper canopy are larger. TSS are highest in the upper canopy, while TA values for Satsumas and Clementines are higher in the lower canopy.	Verreyne <i>et al.</i> (2004)
Mandarin 'Nules Clementine'	Comparison of quality by position in 13-year-old trees in South Africa	The levels of sucrose, glucose, and fructose in the pulp, as well as the flavedo (exocarp) color, are lower (higher hue angle) in fruits from the interior of the canopy compared to those from the exterior.	Cronje <i>et al.</i> (2013)

TSS: total soluble solids; TA: titratable acidity.

positions) to have higher levels of total soluble solids (TSS) and more vibrant external color compared to fruits located within the inner canopy (Cronje *et al.*, 2013; Serna-Escolano *et al.*, 2024; Timilsina & Tripathi, 2019; Verreynne *et al.*, 2004; Wlosek-Stańgret *et al.*, 2016; Youryon & Supapvanich, 2019). An exception is noted in oranges in Iraq (northern hemisphere), where fruits from the inner canopy on the south-facing side had higher TSS and peel carotenoid content (Al-Douri *et al.*, 2021). However, for the cultivar 'Pontianak' (*Citrus nobilis*), fruit position does not impact these attributes, including titratable acidity (TA) (Sakhidin *et al.*, 2018). In terms of TA, a tendency toward higher values in the shaded part of the canopy is observed (Olarewaju *et al.*, 2018; Verreynne *et al.*, 2004), though, in some cases, fruit position does not significantly influence this variable (Youryon & Supapvanich, 2019). It is important to note that the fruits in the inner canopy exhibit delayed maturation, not only due to reduced light availability but also because of a phenological effect associated with their position. Therefore, harvesting all fruits at once introduces a bias, as internal fruits are typically less mature. So, harvesting at the same phenological stage reduces the differences between "external" and "internal" fruits.

In Spain, fruit orientation in the canopy (*e.g.*, east- or west-facing) does not consistently influence TSS or external fruit color (Serna-Escolano *et al.*, 2024), whereas in mandarin in Nepal (northern hemisphere), TA and ascorbic acid levels are higher in the fruits on the west-facing side of the canopy (Timilsina & Tripathi, 2019). Similarly, in South Africa, TSS is higher in fruits harvested from the northern (warmer) canopy sector compared with the southern side for 'Fairchild' and 'Temple' tangors. However, no significant effect is observed for Clementine and Satsuma (Verreynne *et al.*, 2004). The increased sugar content and exocarp coloration of 'Clementine' fruits on the outer canopy is attributed by Cronje *et al.* (2013) to higher pigment levels, which enhance photosynthetic activity and result in greater sink strength in the exposed fruits.

Mango

In mango (*Mangifera indica*), environmental conditions within the canopy, such as high light intensity, raise fruit temperature, which affects fruit development and physiological age, and also causes metabolic and physiological disorders that lower yield and fruit quality (Joas *et al.*, 2013; Léchaudel *et al.*, 2013). Excessive temperatures may also reduce auxin production in the fruits, leading to smaller fruits (Wahid *et al.*, 2007). Additionally, the number of fruits in the inner canopy tends to be higher than in the outer canopy (Kawphaitoon *et al.*, 2016); conversely, the greater the number of fruits, the greater the fruit set.

Léchaudel *et al.* (2013) report that daily fruit temperature gradients in mango depend on exposure to sunlight and canopy position. These factors influence fruit transpiration by decreasing water conductance in sun-exposed fruits compared to those inside the canopy. Likewise, cuticle thickness increases not only with fruit maturity but also with increased sunlight exposure (Léchaudel *et al.*, 2013). Shaded fruits inside the inner canopy have lower sugar levels, mainly sucrose, in both 'Cogshall' (Joas *et al.*, 2013) and 'Kent' (Olale, 2024). However, fruit position does not affect fructose, glucose, or maltose contents (Olale, 2024).

In the mango cultivar 'Nam Dok Mai Sithong,' the maturity index (TSS/TA) is higher in fruits located in the upper outer canopy than in other tree positions (Kawphaitoon *et al.*, 2016), which is especially true for mango trees with large canopies, but is irrelevant for small-sized trees. Due to these differences in ripening, Lo'ay *et al.* (2021) suggest fruit position as a valuable criterion for determining harvest timing and for fruit grading before cold storage.

Avocado

In avocado (*Persea americana*) 'Gem' in South Africa, fruits located within the inner canopy have 2% lower dry matter (DM) (26.9%) compared to those on the outer parts of the tree (28.9%). According to Shezi, Magwaza, Mashilo *et al.* (2020), the lower photosynthetic efficiency of avocado trees in the inner canopy does not significantly reduce fruit DM content but does delay fruit ripening by up to two weeks. The higher DM content in fruits from the outer canopy is positively associated with the higher photosynthetic rate of the outer leaves ($A = 29.46 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) compared to interior leaves ($19.27 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$) (Shezi, Magwaza, Mashilo *et al.*, 2020). Similarly, in 'Hass' avocado in Australia, DM is significantly higher in fruits from sun-exposed positions in the upper, western, and eastern canopy (Ullah & Joyce, 2024). Regarding nutrient content, Ullah and Joyce (2024) find that 'Hass' fruits from well-exposed canopy positions had lower pulp concentrations of N, K, and Mg compared with fruits from the inner and lower canopy.

Similarly, Shezi, Magwaza, Tesfay *et al.* (2020) report in South Africa that the highest oil and DM contents in 'Hass' and 'Carmen' avocados are found in fruits from the outer canopy, which is attributed to faster ripening compared to fruits from the inner canopy. Conversely, Shezi, Magwaza, Tesfay *et al.* (2020) measure higher concentrations of C7 sugars (perseitol and D-mannoheptulose) in fruits from the center of the canopy, where cooler temperatures favor the buildup of reserve carbohydrates due to a lower respiration rate, unlike what is observed in outer canopy fruits.

Kiwifruit

In kiwifruit (*Actinidia deliciosa*) ‘Hayward’ trees in Turkey (northern hemisphere), fruit weight, thickness, and length are greater on vines located on the eastern and southern sides of the canopy, along with higher DM and TSS contents in fruits exposed to the south (Sulusoglu Durul & Efe, 2023). Accordingly, these authors suggest harvesting fruits based on maturity status, which depends on canopy position. Similarly, in Pisa (Italy), ‘Hayward’ kiwifruits located in the upper outer canopy of plants trained as free palmettes exhibit the highest pulp firmness (receiving 100% of solar radiation) compared with fruits from the lower inner canopy (receiving 15% of solar radiation) (Tavarini *et al.*, 2009). In Chile, Cooper *et al.* (2005) also report that kiwifruits that had greater initial firmness when directly exposed to sunlight; however, although these fruits soften more rapidly during storage, their firmness remains higher than that of fruits harvested from shaded positions within the canopy.

Interestingly, the total sap influx into kiwifruits during maturation was 30% higher in the sun-exposed fruits, reaching up to 140 g per fruit, compared to shaded fruits, which accumulate only 50% of the Ca found in well-exposed fruits. Montanaro *et al.* (2006) therefore conclude that light is also an essential factor influencing the Ca transport in plants. Because light is a key factor in stomatal opening, transpiration, and consequently mass flow, it is the mechanism that enables Ca transport to the aerial parts of plants (Taiz *et al.*, 2017).

Starfruit

In 12-year-old starfruit (*Averrhoa carambola*) trees in Malaysia (northern hemisphere), fruit position—whether (1) inside the canopy, (2) facing the morning sun, or (3) facing the afternoon sun—does not affect fruit TSS. However, fruits grown under full sun have higher ascorbic acid concentrations (Zabedah *et al.*, 2009). Similarly, carotenoid levels increase with exposure to PAR and accumulated heat units, indicating that irradiation may play an essential role in carotenoid biosynthesis (Zabedah *et al.*, 2009). Nonetheless, excessive irradiation of exposed fruits results in less glossy, darker green fruit color (lower L values). In contrast, shaded fruits within the canopy appear more appealing for export due to their better visual quality (Zabedah *et al.*, 2009).

In Florida, during the hottest summer months, starfruit have higher TSS in the southern canopy quadrant and in the middle and upper canopy layers. However, this difference is not seen during winter months, when winter-harvested fruits are heavier than summer ones (Kohout & Crane,

2004). Similarly, Zabedah *et al.* (2007) report greater fresh and dry weights in fruits grown under a shaded canopy than under full sunlight; however, fruits under higher insolation develop higher ascorbic acid content. Regarding fruit distribution by canopy position, the fewest fruits were found in the lower canopy layer, followed by the middle layer. In contrast, most fruits are recorded in the upper canopy layer (Kohout & Crane, 2004).

Zabedah *et al.* (2007) measure fruit temperature and irradiance under protected cultivation in Malaysia. They find that canopy position strongly influences fruit heat unit accumulation. At 80 days after anthesis, fruits exposed to morning sun accumulate 20°C more degree-days than those exposed in the afternoon, and 125°C more degree-days than those growing inside the canopy. Likewise, morning-exposed fruits receive a total PAR of 1,017 M m⁻², which is 268 M m⁻² higher than fruits exposed in the afternoon and 974 M m⁻² higher than those located within the canopy (Zabedah *et al.*, 2007).

Guava

In New Delhi, India, guava (*Psidium guajava*) ‘Allahabad Safed’ fruits from the upper canopy layer develop higher total sugar content (7.5%), TSS (11.85%), and specific gravity, reaching maturity earlier but with lower titratable acidity (0.28%) compared to fruits from the middle and lower canopy, which exhibit the highest ascorbic acid content (Asrey *et al.*, 2007). However, in Pantnagar, India, ‘Pant Prabhat’ guava fruits mature earlier in the lower canopy, while the fruits in the upper canopy contain the highest levels of Ca and K (Tamta *et al.*, 2012).

Feijoa

When assessing feijoa (*Acca sellowiana*) fruit quality across five canopy positions—internal base, external base, internal middle, external middle, and upper canopy—Martínez-Vega *et al.* (2008) observe that fruits in the upper quadrant have lower weight and less typical green coloration but show signs of more advanced maturity. They suggest that high radiation exposure, especially UV radiation, at an altitude of 2,350 m a.s.l. in Colombia, is responsible for these effects. However, TA, TSS, pH, and dry matter percentage are not significantly affected by canopy position, although fruits from the external middle quadrant generally had better quality attributes.

Annon

In India, Chander and Kurian (2019) observe a progressive decrease in fruit size of the cultivar Arka Sahan (*Annona atemoya* × *A. squamosa*) from the bottom to the top of the shoot. González and Cuevas (2008) report a similar pattern

in cherimoya (*Annona cherimola*), where larger fruits appear at the bottom of the fruiting shoots, indicating that sufficient light penetration within the canopy is crucial for producing high-quality fruits.

Pomegranate

Nuncio-Jáuregui *et al.* (2014) report in Alicante, Spain, that different fruit positions within the pomegranate (*Punica granatum*) tree do not significantly influence quality attributes such as TSS, TA, maturity index TSS/TA, organic acids, pH, sugar levels, antioxidant activity, proline, and total phenolic compounds. However, sun-exposed fruits show darker color (lower L*), lower b* values, and higher a* values, which are typical of high-quality pomegranates grown under full sun conditions (Nuncio-Jáuregui *et al.*, 2014).

Cape gooseberry

In the case of cape gooseberry (*Physalis peruviana*), where the calyx fully encloses the fruit during its development (Fischer, Balaguera-López, & Melgarejo, 2024), fruits harvested inside the canopy in a greenhouse in Mexico have an average weight of 2.9 g, while those from the outer canopy average only 2.6 g (Colli-Cortés *et al.*, 2020). It is believed that fruits located within the inner canopy, due to cooler temperatures, respire less and thus retain more carbohydrates compared to those on the outer canopy, where greenhouse conditions may cause significantly higher temperatures, as Shezi, *et al.* (2020) report for other fruit crops.

Fig

Fig (*Ficus carica*) 'Bouhouli' trees grown in Tunisia, with a leaf area index of 3.3, fruits on the outer canopy have lower acidity than those from the inner canopy. However, dry matter and TSS contents do not significantly differ among canopy positions. As a result, the TSS/TA ratio is higher in fruits from the tree's periphery, which also has a greater number of fruits (Trad *et al.*, 2013).

Cactus pear

In cactus pear (*Opuntia ficus-indica*) cultivars 'Gialla' and 'Rossa' in Sicily, Italy (Northern hemisphere), Inglese *et al.* (2010) found that fruits in the southeastern and northeastern canopy sections and in the upper layer, with PAR >20 mol m⁻² d⁻¹, grow larger but do not differ in TSS compared to fruits in other canopy positions.

Wax apple

When comparing five different fruit positions on the wax apple (*Syzygium samarangense*) cv. Jambu Madu, Khandaker *et al.* (2017) report higher fruit yield and quality (larger size, higher TSS, and better color) from the exterior canopy, which also show reduced fruit drop.

Influence of fruit position on bioactive compounds in fruits

The concentration of bioactive compounds in fruits largely depends on microclimate conditions within the tree canopy, such as light, temperature, and air humidity (Balaguera-López *et al.*, 2024), which vary depending on the fruit's position in the canopy. In citrus fruits (Tab. 2), those

TABLE 2. Impact of canopy position on bioactive compounds in tropical and subtropical fruits.

Species, variety	Research	Effect on bioactive compounds of fruits	Authors
Orange 'Monte Parnaso' (<i>Citrus sinensis</i>)	Comparison of canopy position and AsA activity in Paraná State, Brazil	The highest AsA levels in the fruit are observed in the apical third of the canopy, particularly in the southeast and northeast orientations (morning sun), as well as in the southwest part of the basal third (afternoon sun).	Gasparin <i>et al.</i> (2017)
Mandarin 'Clementine' (<i>Citrus reticulata</i> Blanco)	Comparison of canopy position and the activity of AsA and bioflavonoids (flavone glycosides) in the fruit rind in South Africa	The AsA content in the rind of fruits from the outer canopy is higher than in fruits from the inner canopy. Meanwhile, the rind of fruits from the outer canopy shows lower concentrations of the flavonoids hesperidin and narirutin compared to fruits from the inner canopy, with no difference observed for didymin.	Magwaza <i>et al.</i> (2013)
Mandarin 'Shogun' (<i>Citrus reticulata</i> Blanco)	Comparison of fruit position in the canopy with antioxidant activity and phytonutrients in Thailand	Fruits from the upper canopy have the highest antioxidant activity (AA) and the most significant levels of total phenolics, flavonoids, and AsA compared to those from the middle and lower canopies.	Youryon and Supapvanich, 2019
Kinnow (<i>Citrus nobilis</i> Lour × <i>Citrus deliciosa</i> Tenara)	Comparison of fruit position in the canopy and bioactive compounds in New Delhi, India	Fruits that develop on the outer part of the canopy outperform those in the interior in terms of AsA and total carotenoid content.	Thakre <i>et al.</i> (2015)
Mango 'Zibda'	Comparison of fruit canopy position and antioxidant enzyme activity during postharvest (4°C, 96% RH) in Egypt	Fruits harvested from the shaded interior of the canopy show higher POD, APX, SOD, and CAT activities, while H ₂ O ₂ and O ₂ ^{•-} levels decline during storage.	Lo'ay <i>et al.</i> (2021)
Mango 'Cogshall'	Comparison of fruit position in the canopy and antioxidant enzyme activity in the rind of freshly harvested fruits in Réunion Island	In the sunlit part of the fruit, levels of MDA, H ₂ O ₂ , and both reduced and total ascorbate, as well as the activities of APX, SOD, and MDHAR, are higher. The lowest values are observed in the epidermis of fruits in the shaded interior of the canopy.	Léchaudel <i>et al.</i> (2013)

AsA: ascorbic acid; AA: antioxidant activity; POD: peroxidase; APX: ascorbate peroxidase; SOD: superoxide dismutase; CAT: catalase; O₂^{•-}: superoxide radical; H₂O₂: hydrogen peroxide; MDA: malondialdehyde; MDHAR: monodehydroascorbate reductase.

located on the outer canopy (Fig. 2) and oriented toward the sun show the highest concentrations of ascorbic acid (AsA). Similarly, sun exposure promotes the accumulation of total phenolics and flavonoids (Youryon & Supapvanich, 2019) and total carotenoids (Thakre *et al.*, 2015). These findings align with the observations of Interdonato *et al.* (2011), who report that increased UV-B levels enhance the accumulation of secondary metabolites in lemon (*Citrus*

x limon 'Limoneira 8A') peel. According to Magwaza *et al.* (2017), the higher AsA concentrations in sun-exposed citrus are due to increased photosynthetic activity under these conditions, considering that carbohydrates serve as precursors for AsA biosynthesis. In contrast, for tocopherol in the flavedo of 'Star Ruby' grapefruits, its content does not differ between sun-exposed fruits and shaded ones within the tree (Rey *et al.*, 2021).

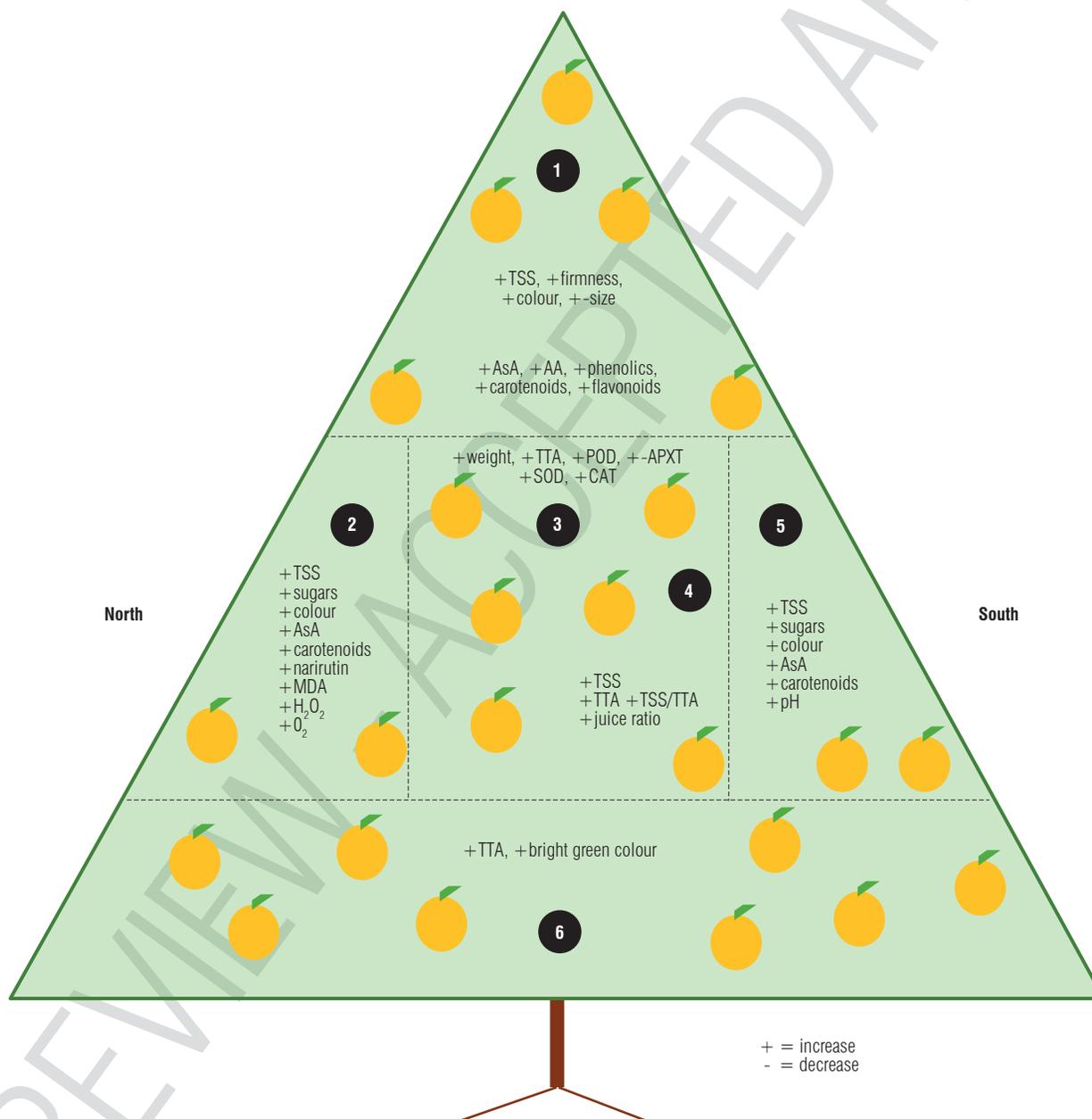


FIGURE 1. Effect of the fruit position in the canopy on fruit quality properties of tropical and subtropical species. The fruit positions: (1) upper external, (2) external north-facing lateral, (3) internal, (4) internal south-facing, (5) external south-facing lateral, (6) internal basal. The properties of fruits with external north-facing lateral position in the canopy (2) were measured in countries of the southern hemisphere. In contrast, the other positions in the canopy refer to the northern hemisphere. TSS: total soluble solids, AsA: ascorbic acid, AA: antioxidant activity, TTA: total titratable acids, MDA: monodehydroascorbate reductase, H_2O_2 : hydrogen peroxide, O_2^- : superoxide radical, POD: peroxidase, APX: ascorbate peroxidase, SOD: superoxide dismutase, CAT: catalase.

Regarding antioxidant enzyme activity in mango, differences in APX and SOD activities are observed after harvest and during storage, depending on cultivar, orchard location, and the fruit's position in the outer or inner canopy. Meanwhile, the content of reactive oxygen species (ROS) (H_2O_2 , $O_2^{\cdot-}$) increases similarly in sun-exposed fruits (Tab. 2) (Léchaudel *et al.*, 2013; Lo'ay *et al.*, 2021). Two studies conducted in Egypt on mango report that, in the cultivars 'Ewas' (Hamza, 2019) and 'Zibda' (Lo'ay *et al.*, 2021), fruits in the shaded inner canopy have higher activities of the antioxidant enzymes POD, APX, SOD, and CAT compared to fruits from other canopy positions (Fig. 1). In mango, as in many different fruits, direct sun exposure within the tree canopy promotes skin blush development, which is caused by the accumulation of anthocyanins (Yu *et al.*, 2016).

Influence of the fruit position in the canopy on physiological disorders and diseases in fruits

The incidence of fruit diseases and physiological disorders also depends on fruit position. In avocado, fruits harvested from the outer canopy show a lower incidence of disorders and a longer postharvest shelf life (Tab. 3) (Kimeu *et al.*, 2012). Similarly, Ullah and Joyce (2024) report lower susceptibility to stem end rot and body rot diseases in 'Hass' fruits collected from the outer canopy in Australia (Tab. 3), consistent with findings by Llanos and Apaza (2021) in Peru for stem end rot (*Lasiodiplodia theobromae*) in the same cultivar. In 'Clementine' mandarin, fruits well-exposed to

sunlight reduce the incidence of rind breakdown during postharvest storage (Cronje *et al.*, 2013). Likewise, in mango fruits exposed to sunlight, the accumulation of flavonoids and anthocyanins in the peel is associated with increased resistance to anthracnose (Taïbi *et al.*, 2021).

In contrast, loquat (*Eriobotrya japonica*) fruits exposed directly to morning sunlight demonstrate a higher incidence of the physiological disorder purple spot (Jiménez *et al.*, 2022). Similarly, in 'Zibda' mango, fruits harvested from the outer canopy exhibit greater chilling injury during storage compared to those from the inner canopy (Lo'ay *et al.*, 2021). This pattern is observed not only in 'Zibda' (Tab. 3) but also in 'Ewais' and 'Hindi Be-Sennara' cultivars (Lo'ay, 2010). Meanwhile, in 'Kent' mango, fruits growing inside the canopy have a lower incidence of diseases compared to those in contact with the soil (Diedhiou *et al.*, 2007).

During fruit maturation, periods of high temperatures combined with drought can coincide with intense radiation, which may cause peel discoloration, cracking, and wrinkling, thereby reducing fruit quality and yield (Muchie & Assefa, 2021). In cape gooseberry cultivated under greenhouse conditions, fruits harvested from the upper part of the plant exhibit the highest cracking percentage (Álvarez-Herrera *et al.*, 2012) (Tab. 3), possibly due to limited Ca supply to the upper parts of the plant, which could be linked to issues related to mineral nutrition, irrigation, or the microclimate during the fruit-growth phase and

TABLE 3. Impact of canopy position on diseases and physiological disorders in tropical and subtropical fruits.

Species, variety	Research	Effect on fruit quality	Authors
Avocado 'Hass'	Diseases based on fruit position in the canopy in south-central Queensland, Australia	Sun-exposed fruits show lower K/Ca, N/Ca, and (K+Mg)/Ca ratios in both the rind and pulp. Therefore, fruits with an N/Ca ratio below 23 in the rind and below 40 in the pulp have a lower incidence of stem end rot and body rot diseases.	Ullah and Joyce (2024)
Avocado 'Hass' y 'Fuerte'	Fruit deterioration and spotting vary depending on their position in the canopy in Kenya.	While 8% of the fruits from the inner canopy have a shelf life of 15 d, 28% of those from the outer canopy last 18 d, showing greater firmness and less deterioration.	Kimeu <i>et al.</i> (2012)
Mango 'Zibda'	Comparison of fruit position in the canopy and postharvest susceptibility (4°C, 96% RH) in Egypt.	Fruits harvested from the interior of the canopy are less exposed to UV light and heat, resulting in a lower occurrence of chilling injury, which is linked to higher antioxidant enzyme activity.	Lo'ay <i>et al.</i> (2021)
Mango 'Kent'	Postharvest disease incidence in seven mango orchards, comparing fruits located in the center of the canopy with those in contact with the ground in Senegal	Fruits from the center of the canopy show lower infestation (42%) by <i>Alternaria</i> sp., <i>Dothiorella</i> sp., <i>Botryodiplodia theobromae</i> , <i>Colletotrichum gloeosporioides</i> , <i>Aspergillus niger</i> , and <i>Phoma mangiferae</i> compared to those in contact with the soil (>65%).	Diedhiou <i>et al.</i> (2007)
Loquat (<i>Eriobotrya japonica</i>)	Comparison of fruits affected by purple spot based on canopy position in Almería, Spain	On the southeastern side of the canopy, 35% of the fruits are affected by purple spot. In this orientation, the fruits receive more sunlight, grew more quickly, and ripened more quickly.	Jiménez <i>et al.</i> (2022)
Mandarin 'Nules Clementine'	Physiological disorders based on fruit position in the tree in South Africa	Fruits in the canopy are more susceptible to the postharvest physiological disorder called rind breakdown.	Cronje <i>et al.</i> (2013)
Cape gooseberry ecotype 'Colombia.'	Assessment of cracked fruits at the following strata: 1) 90–120 cm, 2) 120–140 cm, and 3) 140–160 cm above the ground in Bogotá, Colombia	The highest percentage of cracked fruits are found in strata 3 (apical) and 2 (middle), with 38% and 37%, respectively, while stratum 1 (lower) shows only 25%.	Alvarez-Herrera <i>et al.</i> (2012)

its effects on transpiration. In Washington navel orange grafted onto sour orange rootstock in Egypt, the highest incidence of fruit cracking occurred on the lower southern side of the canopy (El-Sayed, 2016).

Since the contents of cytokinins (CK) and indole-3-acetic acid (IAA) in the fruits are essential due to their association with the physiological disorder rind breakdown during postharvest, these parameters were evaluated in 'Clementine' mandarin fruits based on canopy position by Olarewaju *et al.* (2022). They report that the contents of cis-zeatin-type cytokinins are higher in fruits from the outer canopy. At the same time, the most abundant CK, dihydrozeatin, is greater in fruits from the inner canopy. Similarly, IAA concentration is higher in fruits located in the inner canopy compared to those from the outer canopy. Taibi *et al.* (2021) compare fungal and bacterial infections in mango fruits ('Cogshall' and 'José') from two geographically distant orchards in Réunion island and find that the factors most strongly influencing microbial communities (fungal and bacterial) are, in order of importance: geographical site of the orchard, cultivar, fruit tissues, harvest time, and finally, fruit position within the canopy.

Examples of orchard management practices influencing fruit position within the canopy

Pruning

Pruning branches and removing leaves that cover the fruits promote better light exposure, which generally enhances fruit color, size, and quality, as long as solar radiation isn't too intense (Balaguera-López *et al.*, 2024). This practice is especially crucial for producing uniform fruits in pruned orchards (Joas *et al.*, 2013). Many studies, especially in temperate fruit crops, show the positive effects of pruning on the fruit quality.

Training systems, along with fruiting and rejuvenation pruning, significantly influence the position of the canopy where high-quality fruits are formed and ripen, as well as the number and size of fruit (Casierra-Posada & Fischer, 2012). However, fruit quality also depends on genetic traits (variety and rootstock), plant physiology, orchard location, soil conditions (Arjona & Santinoni, 2007; Casierra-Posada & Fischer, 2012), and orchard management.

According to Agustí (2010), tropical and subtropical fruit trees are trained following three central systems: round, with three main branches and no central leader (*e.g.*, citrus, mango, and avocado); triangular, with a central leader (*e.g.*, feijoa); or espalier-trained (*e.g.*, passionfruit and cape

gooseberry). In this context, Fischer (2012) notes that canopy architecture affects the amount of shade within the crown, which significantly influences the development of higher-quality fruits, usually located in the more illuminated areas of the tree. In intensively managed feijoa orchards, preferably trained with a central leader and three tiers of lateral branches at 90° angles (Quintero, 2012), shading inside the canopy is minimal, enabling all fruits to develop uniform quality.

The cv. 'Masui Dauphine', replacing the usual short pruning of fruiting branches trained upright on the two main horizontal scaffold branches with a long renewal pruning that encourages downward-hanging branches, led to earlier ripening and larger fruits (Hosomi *et al.*, 2015). Likewise, Arjona and Santinoni (2007) note that, although unpruned trees tend to bear fruit earlier, insufficient light reaching the canopy can cause them to become less productive quickly. Under such conditions, fruits are concentrated mainly at the top and edges of the tree, resulting in poorer quality.

Thinning

Generally, fruit growers monitor their orchards by removing diseased, malformed, and undersized non-marketable fruits, while also preventing excessive fruit loads that could cause branch breakage (Lammerich *et al.*, 2020). However, many species and cultivars naturally regulate fruit overload through self-thinning. For example, in citrus, Orduz (2012) reported that commercially important cultivars produce abundant flowers. Yet, among the 100,000–200,000 flowers on an adult tree, only 1%–2% develop into harvestable fruits.

Fruit thinning, whether due to natural thinning by the tree itself, mainly due to a lack of carbohydrates (Agustí, 2010), or manual, mechanical or chemical thinning by the fruit growers, improves exposure to light (Páez Redondo, 2003), enhances the production of high-quality fruits, and prevents alternate bearing from year to year (Costa *et al.*, 2013). Additionally, thinning allows the remaining fruits to grow and develop properly, as enough leaves stay on the branches to support their development (Paull & Duarte, 2011). In tropical and subtropical fruits, thinning is usually done manually, unlike in temperate-region pome and stone fruits, where mechanical or chemical thinning is often used (Costa *et al.*, 2013).

In mango cv. 'Irwin' grown in Venezuela, removing malformed fruits 30 d after fruit set increases both the weight and pulp percentage of the remaining fruits (Quijada *et al.*, 2012). Similarly, Agustí (2010) recommends thinning 25% of all set fruits in mango cultivars with heavy fruiting, leaving the largest fruits to grow.

In guava, thinning serves not only to increase light penetration but also, for Taiwanese cultivars grown for fresh consumption, to produce fruits of higher market quality. For this purpose, no more than four fruits are kept on each branch (usually 1-2 per node) (Paull & Duarte, 2012). In Brazil, however, larger fruits are achieved by selecting the biggest among four, typically the central fruit of the node (Paull & Duarte, 2012).

For Solo-type papaya in Colombia, Páez Redondo (2003) recommends thinning the fruit to improve solar radiation efficiency, lower canopy humidity, enhance external color and organoleptic qualities, and promote even fruit ripening, while also reducing disease incidence.

Similarly, in starfruit, in addition to providing adequate nutrients and water, fruit thinning is used to improve fruit size and extend the harvest period (Paull & Duarte, 2012). These authors suggest leaving three fruits per inflorescence (cluster) and thinning them three to four weeks after flowering. In durian production in Thailand, excessive fruit set is managed by keeping only 1-2 fruits per inflorescence, depending on the cultivar, four to six weeks after flowering, which results in 50 to 150 fruits per tree at harvest (Paull & Duarte, 2012).

Bagging and shading nets

Fruit bagging, commonly used to protect fruits from pests, diseases, and sunburn (Fischer *et al.*, 2022), can be applied at any point within the tree canopy. However, in some cases, the position of the bagged fruit has also been shown to influence fruit quality. For instance, Akmal *et al.* (2023) report that mangosteen fruits bagged with black plastic and located on the outside of the canopy were larger but of lower quality and poorer phytosanitary condition (gamboge disorder) than those bagged inside the canopy. Conversely, in 'Clementine' mandarin, bagged fruits located in the inner canopy contained 1.4 times lower carbohydrates and 1.1 times lower soluble solids, as well as 24% higher weight loss during storage at 8°C, along with greater rind breakdown, compared with non-bagged fruits in the outer canopy (Magwaza *et al.*, 2013). These findings suggest that microclimatic differences within the canopy can alter the biochemical traits of the fruit epidermis, contributing to aging and increasing vulnerability to rind breakdown.

The use of shading nets to improve the canopy microclimate (Musacchi & Serra, 2018) does not directly influence the spatial distribution of fruits within the canopy. Still, it does protect the upper canopy fruits from sunburn and

hail damage. However, fruits located in the lower inner canopy might show inadequate coloration depending on the shading intensity of the material. For example, in 'Hass' avocado, white, blue, and red shading nets that provide 20% shade increase the yield of marketable fruits by up to 40% and improve oleic acid content; however, they also raise the incidence of anthracnose (Tinyane *et al.*, 2018).

Conclusions

The position of tropical and subtropical fruits within the canopy is crucial for their quality development, as it is strongly influenced by the microclimate, particularly solar radiation, whether directly on the outer canopy or indirectly within the tree interior. In addition to light availability, radiation affects fruit temperature and the humidity of the surrounding air inside the canopy. Species responses vary according to geographic factors such as latitude and altitude, which shape solar and UV radiation levels, as well as genetic factors that determine canopy architecture.

In general, fleshy fruits located on the well-exposed outer canopy exhibit higher levels of total soluble solids, sugars, ascorbic acid, antioxidant activity, phenolics, carotenoids, flavonoids, and better peel coloration. In contrast, fruits from the inner canopy tend to show higher activities of antioxidant enzymes such as POD, APX, SOD, and CAT, along with greater titratable acidity. Sun-exposed fruits typically reach maturity earlier and are harvested before those growing inside the canopy or in less-exposed sections of the crown. This highlights the importance of fruit position in determining optimal harvest timing.

Fruit position also influences the incidence of disorders and diseases. Shaded, more humid conditions within the canopy favor fungal development. In contrast, physiological disorders—such as discoloration, necrosis, cracking, and peel wrinkling—are more common in fruits exposed to high radiation. Management practices that modify fruit light exposure include pruning, fruit thinning, bagging, and shading nets. Pruning and thinning enhance light penetration, thereby improving fruit quality; bagging helps improve phytosanitary conditions across canopy positions; and shading nets protect upper external fruits from sunburn.

Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Author's contributions

GF: conceptualization, visualization, writing, editing, and supervision. HEBL: conceptualization, writing, and editing. JGAH: conceptualization, writing, editing. All authors have read and approved the final version of the manuscript.

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