MACADAMIA: HARVEST AND POST-HARVEST STRATEGIES FOR HIGH QUALITY AND COMMERCIAL VALUE

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ABSTRACT: Macadamia is a high-value nut, whose market appreciation and quality are directly influenced by harvest and post-harvest practices. Successful production depends on efficient management from fruit maturation to final storage, ensuring a product with preserved flavor, texture, and oil content. Macadamia matures in different stages, making it essential to determine the optimal harvest time to prevent losses and maintain nut quality. Harvesting can be performed manually or mechanically, each method presenting specific challenges. Labor shortages, soil moisture-which can affect fruit integrity- and irregular topography pose obstacles to mechanization in certain regions. After harvesting, proper handling is crucial to prevent product deterioration. Processes such as controlled drying, dehusking, and grading are essential to ensure the nut's safety and quality. Storage under optimal humidity and temperature conditions reduces lipid oxidation and preserves the product's sensory characteristics for an extended period. The market value of macadamia depends on the adoption of innovative post-harvest strategies. Technologies such as modified atmospheres, vacuum packaging, and automated sorting have contributed to extending shelf life and maintaining product quality. Additionally, quality certifications and sustainable practices add value and enhance the nut's competitiveness in international markets. Thus, efficient harvest and post-harvest management not only preserves nut quality but also enhances profitability, strengthens the production chain, and ensures competitiveness in the global agricultural sector.

INTRODUÇÃO

Macadamia (*Macadamia integrifolia*) is a crop of great economic and commercial significance, particularly in the gourmet nut and food product markets. Native to Australia, macadamia cultivation has expanded to various tropical and subtropical regions worldwide, with notable

production in Australia, Brazil, China, South Africa, the United States, and several Asian countries (Zuza et al., 2021). Recognized as one of the most valuable nuts due to its high nutritional value and premium market price, macadamia has attracted increasing interest from both producers and investors (Gitonga et al., 2009).

The post-harvest phase of macadamia is particularly critical, as nut quality is highly influenced by pre and post-harvest handling conditions. Macadamia is sensitive to environmental variations, and proper drying and storage practices are essential to prevent deterioration and quality loss, such as the development of undesirable flavors and degradation of oil content (Wall, 2013). Moreover, strict control of relative humidity and temperature during storage is crucial to extending the shelf life of the nuts and preserving their nutritional and organoleptic properties (Siebeneichler et al., 2023). These measures not only ensure product quality but also enhance crop profitability, as high-quality nuts better meet the demands of premium markets, including international buyers who increasingly prioritize sustainable and superior-quality products.

However, macadamia production faces significant challenges during the harvest and post-harvest phases. Improper harvesting, inadequate post-harvest handling, and inefficient storage processes can compromise nut quality, directly affecting the commercial value of the final product (Wallace; Walton, 2020). Efficiency in these stages is crucial to ensuring that the nuts reach their full potential in terms of flavor, texture, oil content, and durability-key factors for market acceptance (Wall, 2013).

This chapter aims to present the best practices and strategies for macadamia harvesting and post-harvest management, focusing on techniques that ensure high product quality and optimize commercial value.

PHYSIOLOGY AND FRUIT MATURATION

The macadamia tree (*Macadamia integrifolia*) is a perennial species from the Proteaceae family, whose reproductive cycle directly influences the quality of the harvested nuts (Nock et al., 2016). The fruit maturation process is regulated by genetic, environmental, and physiological factors, which are key in determining the optimal harvest time. Fruit development occurs in three main phases. The first, known as the cell expansion phase, is characterized by rapid fruit growth due to cell multiplication, endosperm formation, and high moisture content (Handa et al., 2012). The second phase, nut filling, involves lipid accumulation in the endosperm, primarily unsaturated fatty acids, which are essential for the final nut quality (Handa et al., 2012). Finally, during the maturation and dehiscence phase, the nut reaches full development, with a reduction in moisture content and partial lignification of the pericarp. The primary indicator of maturity is the natural opening of the epicarp, allowing the nut to fall naturally to the ground, a key determinant for harvest timing (Handa et al., 2012).

Macadamia maturation can be evaluated using different indicators. One of the most commonly used is the color change of the epicarp, which shifts from deep green to brownish tones before fruit opening, as well as its internal coloration, which resembles the color of chocolate (Figure 1). Additionally, nut moisture decreases as the fruit matures, and the optimal moisture level at harvest should be below 30% to prevent deterioration and reduce the risk of rancidity during storage (Kader, 2013).

Foto: Domingues Neto, 2025.

Figure 1. Internal coloration of the macadamia nuts epicarp at harvest

Oil content is another essential parameter, as complete maturation is associated with a high lipid accumulation, which can reach up to 72% of the nut's dry weight (Jardim et al., 2023). Another crucial indicator is the natural dehiscence of the fruit, as most mature cultivars detach spontaneously from the tree. However, some varieties require manual or mechanical harvesting before dropping to prevent losses and contamination (Wallace; Walton, 2020).

The quality of harvested nuts is directly related to the maturity stage at which they are collected. Nuts harvested too early have lower oil content and higher moisture, compromising their texture and flavor. Conversely, late-harvested nuts may undergo oxidative degradation due to prolonged exposure to the environment, reducing their shelf life and sensory quality (Gama et al., 2020). The biochemical composition of macadamia also varies throughout maturation. The content of unsaturated fatty acids, such as oleic and palmitoleic acids, gradually increases and is directly linked to the final product's quality, influencing consumer acceptance and market value (Birch et al., 2010).

In addition to physiological factors, macadamia maturation can be affected by environmental conditions. Temperature is a major influencing factor, with regions averaging 15°C to 25°C promoting uniform fruit development and the synthesis of essential lipid compounds (Carr, 2012). Water availability also plays a key role, as water deficits can either accelerate or delay maturation while also affecting the quality of the accumulated oil in the nut (Carr, 2012). Another important factor is tree yield load, as trees bearing a high number of fruits may experience non-uniform maturation, making selective harvesting necessary to ensure high-quality production.

Considering these factors, proper harvest management and the development of strategies to optimize maturation are essential for ensuring the production of high-quality, high-value macadamia nuts. Understanding the macadamia maturation process allows the implementation of best practices in harvesting and post-harvest management, ensuring a final product that meets consumer market demands while maximizing economic returns for producers.

HARVESTING METHODS

Macadamia harvesting is a critical stage in determining the final quality of the nuts, requiring strategic planning to minimize losses and maximize process efficiency. The harvesting method can be either manual or mechanized, with the choice influenced by factors such as labor availability, terrain topography, and climatic conditions during the harvest period. Regardless of the method adopted, one of the main challenges is ensuring that the nuts are collected at the optimal stage of maturity, preventing both deterioration and post-harvest quality loss.

Manual harvesting is still widely used in regions where mechanization is unfeasible, particularly in areas with uneven topography or small farms where investment in machinery is not economically justifiable. This method allows for more selective fruit collection and reduces mechanical damage, but it also presents significant challenges. The primary limitation of manual harvesting is the shortage of skilled labor, a recurring issue in the agricultural sector, exacerbated by rising labor costs and difficulties in recruiting seasonal workers (Sanjay et al., 2024). Additionally, manual harvesting can be time-consuming and less efficient compared to mechanized methods, potentially leading to a longer residence time of nuts on the ground, increasing the risk of contamination and deterioration.

Mechanized harvesting has emerged as a viable alternative for large-scale producers, improving efficiency and reducing operational costs. Collection machines are used to vacuum or sweep nuts from the ground, streamlining the process and reducing labor dependency (Sauk et al., 2023). However, mechanization faces challenges, particularly concerning terrain topography. Steep slopes or irregular soils hinder machine operation, decreasing efficiency and increasing the risk of fruit damage during collection. Furthermore, mechanization requires substantial initial investments in specialized equipment, which can be a limiting factor for small and medium-sized producers.

Another critical factor in macadamia harvesting is soil moisture. Since macadamia nuts ripen and naturally fall to the ground before being collected, rainy periods or excessive irrigation can lead to water accumulation in the soil, increasing the moisture content of harvested nuts. High moisture levels can accelerate fungal and bacterial growth, promoting fermentation and reducing nut quality during storage (Kader et al., 2013). Additionally, waterlogged soils hinder harvester operation and raise post-harvest drying costs, making

the process more expensive and impacting the economic viability of production (Kaur et al., 2020).

The choice of the ideal harvesting method depends on the combination of various factors, including farm structure, resource availability, and climatic conditions. The search for efficient alternatives to optimize this stage-whether through mechanization adapted to the terrain or improved soil management techniques to minimize moisture-related impacts-is essential for ensuring the final quality of macadamia nuts and maintaining their competitiveness in the global market.

POST-HARVEST MANAGEMENT

Post-harvest management of macadamia nuts is one of the most critical aspects in ensuring quality and commercial value. The post-harvest phase includes several stages, such as transportation, drying, processing, and moisture and temperature control. Each of these steps is essential to prevent product deterioration and preserve its sensory and nutritional characteristics.

After harvesting, the nuts must be transported to the processing unit as quickly as possible. Since macadamia nuts naturally fall to the ground, there is a significant risk of contamination by microorganisms, especially when soil moisture levels are high. Water accumulation on the surface of the nuts can promote fungal growth, particularly *Aspergillus* species, which can produce mycotoxins harmful to human health (Mirabile et al., 2021). To minimize this risk, nuts should be collected frequently (biweekly in dry conditions and weekly in rainy periods) and transported in ventilated containers to prevent moisture accumulation and undesirable fermentation.

Drying is one of the most important post-harvest processes, as it reduces internal moisture and inhibits microbial growth, which can compromise nut quality. At the time of harvest, macadamia nuts typically have high moisture content, ranging from 25% to 30% (Phatanayindee et al., 2012). For safe storage and commercialization, this moisture level must be reduced to below 1.5% (Wall, 2013). Drying can be performed naturally or artificially using dryers with controlled temperature and ventilation. Natural drying is more economical but more susceptible to climatic variations, whereas artificial drying allows precise control of conditions, reducing deterioration risks and accelerating the process.

After drying, the processing stage involves the removal of the endocarp, the hard shell that protects the macadamia kernel. This process must be carried out carefully to avoid mechanical damage to the nut, which could compromise its appearance and reduce its commercial value. Shelling is typically performed using controlled mechanical impact, utilizing specialized equipment to prevent excessive breakage of the kernels. Once the shell is removed, the nuts are classified according to size and quality, destined either for direct

consumption or further processing into derived products such as roasted macadamia nuts and macadamia oil.

Moisture and temperature control during storage is also essential to maintain macadamia nut quality. After drying, nuts should be stored in dry, ventilated environments with relative humidity below 65% and controlled temperatures between 10°C and 15°C. Improper storage conditions can lead to lipid rancidity, and formation of volatile compounds, compromising flavor and consumer acceptance (Clarke et al., 2020). The use of modified atmosphere packaging and vacuum-sealed storage has proven effective in extending shelf life, reducing lipid oxidation, and preserving the crunchiness and characteristic aroma of macadamia nuts (Wall, 2013).

Proper post-harvest management of macadamia nuts is fundamental to ensuring quality and maximizing market value. Implementing best practices in transportation, drying, processing, and storage directly contributes to product competitiveness, ensuring that it meets consumer demands and international market standards. Thus, investing in technology and training for proper post-harvest handling is essential for strengthening the macadamia supply chain and enhancing the final product's value.

CHALLENGES, MARKET STRATEGIES, AND INNOVATIONS IN POST-HARVEST PROCESSING

The global macadamia market is expanding, driven by the increasing demand for healthy foods and premium products. To meet consumer expectations, producers must adhere to strict quality standards, including certifications such as GLOBALG.A.P., which add value and facilitate access to demanding markets such as the European Union and the United States. Additionally, product differentiation, through the offering of premium macadamia nuts or derived products such as oils and flours, can enhance competitiveness and expand commercial opportunities.

The adoption of innovative post-harvest technologies has been fundamental in ensuring product quality and extending shelf life. The use of automated sorting and grading systems, based on computer vision and artificial intelligence, improves efficiency and reduces losses. Furthermore, controlled atmosphere storage, which regulates oxygen and carbon dioxide levels, has shown promising results in preserving macadamia nuts' sensory characteristics and reducing lipid oxidation.

Sustainability has also gained importance in the macadamia supply chain. Practices such as energy-efficient drying processes, biodegradable packaging, and circular economy strategies help minimize environmental impact and meet consumer demands for more sustainable products. Therefore, investing in innovation and certifications, combined with good post-harvest practices, enables producers to adapt to market demands and ensure greater product value.

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