Chapter

Challenges and Advances in the Production of Export-Quality Macadamia and Its Integral Use with Green Technologies

Laura Graciela Mereles, Mario Smidt, Karen Patricia Martínez, Eva Eugenia Soledad Coronel, Edelira Velázquez and Laura Correa

Abstract

Macadamia nut is an alternative crop for agricultural production in tropical Latin American countries. Its cultivation in itself constitutes a challenge for countries with high relative humidity temperatures, especially in the postharvest period. Environmentally friendly technologies suggest a comprehensive nut in shell (NIS) and kernels treatment, taking advantage of the waste generated in the drying process, critical point. This chapter explores the methods of the literature and those applied in local research for the integral use, drying of macadamia nuts, and their processing until obtaining products of high nutritional quality (dried nut and oil) and with clean technologies applicable to small producers.

Keywords: *Macadamia integrifolia*, production, composition, quality, analysis, oil extraction, byproducts, tropical countries

1. Introduction

Since the first scientific evidence on the frequent consumption of nuts on health, macadamia nuts, produced in various tropical regions of the world since their origin in Australia, have gained great interest as part of a healthy diet. In vivo studies in rats, mice, and humans have shown that macadamia nut oil reduces total cholesterol, low-density lipoprotein (LDL) cholesterol, body weight, and body mass index, inhibits the development of sucrose–/fructose-induced hepatic steatosis, and attenuates adipocyte hypertrophy and inflammation in adipose tissue and macrophages [1]. In addition to the high concentration of monounsaturated, the main source of health nutrition and pharmacological properties of these oils comes from their minor components that are phytosterols, tocopherols, phenols, squalene, carotenoids, and others [2]. Its antioxidant potential is attributed to these compounds together. Dried macadamia nuts have shown good total antioxidant capacity and may be useful when

consumed alone or in combination with traditional pharmacotherapy to reduce the risk of cardiovascular disease. Intervention studies consistently show that the consumption of macadamia nuts causes a decrease in plasma total cholesterol and LDL cholesterol, and despite its high fat content, the regular consumption of macadamia nuts has been shown to have no effect on the body weight [3]. These studies have been carried out using macadamia nuts which, due to their unique composition, are influenced by the quality of the kernel, so the production system has a major impact on their commercialization and health effects.

The great challenge of macadamia production for the world has been to maintain sensory and nutritional quality, due to its high composition of oils, which are susceptible to oxidation and require a careful system of cultivation, selection, drying, and packaging to reach the consumer with all their nutritional and bioactive properties [4]. Compositional differences observed in different studies on macadamia nut and oil could be explained by the variation in cultivars, growth conditions, harvest time, degree of maturity, and storage conditions [1]. Several studies have addressed this problem, and its composition has been studied in different production regions, which opened a field of research on its sustainable production and use of green technologies that generate new markets with which the macadamia nut has become a product of great value based on these experiences [5–8].

The macadamia producers par excellence are Australia (where it originates from), South Africa, and the United States [9]. In South America, the macadamia nut represents an alternative crop to those of great expansion such as soybean or corn; however, it is a noble crop that allows the use of the soil in the spaces left by the treetops, with the production of other foods such as pineapple or medicinal herbs [10]. This, added to the added value that can be obtained from its integral use, from the exocarp (green) and the mesocarp (brown) of the fruit and the dried and split nuts (kernel) that are used to obtain oil, is viable and attractive alternatives for small- and medium-sized producers [5, 11, 12]. The rich fatty acid composition of the oil obtained from macadamia nuts allows its diverse use in many industries, i.e., cosmetic and pharmaceutical [11]. Macadamia nuts are marketed in the export market mainly in two forms: shelled nuts (kernel) and nuts in shell (NISs) (**Figure 1**). The market by application



Figure 1.
Cross section of the NIS with the almond (kernel) inside and the woody shell outside (mesocarp).

can be divided into snacks, confectionery and bakery, cosmetics, and others. The international market by region is mainly distributed in North America (the United States, Canada, and Mexico), Europe (Germany, the United Kingdom, France, Italy, Russia, and Spain), Asia-Pacific (China, Japan, Korea, India, Australia, and Southeast Asia), South America (Brazil, Argentina, and Colombia), and the Middle East and Africa (South Africa, the United Arab Emirates, and Saudi Arabia). Many times, the internal challenges and opportunities of the smallest producers are not the same as for the largest producers.

In this chapter, we address the production of nutritional quality macadamia nuts, from the postharvest processing, drying, and packaging system. Its comprehensive use in tropical countries, based on the data established in the literature and the work team's own results, opens a series of accessible low-cost alternatives and green technologies based on the lessons learned for their production in tropical countries with often limited resources.

2. Macadamia nut and oil composition

The nut is rich in protein and has a high energy content, outstanding organoleptic and nutritional characteristics, and a high amount of oil (~ 74% w/w) [13, 14]. Its use for cooking food is limited, and it is mainly used as a flavoring oil [15]. In addition, dried macadamia nuts (kernel) contain other important dietary components, including protein (7.2–10.4%), good levels of dietary fiber (6.2–8.6%), fat-soluble vitamins (especially alpha-carotene), minerals (Mg, Ca, and K), and phytochemicals (phytosterols). They are low in carbohydrates (0.5–13.8%). A comparative study of the centesimal composition and lipid profile of 22 varieties of *M. integrifolia*, grown in Itapirá (Brazil), showed large variations in composition with respect to the composition of macadamia from other origins; however, the samples were taken from very young trees (7 years) [7]. After 8 years of cultivation, adult trees are considered with a more constant composition of nuts. In another study, it was observed that tocotrienols and squalene were largely affected by varieties and their content in seven macadamia cultivars produced in Hawaii ranged from 31 to 92 and 72 to 171 μg/g of oil, respectively [6]. With several studies on its chemical composition, it is now known that it can vary greatly due to the influence of the type of cultivar (genetics), the ripeness of the grain, the time of harvest, the geographical location, and the conditions of the crop [1]. Macadamia nut proteins have all the essential amino acids, and their limiting amino acids include tryptophan, lysine, and threonine [16]. The sugar content is mainly represented by fructose, glucose, maltose, and sucrose. The cultivars differ in the sucrose content of the nut, but not in the content of reducing sugars [17]. Regarding the mineral content, macadamia nuts are considered a source of magnesium, calcium, and potassium [13]. Macadamia nuts from Australia have been reported to contain 5.77 mg/100 g of iron and low levels of zinc and copper [18].

Regarding the oil, in most published studies, the content of monounsaturated fatty acids (MUFAs) predominates, among which oleic acid C18:1 and palmitoleic acid C16:1 stand out. Other monounsaturated fatty acids, such as gondoic acid C20:1 and erucic acid C22:1, are also reported by some authors among the components of macadamia oil [19, 20]. Macadamia nut oil has various food and nonfood applications including food fortification, development of skin, hair, and healthcare products. Rich in monounsaturated fatty acids (oleic and palmitoleic acid), macadamia oil also contains a significant concentration of bioactive phytochemicals

including β-sitosterol, α-tocopherol, α-tocotrienols, ρ-hydroxybenzoic acid, and caffeic acid [1]. Macadamia oil contains significant concentrations of phytosterols (~165 mg/100 g), especially β-sitosterol in 82% with levels from 96.9 to 151 mg/100 g of oil. Other components identified in this fraction are campesterol (11.6 mg/100 g), stigmasterol (2.2 mg/100 g), and avenasterol (16 mg/100 g) [20–22]. A study carried out on different oils from nuts and avocado and sesame describes that macadamia nuts contain more phytosterols (184 mg/100 g oil) than oils from other nuts such as walnuts (165 mg/100 g oil), almonds (122 mg/100 g oil), and hazelnuts (89 mg/100 g oil); however, avocado and sesame oils contain much higher amounts (434 and 620 mg/100 g oil, respectively) where the majority component is always β-sitosterol [20]. In addition, the oil has good oxidative stability, which can vary with the harvest season and the crop [17]. There is a positive correlation between antioxidant activity and oxidative stability of the oil. Although there is considerable variation in the oxidative stability of macadamia oil among the studies found in the literature, it is always related to the composition of phytochemicals. In a study, the chemical composition and antioxidant capacity of macadamia oils obtained from 15 cultivars of *M. integrifolia* were comparatively analyzed, and the analysis strongly supported the positive contribution of polyphenols and squalene to the antioxidant capacity of macadamia oils [5].

All these bioactive compounds in macadamia nuts and its high levels of monounsaturated fatty acids make them beneficial for health with frequent consumption, and at an industrial level, they allow the nuts to be minimally processed or industrialized for the production of oil and defatted meal [11].

The comparison of tocopherols, tocotrienols, and squalene content in seven varieties of *M. integrifolia* revealed that macadamia oil has significant amounts of tocotrienols (46.5–91.6 μg/g oil) and squalene (72.4–171 μg/g oil), with variations in the total content of tocotrienols between harvests [6], suggesting a considerable environmental effect on the accumulation of these phytochemicals during nut development. Compared to other nuts, they tend to contain the lowest levels of tocopherols [23, 24] despite being the most stable oil compared to almond, hazelnut, and walnut oils. This seems to indicate that its stability is due in part to its mainly monounsaturated fatty acids (MUFAs) profile, with low percentages of polyunsaturated fatty acids (PUFAs), rather than to the composition of its antioxidant compounds. High oleic oils offer excellent oxidative stability and low-temperature flow properties for many applications. In the vegetable kingdom, oils with a high content of natural oleic acid stand out, such as avocado, macadamia, and olive oils. Macadamia oil has the highest monounsaturated oil content (80%) among common edible oils, followed by olive oil (74%) and avocado (65%) [2]. However, roasting nuts, a process normally used to improve sensory characteristics such as texture and flavor, can alter the fatty acid profile and minor components of the nuts depending on the roasting temperature [25], so recommendations indicate that its healthiest consumption is as dry nut, without roasting.

Macadamia nuts are one of the main sources of palmitoleic acid and can serve as the main dietary source of palmitoleic acid in the diet. Palmitoleic acid is an unusual omega-7 monounsaturated fatty acid found naturally in high levels in macadamia plants (17–20% of the oil) and shares the same structure as the endogenously synthesized form of palmitoleic acid in humans, for which it receives a lot of attention regarding metabolism and health. Recently, palmitoleic acid has been shown to be a lipokine with many beneficial health effects, including anti-inflammatory properties, reduction in body weight, blood glucose, and triglyceride levels, and

improvement in insulin sensitivity [2]. The importance of regulating its content as an indicator of its nutritional quality and commercial value has been discussed, especially given its ability to increase insulin sensitivity and reduce the risk of diabetes. Other described effects on the pathogenesis of obesity, liver, and cardiovascular health remain unclear [26].

On the other hand, nuts such as peanuts or walnuts may present certain food intolerances; in the case of macadamia nuts, a systematic proteomic description has recently been presented. The most abundant proteins belong to the 11S globulins and the 7S vicilins. In silico analysis revealed homology and linear epitope similarities with known allergens from lupine, walnut, and peanut, among others. This opens a path in clinical diagnosis and food analysis toward possible protein candidates with allergenic and cross-reactive potential for further immunoglobulin E (IgE) characterization studies of allergenic foods [27].

3. Industrial processing of *M. integrifolia* nuts

In South America and mainly Paraguay, a country with a very hot tropical climate, the rational cultivation of macadamia began in the 1960s, with seedling of genetically improved macadamia species [14]. In the last 10 years, there has been a significant increase in the export volume of this nut (**Figure 2**), ~ 70 tons were exported in 2020, generating important profits to the productive sector.

Figure 3 shows the main stages of the production process, which begins with the harvest, carried out manually, where the ripe nuts naturally fall off and can be harvested directly from the ground or collected with nets. Harvesting of ripe fruits should be done at least once a week, and this frequency should be increased on rainy days [28]. In the processing plant, the first operation is dehulling, whose purpose is the removal of the green husk (pericarp) that protects the fruit within 24 h after

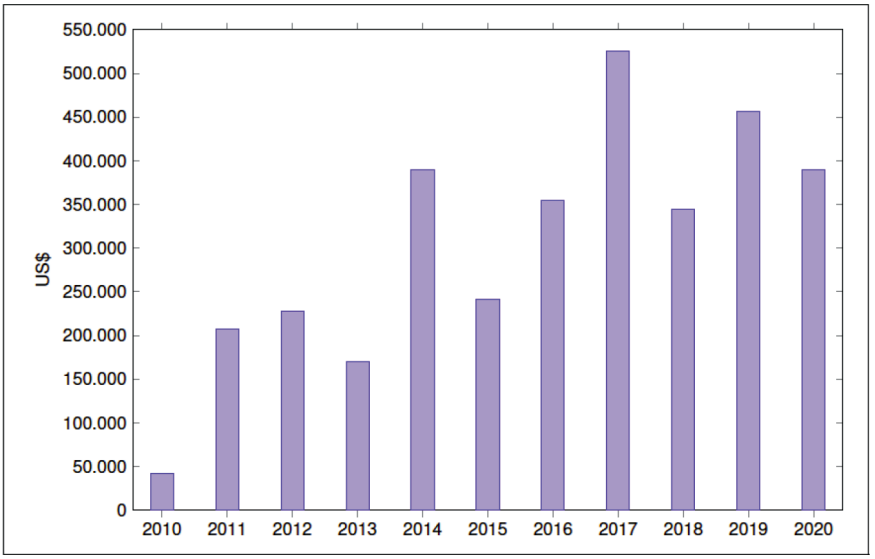


Figure 2.
Evolution of income derived from the export of M. integrifolia nuts in Paraguay. Source: Central Bank of Paraguay.

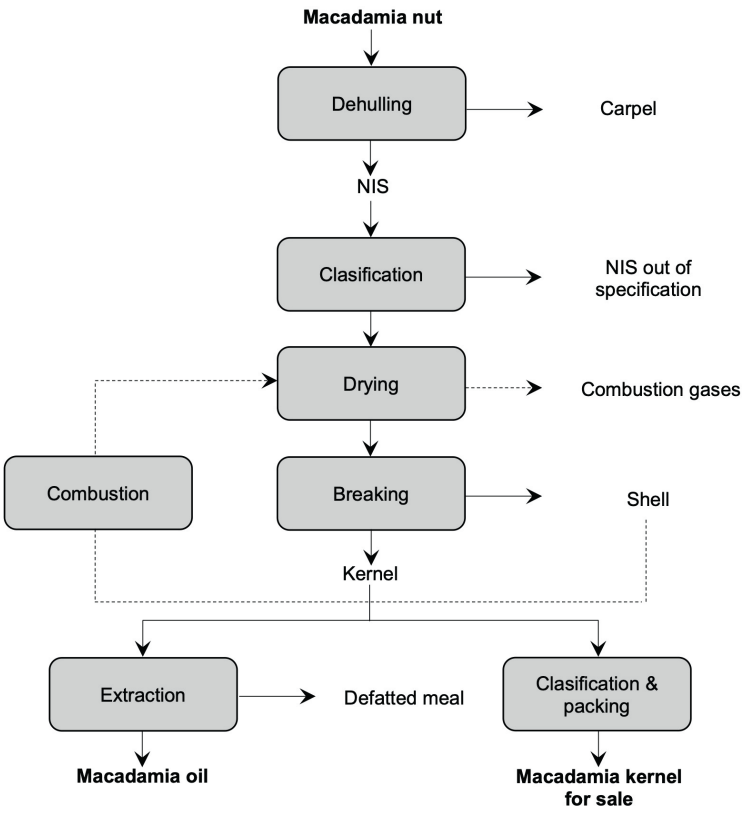


Figure 3.
Block diagram of the industrial processing of M. integrifolia nuts. Elaboration: Smidt, M.

harvest. This operation is important because its presence indicates to the seed that it must germinate, which leads to the translocation of sugars in the kernel and the beginning of the formation of a dark halo in the circumference of the macadamia. The carpel is a nutrient-rich material that is usually used as organic fertilizer for the crop itself. The NISs are then subjected to manual cleaning and classification by flotation, which allows the separation of unripe nuts because those with a high oil content sink. This operation also removes foreign particles and allows the product to be washed, but it is only effective when the moisture content of the NIS is greater than 17% [29].

The next operation is the most important phase in the processing of macadamia nuts, drying, which consists of removing water to a level that prevents the growth of fungi and bacteria, in order to allow the preservation of the nutritional quality of the grain as food or its viability as a seed. When the NIS falls from the tree, it has a moisture content of ~25% (wb) in the almond (kernel), which must be reduced to a percentage less than 1.8% (wb) [9], to avoid the attack of fungi mainly, as well as to avoid the oxidative deterioration of lipids.

Studies conducted in Paraguay indicate that moisture can be removed in two stages of drying at low temperature, which prevents kernel rancidity, evidenced by a high peroxide and acidity index. During the first stage, work is carried out at a temperature of 40°C for ~14 h, which allows a decrease from the natural moisture content of the NIS to ~8%, with a minimum air speed of 0.5 m/s. The next stage of drying allows the temperature to be increased to 65°C for ~15 h, a minimum air speed of 5.4 m/s,

allowing the moisture content to decrease to 1.5%, value required almond packaging. The composition characteristics of macadamia nuts have led to an important assessment of their origin and nutritional and bioactive properties, which has allowed the regulation of the market based on well-established quality criteria. The physicochemical and microbiological quality specifications established and internationally accepted in most markets are moisture content less than 1.8%, peroxides 3–5 mEq/kg, free fatty acids 0.5% max, total aflatoxins 4–20 ppb, B1 aflatoxin 0–2 ppb, total plate count <30,000 cfu/g, molds and yeasts <20,000 cfu/g, *Escherichia coli* < 3/g, not detectable Salmonella 25 g, coliforms <300 cfu/g, no insect infestation, "normal" uniform cream color, oil-free appearance on surface, no foreign material, and no bad smells or flavors [9].

Laboratory-scale tests were conducted to evaluate the physicochemical and microbiological characteristics of the nuts subjected to drying, which were then transferred to the design and construction of an industrial dryer (**Figure 4**). The heat necessary to dry the nuts was produced by the combustion of the shell, obtained in the next stage of the macadamia processing (cracking); this material is hard and has a high calorific value (~ 19,600 J/g).

The air required for combustion enters through the ashtray, passes through a rack through its slots, and comes into contact with the fuel. The combustion gases circulate inside tubes with an extended surface (fins) to later be evacuated through the chimney. The drying air is driven by a centrifugal fan, circulates transversely to the finned tubes, and is heated by heat transfer from inside the tubes. Finally, the hot air

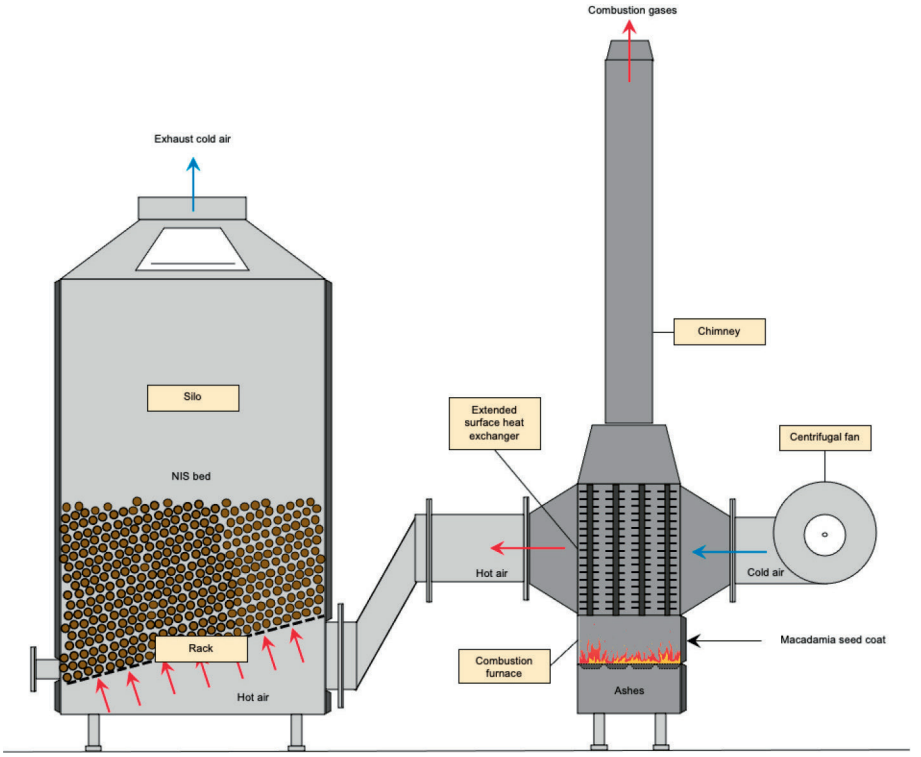


Figure 4.
Silo-type dryer with an air heating system. Source: Adapted from [30].

enters the silo from the bottom through an inclined rack. A detailed description of the design, construction, and operation of the equipment can be found in [30].

Continuing with the production process, the next operation, once the required moisture content (1.5%, wb) has been reached, is the breaking of the NIS carried out with a breaking machine. The separation of the kernel and the shell is done manually, obtaining a product with variable sizes, with whole nuts (~ 38%) being the most valued product, followed by whole nuts with small cuts (~ 12%). About 31% of the kernels obtained in this operation are halved in the breaking machine and 28% are smaller than half a kernel. Finally, the nuts are packaged to improve their shelf life and prevent spoilage.

Macadamia nuts from South America and other tropical countries have had to face certain challenges in their production and meet these quality criteria such as low levels of moisture and low levels of peroxides. The climatic and soil conditions of tropical countries were appropriate for the implantation of *M. integrifolia* crops and allowed the adaptation of varieties of the exotic species from Australia; however, it has become a nontraditional production item that has gained presence in the national and international market as an exportable resource. The process to reach production levels in South America has been slow and involves a great commitment to offer a product with characteristics that make it competitive in high-demand markets, which are characterized by demanding the satisfaction of rigorous quality criteria, sustainable over time.

The main factors affecting the production of macadamia nuts during postharvest are as follows:

- **Moisture:** The quality and storability of freshly harvested macadamia nuts are mainly limited by a high initial moisture content of approximately over 80% in the green carpel and 33% in the NIS. This high moisture content promotes microbial growth and lipolytic enzyme activity, leading to the development of rancidity and limited shelf life [31].

- **Rancidity:** This factor is closely related to moisture. Rancidity, caused by the high content of lipids in contact with moisture or air, constitutes the main quality defect of macadamia nuts that occurs in two main ways: oxidation and hydrolysis [25].

- **Browning:** A problem observed during the nut drying process is internal browning, caused by an accumulation of reducing sugars (glucose and fructose) in the center of the kernel, which, in turn, react with amino acids to give nonenzymatic browning products through Maillard reactions [17, 32]. On the other hand, macadamia nuts are temperature sensitive based on their moisture content. When fruits with a high initial moisture content are rapidly dried at temperatures above 38°C, sucrose (the predominant sugar in fresh macadamia nuts) may undergo hydrolysis to produce glucose and fructose, substrates for the Maillard reaction. Under these conditions, brown color develops in dried grains; therefore, browning may develop in the center of the kernel, or externally, depending on drying conditions. Physiological ripening also influences browning; the presence of unripe nuts (higher concentration of sugars) can contribute to kernel browning. Unripe grains have a higher content of sucrose and reducing sugars and more browning than ripe grains [17].

Therefore, the quality of the macadamia nut depends on the conditions of the initial composition of the nuts prior to the drying process and the methods by which

they are processed, packaged, and stored. To combat these adverse factors for quality, adequate postharvest process, efficient drying systems, and the implementation of packaging systems that reduce susceptibility to lipid hydrolysis and oxidation are proposed in the industry.

Macadamia grain quality is more affected by slow drying at room temperature than by postharvest processes such as the type of huller used [33]. Grain drying consists of the removal of water to a level that prevents the growth of fungi and bacteria, so that the appearance and nutritional quality of the grain as food, or its viability as seed, is preserved [34]. The drying methods for the nuts can be summarized as follows:

- **Drying at low temperatures on the farm:** Those that use air at room temperature or heated 3°C ± 2°C above room temperature as a means of transporting moisture and energy. In these procedures, low specific air flows are used (2.0–5.0 $m^3 / min.ton$)[1]. The low air flows make the drying procedures at low temperatures typically slow, and the product obtained has good quality [34]. The first stage begins in the field when freshly harvested and shelled nuts, with a moisture content of 20–30% (db), are subjected to natural air convection drying, using aerated boxes, trays, and silos. Under these conditions, it takes 3–4 weeks to reduce the moisture content to 10% (db) [35].

- **Silo drying:** Only natural or slightly heated air is used. The procedure is relatively simple and inexpensive and maintains good grain quality. To apply this method, the moisture content of the grain must not be higher than 20%; if it is higher, the air temperature must be lower than 15°C and use higher air flows to avoid alterations in some layers of the grain mass [36]. It is recommended that the temperature does not exceed 40°C when the nuts have a moisture content greater than 8%; later, the temperature can be increased up to 70°C. The reason for this gradual increase in temperature to dry the nuts is to prevent the kernel from suffering color changes in the center; because the shell has a higher percentage of moisture than the kernel, the shell becomes saturated and has no space to release more moisture; then, the central part of the kernel is stained and changes its consistency with irreversible damage and impact on the quality of the kernel [30].

- **High-temperature drying:** They are characterized by the use of heated air, at least 10°C above room temperature. The specific air flow rates are higher and the drying time is shorter. The final stage of nut drying is carried out at a temperature between 50°C and 70°C, to reduce moisture to 1.5%. Conventional heating uses the application of energy on the surface, and this is transported to the interior of the material by conduction to perform the drying process [34]. The predried nuts that are transported to the industrial plant are placed inside a silo-type dryer, which operate with forced air flow heated by convection at a controlled temperature [35]. In places where the relative air humidity is high, as in many tropical countries, increasing the air flow rate is not enough to achieve drying, since this variable does not influence the drying potential of the air. In these cases, heating the air is favorable to increase the speed of movement of the drying front [34]. An alternative for kernel drying is microwave heating and

[1] Specific flow, which refers to the amount of air received by a cubic meter or ton of grain in a defined unit of time.

drying. Microwave heating works at frequencies between 300 MHz and 300 GHz [37]. Industrial ovens frequently combine both the conventional and microwave heat sources to obtain different degrees of browning and surface crispness, to accelerate moisture removal, and to reduce surface counts of microorganisms. Macadamia nut drying using microwaves, especially from the sensory point of view, allows obtaining a product with characteristics similar to those of the conventionally dried product. The advantage of this process is the lower impact on lipid rancidity, once the drying process is finished and after 6 months of storage [35]. The experiences carried out have been promising in terms of the greater drying speed, but have caused some problems of deterioration of the quality of the kernel, in terms of the characteristic cream color that it should present, without considering that this technology is even more expensive than conventional drying systems [30].

4. Macadamia nut packaging systems

Once dried, the macadamia nuts (kernels) contain a large amount of unsaturated lipids that can still be affected by oxygen, light, humidity, and heat during storage. For this reason, it is necessary that the relative humidity in the storage place does not exceed 70%. Similarly, an excessively dry environment can cause the nut to lose weight and lead to rancidity processes, so it is not convenient for the ambient humidity to be less than 40% [31]. In order to choose the appropriate preservation technique for the storage of dried kernels, it is necessary to know the estimated time and storage conditions of the packaged product.

Packaging fulfills the basic functions of containing and protecting the food, informing and attracting consumers. The use of packaging with new protection techniques has made it possible to extend the shelf life of these foods. The packages used in vacuum systems and protective atmospheres are made with coextruded materials, i.e., those that are made up of more than one polymer, generally low-density polyethylene and polyamides [38].

The appropriate packaging options have proven to be vacuum packaging in modified atmospheres or protective atmosphere.

- **Vacuum packaging:** It consists of the total extraction of the air that surrounds the product so that the packaging material folds around the food as a result of the decrease in internal pressure compared to atmospheric pressure. This material must have a very low permeability to gases, including water vapor.

- **Protective atmosphere packaging:** Mostly inert atmospheres of nitrogen and/or some noble gas such as argon and helium are used. Sometimes, carbon dioxide is also included for its antimicrobial action [38]. Organoleptic alterations are reduced when oxygen levels are below 0.2%. The characteristics of the most used gases for the packaging of the macadamia kernel are described below.

- **Carbon dioxide (CO_2):** CO_2 is a colorless gas with a slight pungent odor at very high concentrations. It dissolves easily in water (1.57 g/kg at 100 kPa, at 20°C), producing carbonic acid (H_2CO_3), which increases the acidity of the solution and reduces the pH. This gas is also soluble in lipids and other organic compounds. The solubility of CO_2 increases with decreasing temperature. Packaging with CO_2

registers a high diffusion through plastic materials; the high solubility of CO_2 can lead to the breakage of the package due to the reduction in headspace [39]. Also, CO_2 exerts a fungicidal and inhibitory effect on bacterial growth that reproduces rapidly in normal atmosphere. The absorption of CO_2 depends on the moisture and fat content of the products; therefore, most foods absorb this gas. In addition, high concentrations of CO_2 can cause discoloration and the development of pungent acid flavors [38].

- **Nitrogen (N_2):** N_2 is a gas that is not very reactive, odorless, tasteless, and colorless. It has a lower density than air, is nonflammable, and has low solubility in water (0.018 g/kg at 100 kPa, at 20°C) and other food components. The solubility of N_2 in foods prevents the breakage of packages, if enough gas is included in the atmosphere of the package to balance the reduction in volume due to the passage of CO_2 gas to the dissolved form [39]. Nitrogen is fundamentally used in a modified atmosphere to displace and eliminate the maximum amount of oxygen, avoiding oxidation of vitamins, aromas, color, and fats, inhibiting aerobic bacteria [40].

To take advantage of the benefits of the different gases, modified atmosphere packaging usually requires a mixture of at least two gases, with the optimum proportions varying from product to product. An example of commercially available products is the 50:50 gas ratio of N_2 and CO_2. Packaging in N_2, CO_2, and mixed N_2/CO_2 atmospheres can be a useful alternative to control the parameters that threaten the physicochemical and nutritional quality of macadamia nuts. In a practical case study on macadamia nuts produced in Paraguay, the influence of packaging the kernels in different atmospheres for 180 days was studied. The nuts were dried using a silo-type dryer in two stages:

The first consisted of predrying in a silo-type dryer at a temperature of 39°C and 0.932 m^3/min of air input, until reaching a moisture content of 8.0% ± 0.5%. In the second stage, the nuts were processed in a Sherwood 501 dryer from a moisture content of 8.0% ± 0.5% to 1.5% ± 0.3% at a temperature of 65°C and an inlet air flow of 2.00 m^3/min. Maintaining the height of the nuts bed, without exceeding one-third of the dryer capacity.

The dried kernels were packed in polyamide polyethylene bags using a vacuum packing machine up to 8 mbar and then injection of N_2, CO_2, and gas mixture

	Moisture (g/100 g)	**Lipids (g/100 g)**	**CH (g/100 g)**	**Proteins (g/100 g)**	**Ash (g/100 g)**	**DF (g/100 g)**
Postharvest	18.2 ± 1.25	66.26 ± 6.2	16.22 ± 0.78	6.05 ± 0.59	1.34 ± 0.05	15.71 ± 0.0
Dry raw material	1.05 ± 0.14	76.62 ± 1.7	8.36 ± 1.43	8.01 ± 1.67	1.59 ± 0.25	4.92 ± 0.0
CO_2/N_2	1.19 ± 0.21	77.06 ± 0.6	9.04 ± 0.85	7.30 ± 1.05	1.36 ± 0.03	7.19 ± 0.0
N_2	1.30 ± 0.04	76.18 ± 0.2	8.71 ± 0.32	8.09 ± 1.20	1.48 ± 0.01	7.76 ± 0.0
CO_2	1.01 ± 0.19	78.62 ± 1.3	7.29 ± 0.35	8.07 ± 1.53	1.35 ± 0.08	5.95 ± 0.0
Air	1.97 ± 0.17	77.37 ± 0.5	7.39 ± 1.37	8.28 ± 1.41	1.27 ± 0.01	5.16 ± 0.0
Vacuum	1.23 ± 0.14	77.55 ± 0.5	8.38 ± 0.65	9.18 ± 1.13	1.49 ± 0.04	7.46 ± 0.0

Table 1.
Centesimal composition of macadamia nuts in postharvest stages, drying and 180 days of storage in different protective atmospheres.

CO_2/N_2 (50,50) as a protective atmosphere up to a pressure of 300 mbar. Nuts were also vacuum packed and packed in polyethylene bags as a control for conventional packaging.

Values are presented as mean ± SD (n = 3). In each row, different lowercase letters indicate a statistically significant difference (ANOVA, post Tukey test, $p < 0.05$). Statistical analyses were performed separately at each stage, because the nuts analyzed were not the same in phase.

The results showed that under these drying conditions, the nuts maintain the quality required for export for up to 6 months, conserving the parameters of peroxide index, acidity, mesophilic aerobic count, fungi and yeasts, and coliforms at 45°C. This processing system used allowed to obtain a good quality product, in accordance with national and international standards, at the time of analysis, up to 180 days of storage and kept in a place with low relative humidity. Regarding the organoleptic characters through a sensory profile of taste and texture, there was a significant difference at 45 days; according to the tasters, a lower moisture content was perceived in the nuts packaged in an atmosphere of CO_2/N_2 (50:50). After 90 days of storage, a greater intensity of the bitter taste was perceived in the nuts packed in a CO_2 atmosphere, with a significant difference compared to the samples packed with other gases. At 180 days of storage, a significant difference was observed in the bitter taste of nuts packed under conventional conditions. The most important variation in the centesimal composition of the macadamia nuts was observed between the postharvest stage and the dry raw material; in the postharvest, the nuts presented 18% moisture and it was possible to reach 1% in the drying stage. The results of the centesimal composition of the macadamia nuts obtained in the different stages are shown in **Table 1**.

5. Drying versus browning: color analysis

Color is a very important quality parameter of macadamia nuts and varies from white to creamy [33]. Variations in ripeness, sugar composition, moisture content, and drying conditions of macadamia nuts contribute to internal browning [41] caused by an accumulation of reducing sugars in the center of the kernel, which, in turn, react with amino acids to give nonenzymatic browning products through Maillard reactions [42]. The roasting process in macadamia nuts is widely used because it improves the shelf life of the nuts, inactivating the oxidative enzyme system (lipoxygenic enzymes) and improves the flavor, aroma, texture, color, and appearance of the nuts through the reaction of Maillard and lipid peroxidation [43]. However, it is the main cause of intense color variations [44]. Conventional industrial roasting (120–160°C for about 10–20 min) must be controlled to achieve the desired color and sensory characteristics. Color variations can be detected by human vision, which is subjective, so detection by instrumental means is better [45]. Currently, color spaces and numerical values are used to create, represent, and visualize colors in a space of two or three dimensions [46]; in the case of food, as agreed by the International d'Eclairage Commission, it is adapted to a system by the CIE 1976 (ISO 11664–4, 2008) where the color space usually used is the L^*a^*b, which is the Euclidean distance between two different colors corresponding to the color difference perceived by the human eye. The L^* value represents lightness and darkness, its value is between zero for complete darkness and 100 for complete lightness, and the parameters a^* (from green to red) and b^* (from blue to yellow) are the two chromatic components, ranging from −120 to 120 [47]. It is necessary to know the color value in each pixel

of the surface of the macadamia nut in order to perform a detailed characterization of it and thus evaluate its quality with greater precision. However, the colorimeters available in the market measure L*a*b in a few square centimeters (~ 2 cm^2), and therefore, their measurements are not very representative in heterogeneous materials, as is the case of macadamia nuts [48]. On the other hand, the high cost of colorimeters for small producers in tropical countries such as Paraguay has led to the exploration of other methods of color measurement under standard conditions through photographic images. An alternative to measure color is through computer vision techniques [46, 48–51]. With a digital camera, it is possible to record the color of any pixel in the image of the object using three color sensors per pixel. The most widely used color model is the RGB model in which each sensor captures the intensity of light in the red (R), green (G), or blue (B) spectrum, respectively, which can be analyzed and presented in a histogram; these results can later be converted to the L*a*b color model [50]. For this conversion, most of the computerized vision systems described in the literature use specialized equipment or algorithms that are not easily accessible to most researchers, a problem that could be overcome with the use of software already available on the market [48].

To solve the problem of color analysis, a simple, practical, and economical method for color measurement was developed, using a BYK byko basic ® light booth (Columbia, USA), illuminated with two 60-cm-long D65 "daylight" fluorescent lamps, GTI Color Matcher ® (USA), a Canon PowerShot SD1400 IS digital color camera, placed horizontally to the samples at a distance of 10 cm and Image J ® and Adobe Photoshop CC 4.0.1.192. software. Color variation was monitored throughout the nut industrialization process. The same parameters were measured on nuts at different conditions; fresh, dried at 65°C (5,36 m/s air flow), in a silo-type dryer (Sherwood model 501, fluid bed dryer), and nuts stored for 180 days vacuum packed in different modified atmospheres (air, vacuum, CO_2, N_2, and CO_2/N_2, 50:50; see **Figure 5**). On the other hand, the content of reducing sugars was measured by Clegg's anthrone method, in order to determine the packaging system that underwent the least Maillard reaction during the process from drying to packaging at different atmospheres [52, 53].

Regarding the color of fresh macadamia nuts, a light cream color was observed, with L^* values on the external surface equal to 68.83 ± 1.85. In dry nuts, however, the values obtained for L^* were higher (71.33 ± 1.07), with significant differences being observed (ANOVA and Tukey's a posteriori test, $p < 0.05$), which indicates a greater luminosity in the dry samples (**Figure 6**). Besides, in the internal surface, we

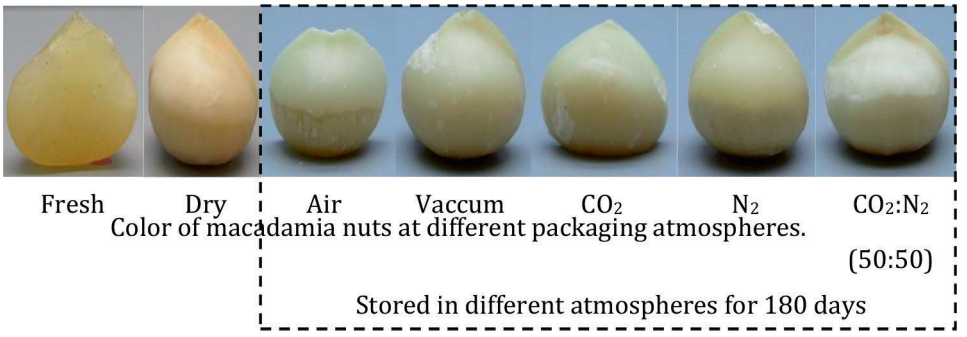


Figure 5.
Color of macadamia nuts at different packaging atmospheres.

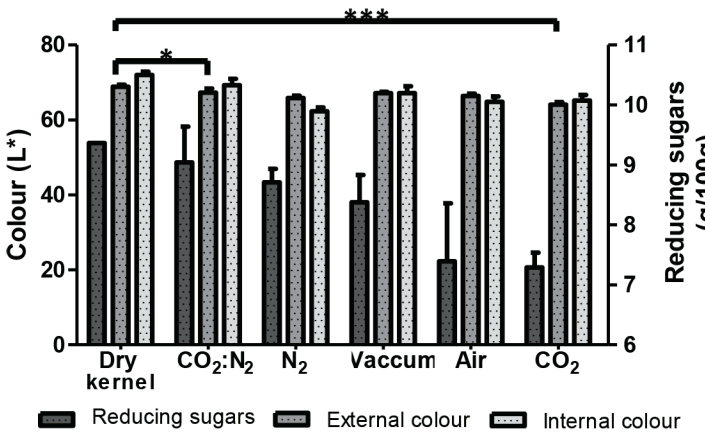


Figure 6.
*External and internal color and content of soluble sugars in dry macadamia nuts, prior to packaging and after 180 days of storage in modified atmospheres. The values are expressed as mean ± SD. The nuts analyzed in each condition are not the same. Same letters indicate that are no statistically significant differences (ANOVA and Tukey's a posteriori test, $p < 0.05$). *they express the degrees of statistical significance with respect to dried nuts prior to packaging.*

observed a value of L* = 72.00 ± 2.92 and in dry nuts 76.75 ± 3.82, observing statistically significant differences, which indicates a greater luminosity in the samples (ANOVA and Tukey's a posteriori test, $p < 0.05$).

After 180-day follow-up of packaged nuts, statistically significant differences were observed in both the external and internal surfaces, and nuts stored with CO_2/N_2 were observed to maintain a desirable cream color in external and internal surfaces that was stable for 180 days and good luminosity values (L*), with respect to the other atmospheres used.

Studies on the influence of modified atmospheres with different gases on the Maillard reaction are limited in the literature; however, Birch et al. [54] evaluated the external color change and the sugar content in macadamia nuts when they were heated for 20 min at 135°C and observed that both L* value and sugar content decrease as a function of time.

Once the issue of obtaining whole, dry nuts of high sensory and nutritional quality has been resolved, it is imperative to address the waste that this process entails. They are considered the main byproducts of this drying and packaging process; the cracked, broken nuts or powder of the broken and the shell of the NIS. From cracked nuts, one of the best alternatives is to obtain oil, considering a raw material with a high content of lipids, which require rapid processing due to the susceptibility to oxidation. The main alternatives used for the oil extraction with high added value are described below, as well as the use of biowaste such as the oil extraction cake and macadamia nut shells, which are found in frank development at the level of tropical countries in the productive sector of macadamia.

6. Advances in macadamia oil extraction with green technologies

The traditional extraction method is cold mechanical pressing, a technology that requires a large energy input and provides a product with fine suspended solids and low efficiencies (35–40% w/w) [55]. An alternative to increasing the efficiency and

quality of the product would be extraction with organic solvents, but with enormous disadvantages from the energy, nutritional, and environmental point of view [56]. The growing trend in the consumption of healthy, safe, and functional foods has motivated studies on special cold-pressed oils, including macadamia oil. Consumers prefer cold-pressed macadamia nut oil (CPMO) over refined and solvent-extracted oil due to its exceptional quality and safety attributes [1]. In recent years, the technology of liquefied gases and supercritical fluids has gained relevance due to the use of solvents considered "green," since they are nontoxic, safe, and cheap [57]. The use of supercritical CO_2 (sc-CO_2) for the extraction of various products of interest has gained notoriety [58]; however, for the extraction of oils, it was reported that sc-CO_2 requires long extraction times, high temperatures that could degrade antioxidants present in macadamia, and high pressures that have been shown to negatively influence the profile of fatty acids since lower amounts of unsaturated fatty acids are obtained [11, 59–61]. Besides, subcritical CO_2 or liquefied CO_2 has numerous advantages, such as operating below the critical point, suitability for the separation of thermolabile compounds, avoidance of thermal degradation of components at the time of extraction, and high selectivity to flavor-representative and esterified components [62, 63]. Additionally, it is nonflammable, safe, cheap, odorless, nontoxic, highly available, and environmentally friendly [64]. However, CO_2 is a nonpolar molecule, which is why it is related only to compounds of the same nature. However, the addition of a suitable cosolvent can improve the solvent properties of CO_2, expanding the range of lipid extraction [59, 65]. Due to the ease of removing ethanol from the oil, its use as cosolvent is allowed in the food industry. It was shown that the lipid extraction range is extended if it is used with CO_2; it also decreases the viscosity and surface tension of the oil-CO_2 mixture and decreases the electrical permittivity of CO_2 and, therefore, the polarizability [59, 65]. As for the critical point of the CO_2-ethanol mixture, it increases with the alcohol fraction, a phenomenon that allows the subcritical work zone to be extended [11, 59–61].

Liquefied propane is another permitted cosolvent that has multiple advantages over solvents such as n-hexane (widely used for the extraction of edible oils), since it is cheap and does not leave a toxic residue [66]. The use of light hydrocarbons as cosolvents substantially improves the extraction kinetics due to the good solubility of triglycerides, making the operation faster and more efficient. Regarding the temperature and critical pressure of the CO_2-C_3H_8 mixture, it presents an antagonistic behavior, since as the fraction of C_3H_8 increases, the critical pressure decreases, while, for low fractions of C_3H_8, the critical temperature decreases below the critical temperature of pure CO_2, but then increases substantially. Low concentrations of C_3H_8 are said to push the critical temperature of the mixture [67].

A simple method to study the main operating variables that influence solid–liquid extraction with liquefied gases is the high-pressure Soxhlet, whose operation is similar to the conventional Soxhlet used to determine the fat content of a vegetable matrix (**Figure 7**). To create the necessary temperature gradient, the ends of the extractor must be subjected to a temperature difference such that, at the base, the evaporation of the solvent-cosolvent mixture is verified, while at the head, the condensation of these is allowed. This could be achieved by immersing the base of the extractor in a water bath at a controlled temperature and circulating cold water through the condenser, which must be conveniently located so that the film of condensate drips onto the sample contained in the extraction cartridge. The net effect would be the periodic recirculation of CO_2 in the extraction vessel, working under liquid–vapor equilibrium conditions. An extraction cycle is considered complete when the condensate in the

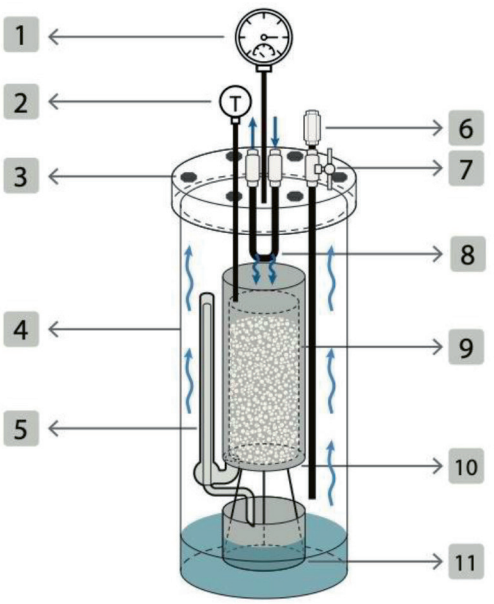


Figure 7.
High-pressure Soxhlet extraction system: (1) pressure gauge, (2) temperature sensor, (3) adjusting and closing nuts, (4) pressure vessel – Parr reactor, (5) siphon, (6) charge and decompression line, (7) shutoff valve, (8) condenser, (9) extraction cartridge, (10) solvent chamber, and (11) sample chamber. Elaboration: Smidt, M.

sample chamber is siphoned into the solvent chamber. The number of extraction cycles is determined by recording the temperature in the extraction chamber, where a temperature sensor is inserted at the same level as the siphon tube. The sensor will record a temperature gradient each time the solvent mixture is siphoned into the sample chamber. This process approximates a continuous multistage countercurrent extraction operation [68]. At the end of the extraction time, the container must be slowly depressurized; the solvent mixture will evaporate by sudden decompression (flashing) obtaining, on one side, an exhausted solid in the extraction cartridge and, on the other side, the extracted oil free of solvent in the solvent chamber.

The efficiency on any solid–liquid extraction operation with liquefied gases strongly depends on the proper selection of the solvent and cosolvent, as well as the nature of the solid matrix and the operating conditions [69]. The extraction temperature is an important variable, since it can significantly affect the quality of the product if it is very high and must be established together with the pressure, so that the working conditions are maintained in the subcritical region. Regarding the cosolvent fraction, it is important since the critical point of the mixture changes in relation to that of the pure solvents, so a fraction that allows the mixture to work in the subcritical region should be selected [59]. Respecting the granulometry, the efficiency is governed by this parameter since the components to be extracted must come into contact with the solvent, which will determine the extraction time and which, in turn, influences which components are extracted [70]. Initially, it is the solubility that controls the extraction process, and over time, it is the internal diffusion that governs the extraction process [71].

Experimental tests were conducted with subcritical mixtures of CO_2-ethanol and CO_2-C_3H_8, separately, by means of the high-pressure Soxhlet method, with the application of a multilevel factorial design, and the effect of extraction

temperature, mass fraction of cosolvent, and average granulometry of the dry kernel on the extraction efficiency of *M. integrifolia* nut oil was evaluated. Twenty grams of kernels was used for each experimental condition, and these were subjected to the different conditions according to the experimental planning; previously, the moisture content of the macadamia was adjusted to <1.5%. For the CO_2-ethanol case, the extraction time was 6 h, while for the CO_2-C_3H_8 case, it was 1 h. At the end of the extraction time, the extractor was decompressed and the oil obtained was physicochemically characterized. The partially defatted solid was subjected to total lipid analysis to determine, indirectly, the extraction efficiency, as well as the characterization of some parameters of interest for its further use. It should be noted that for the CO_2-ethanol mixture, additional vacuum evaporation is required to strip the oil of the cosolvent.

In the case of ethanol-assisted extraction, the highest efficiency (66.5% w/w) was obtained at 45°C, average granulometry 4.05 mm, and 20% (w/w) of cosolvent fraction. On the other hand, the extraction assisted with propane had a maximum efficiency of 72.6% (w/w) at 38°C, average granulometry 4.05 mm, and 45% (w/w) of cosolvent fraction. Both efficiencies are higher than those reported for obtaining macadamia oil by cold mechanical pressing, which is the method mainly applied for the extraction of this oil [72]. **Figure 8** shows the behavior of the extraction efficiency with temperature (X1) and average granulometry (X2) with 20% (w/w) ethanol (**Figure 8a**) and 45% propane (**Figure 8b**). The lowest extraction efficiency with CO_2-ethanol required two cycles/h, while the highest required six cycles/h. On the other hand, the lowest extraction efficiency with the CO_2-C_3H_8 mixture required two cycles/h and the highest four cycles/h; these physical phenomena allow us to visually explain the differences between treatments that lead to higher extraction yields.

In edible oils, the recommended physicochemical quality control determinations include acidity index, peroxide index, and iodine value [4], which can be complemented with the saponification index, refractive index, and rancidity, in order to have a bigger picture of oil quality. Based on this, the aforementioned determinations were made for the oil obtained in the treatment with the highest efficiency for each solvent mixture (**Table 2**). The acidity index is low (< 4, **Table 2**), which implies a reduced

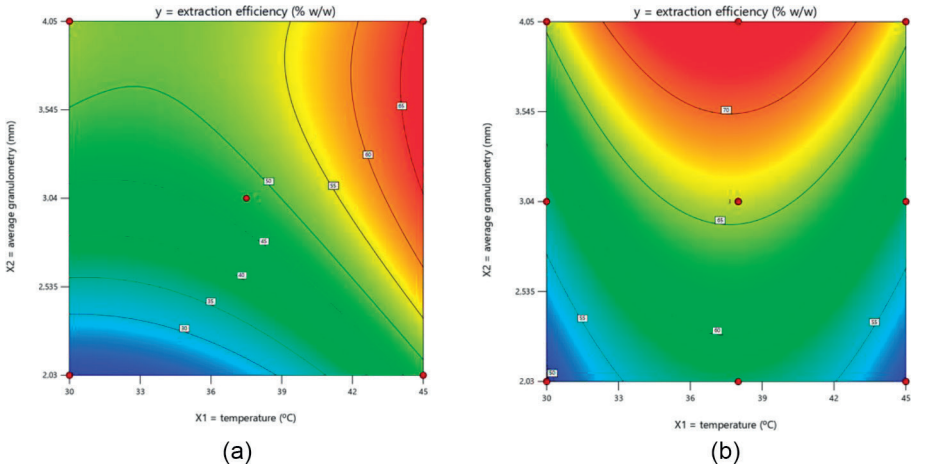


Figure 8.
M. integrifolia oil extraction efficiency against temperature and average granulometry for subcritical extraction assisted by 20% (w/w) ethanol (a) and 45% (w/w) C_3H_8 (b).

Determination	CO_2-ethanol	CO_2-C_3H_8	Reference	Source
Acidity index (mg KOH/g)	0.14 ± 0.03	0.29 ± 0.10	<4	[73]
Peroxide index (mEq O_2/kg)	0.95 ± 0.01	1.12 ± 0.17	<15	[73]
Iodine value (g I/100 g)	70.92 ± 2.93	71.75 ± 1.05	69–78	[74, 75]
Saponification index (mg KOH/g)	227.66 ± 1.10	218 ± 1.67	195–234	[12, 72]
Refractive index	1.46 ± 0.00	1.46 ± 0.00	1.46–1.47	[74, 76]
Rancidity	Negative	Negative	Negative	[76]

Table 2.
Physicochemical determinations of M. integrifolia oil quality carried out on the oil obtained in the best treatment of each solvent mixture.

amount of free fatty acids product of triglyceride degradation reactions that increase the quality of an oil, this complemented by a high oxidative stability verified by the low peroxide index (< 15, **Table 2**) [77], corroborated by a negative test for rancidity. The low iodine value classifies it as a nondrying oil (<100 g I/100 g), which is why a low content of polyunsaturated fatty acid is predicted [74]. Given the high saponification index, its refining is not recommended unless its final destination is the soap industry [72]. These results agree with what was reported by Mereles and Ferro [14], who have characterized freshly extracted macadamia oil from three consecutive harvests.

Regarding the fatty acids present in the extracted oils, these were contrasted with the fatty acid profile of virgin macadamia oil, extracted by the cold mechanical pressing of the raw material itself (**Table 3**). The values are close to each other, with a high and encouraging content of oleic acid as well as palmitoleic acid, both monounsaturated fatty acids of special interest in terms of nutraceutical and skin regenerative benefits [72]. A low content of polyunsaturated fatty acids was found, which is related to the low iodine value reported.

As for the defatted meal from both extraction processes, a high content of protein (> 18% w/w), fiber (>13% w/w), and carbohydrates (> 41% w/w) was verified, which makes it a candidate for the production of protein concentrates, isolated protein for the production of nutritional supplements, and partially defatted flours of interest for celiacs, among others [11, 78].

7. Activated carbon from macadamia nut shells

Several studies have addressed the use of large volumes of shell (mesocarp) that represents 40% of the dry weight of the fruit. In Paraguay, the potential of the shell of the *M. integrifolia* nut was studied as a precursor for obtaining activated carbon, whose volume in a macadamia processing industry is important. Activated carbon is the name applied to a series of porous carbon, which, after undergoing a carbonization and activation process, show great porosity and internal surface. It has been shown that activated is an extremely versatile adsorbent, with a crystalline structure similar to that of graphite, a characteristic that, together with the chemical nature of the carbon atoms that make it up, gives it surface adsorbent properties for a certain type of molecules [79]. The obtaining process basically consists of two stages: the pyrolysis of the carbonaceous material at temperatures below 800°C and the activation of carbon by physical or chemical methods.

Fatty acid	Formula	Virgin oil	CO_2-ethanol	CO_2-C_3H_8
Myristic	C14:0	0.61 ± 0.01	0.55 ± 0.01	0.62 ± 0.01
Palmitic	C16:0	8.14 ± 0.02	7.99 ± 0.05	8.28 ± 0.01
Palmitoleic	C16:1 ($\omega - 7$)	17.66 ± 0.05	15.89 ± 0.08	17.62 ± 0.02
Stearic	C18:0	3.93 ± 0.01	4.01 ± 0.01	3.92 ± 0.01
Oleic	C18:1 ($\omega - 9$)	62.28 ± 0.13	63.84 ± 0.10	62.58 ± 0.04
Linoleic	C18:2 ($\omega - 6$)	1.68 ± 0.01	1.66 ± 0.01	1.66 ± 0.00
Gondoic	C20:1 ($\omega - 9$)	2.29 ± 0.01	3.02 ± 0.02	2.84 ± 0.01
α – Linolenic	C18:3 ($\omega - 3$)	2.05 ± 0.01	2.21 ± 0.01	2.09 ± 0.00
Behenic	C22:0	0.75 ± 0.00	0.83 ± 0.01	0.76 ± 0.01

Table 3.
Fatty acid profile of M. integrifolia oil extracted by cold mechanical pressing, with CO_2-ethanol and CO_2-C_3H_8.

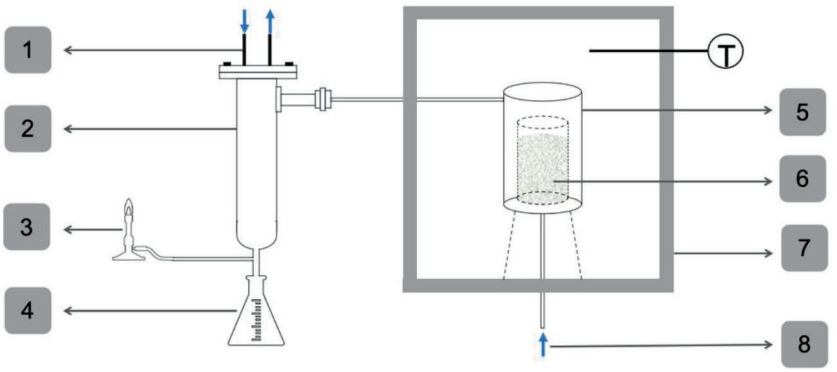


Figure 9.
Fixed bed reactor for obtaining activated carbon: (1) cooling water inlet/outlet, (2) condenser, (3) burner, (4) collector of liquid byproducts, (5) fixed bed reactor, (6) basket with macadamia shells, (7) pyrolysis oven, and (8) pipe for steam injection. Elaboration: Smidt, M.

The physical activation process was studied with a fixed bed reactor, consisting of a reaction chamber that contains a basket built with a metal mesh that supports the material to be carbonized (**Figure 9**). The reactor was placed in an electric furnace that allows the temperature to be controlled up to 1200°C; the steam necessary for activation was supplied by pumping liquid water with a peristaltic pump (not drawn) through a pipe inside the furnace, which allows the vaporization of this water. The gases produced are conducted out of the reactor, and the condensable fraction changes phase thanks to the removal of the heat in an indirect condenser through which cold cooling water circulates, while the incondensable gases are directed to a burner to burn the flammable fraction. About 750 g of macadamia nut shell (granulometry <1 mm) was introduced into the reactor and subjected to a heating rate of

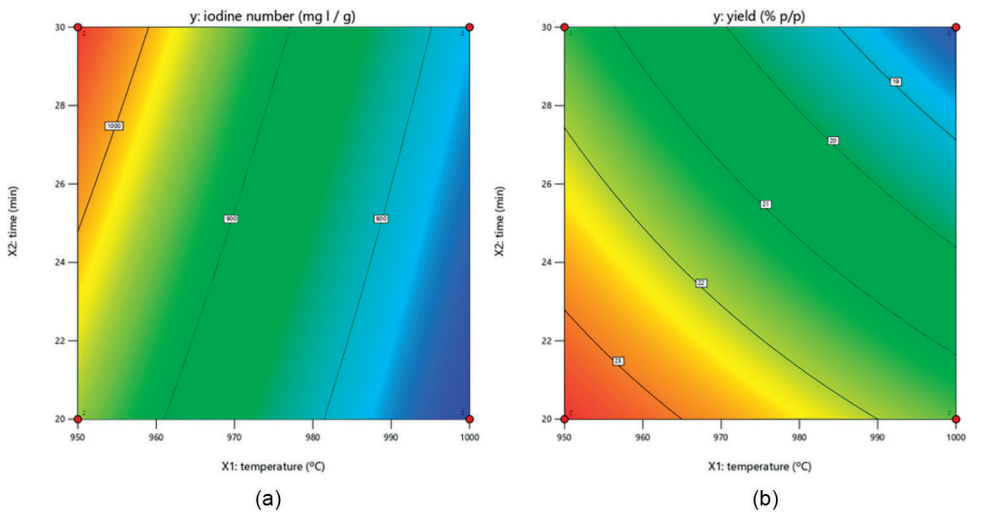


Figure 10.
Behavior of the iodine value (a) and yield of activated carbon (b) with temperature and activation time obtained from macadamia shells.

19°C/min up to 400°C and then 7°C/min until reaching the established temperature. The effect of temperature (950°C and 1000°C) and activation time (20 and 30 min) on the yield of activated carbon and the absorption capacity, evaluated by the iodine value, was studied using a 2^2 factorial design. The flow rate of water injected for activation was 42 mL/min. **Figure 10** shows the behavior of the absorption capacity and the yield obtained in the experimental region. For the case of **Figure 10a**, it is noted that the highest absorption capacity was obtained at 950°C and 30 min. However, higher yields are obtained at the same temperature, but with 20 min of reaction (**Figure 10b**) and with an average difference in the absorption capacity of only 96 mg I/g. The analysis of variance with a 95% confidence interval revealed that, for both the independent variables, the temperature and the activation time are significant. However, the interaction between these variables is only significant for the yield.

8. Use of the shell as nanosorbent in the chemical industry

Adsorption is a commonly used unitary operation for wastewater treatment due to its simplicity, cost-effectiveness, high removal capacity, and low energy consumption in large-scale processes [80]. Agricultural residues have the potential to be used as adsorbents due to their high availability and chemical composition [81]. Various byproducts of agricultural materials derived from adsorbents such as cactus leaves, hazelnut shells, banana peels, wool, almond shells, and coconut shells have been studied as potential adsorbents or contaminant removal from wastewater [82, 83]. Activated carbon is an adsorbent with a microporous structure, usually used for the elimination of polluting substances in wastewater, gases, etc. The microstructure of activated carbons depends not only on the natural texture of each raw material, but also on the activation process. Surface and porous areas are improved by carbonization and activation treatment. Improvements can be added by designing or modifying the activation process, such as carbonization at high temperature or in different atmospheres. Like other plant materials, the main component of the macadamia nut shell is cellulose (41.2%), which can be denatured to become activated [84]. Macadamia shell contains less inorganic content and high fixed carbon content compared to other biomass. Macadamia shells have a higher surface area than other nut shells [85, 86], and their ash content is very low [87]. Research has been conducted using macadamia nut shells to produce activated carbons for the removal of contaminants in water such as microcystin, aurocyanide, phenol, and methylene blue [88–91].

9. Conclusion

The fruits of macadamia nuts have wide advantages in their integral use, considering that the byproducts of the fruit are 100% industrializable, for which they present competitive advantages over other nontraditional crops. Several efforts have been made to improve the quality of nuts in countries such as Paraguay, with a tropical climate of high average temperatures and high relative humidity, which allow the macadamia nut to be a product of high nutritional and sensory quality, with a potential for sustainable and environmentally friendly production, compatible with current demands, within the framework of sustainable food for the future.

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Author details

Laura Graciela Mereles*, Mario Smidt, Karen Patricia Martínez,
Eva Eugenia Soledad Coronel, Edelira Velázquez and Laura Correa
Faculty of Chemical Sciences, National University of Asunción, San Lorenzo, Paraguay

*Address all correspondence to: lauramereles@qui.una.py

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