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OIL EXTRACTION FROM *MACADAMIA INTEGRIFOLIA* KERNELS USING COMBINED CONVECTIVE CIRCULATING DRYING AND THERMAL PRESSING: EXPERIMENTAL STUDY AND BIOACTIVITY EVALUATION

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ABSTRACT:

Macadamia integrifolia (M.I) is a high-value crop, primarily due to its kernels, which are rich in vegetable oil containing a high proportion of unsaturated fatty acids and antioxidant compounds. However, current oil extraction methods for M.I often overlook the importance of pre-drying and drying processes, which may result in reduced oil yield and compromised quality. This study aims to develop and optimize an oil extraction process for M.I using hot-air convective drying combined with hot pressing, and to compare the oil yield and quality with conventional methods such as sun drying and standard thermal drying. M.I kernels were subjected to moisture reduction and convective drying treatment. The oil was extracted using a hot pressing technique, followed by analyses including chemical composition (GC-MS), physicochemical parameters, quality indicators, and evaluations of bioactivity, such as antioxidant capacity (EC_1, ABTS, TEAC) and anti-tyrosinase activity. The results indicated that the convective drying method significantly improved oil yield, reaching up to 95.8%, and produced oil with higher

contents of palmitoleic acid (20.1%), oleic acid (58.6%), and other beneficial compounds. The extracted oil also exhibited enhanced antioxidant activity and oxidative stability. This study highlighted the crucial role of controlled pre-drying and drying conditions in the post-harvest phase to optimize both the yield and quality of M.I oil, thereby promoting its potential applications in the functional food, cosmetic, and natural pharmaceutical industries.

KEYWORDS: *Macadamia integrifolia, convective circulating drying, thermal pressing, antioxidant, anti-tyrosinase.*

INTRODUCTION:

Macadamia integrifolia (*M.I*) is a high-value crop due to its pleasant flavor and high nutritional content, with significant commercial potential in the food, cosmetics, and pharmaceutical industries. The kernels of *M.I* contain more than 75% lipids (Akhtar *et al.*, 2006), of which over 80% are unsaturated fatty acids (Akhtar *et al.*, 2006; Navarro *et al.*, 2016; Nguyen *et al.*, 2023). The oil extracted from *M.I* kernels is especially rich in monounsaturated fatty acids, notably oleic acid (omega-9) and palmitoleic acid (omega-7) - rare and bioactive compounds known for their skin-conditioning, anti-inflammatory, and cardioprotective properties (Navarro *et al.*, 2018).

Figure 1: Structure of *M.I* nut.

Several studies have investigated oil extraction from *M.I* kernels using various techniques such as mechanical pressing, solvent extraction, enzymatic hydrolysis, and supercritical CO_2 extraction (Zhu *et al.*, 2013; Ribeiro *et al.*, 2020; Shuai *et al.*, 2022). However, the influence of hot air convective drying on the oil biosynthesis, extraction efficiency, and quality characteristics of *M.I* oil has not been thoroughly studied or elucidated.

This study aims to develop an optimized oil extraction protocol from *M.I* kernels, focusing on maximizing oil recovery and preserving bioactive compounds. In addition, the chemical composition and bioactivities of the oil including antioxidant capacity and tyrosinase inhibition properties are analyzed and compared with oils obtained via conventional moisture reduction methods. The objective is to highlight the potential of *M.I* oil in the food and cosmetic industries.

The research contributes to a better understanding of the relationship between postharvest treatments (drying and moisture control) and the efficiency and quality of *M.I* oil, thereby

proposing a scientific approach for postharvest technology enhancement. From a practical perspective, the study may provide valuable guidance for *M.I* processing facilities in selecting cost-effective, high-yield, and value-added oil extraction methods that support product development and export potential.

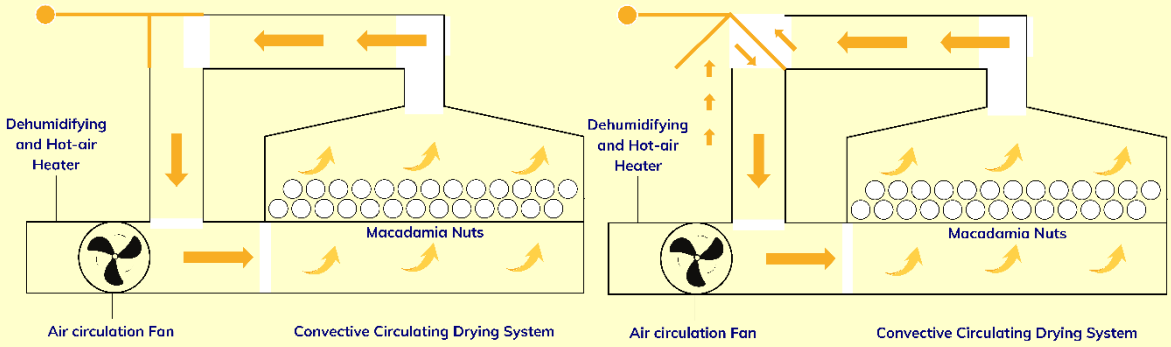
Currently, several studies have been conducted on the cultivation and harvesting of *M.I*. For instance, Dao *et al.* (2017) investigated the biological characteristics of several *M.I* cultivars, including 246, 849, 816, 842, and line OC. Nguyen *et al.* (2017) also examined the growth potential and yield of *M.I* trees, while harvest timing, an important factor affecting kernel quality, was explored by Nguyen (2016). Additionally, the influence of drying temperature on fatty acid composition and peroxide value of the oil was presented in the study by Nguyen *et al.* (2016). Nguyen (2017) further optimized the oil extraction process from macadamia using enzymatic hydrolysis. Moreover, Zhu *et al.* (2012) compared four methods of macadamia oil extraction: solvent extraction, ultrasound-assisted extraction, Soxhlet extraction, and supercritical CO_2 extraction. Somwongin *et al.* (2021) investigated the antioxidant, anti-aging, and anti-tyrosinase properties of *M.I* shell waste. However, existing studies have not thoroughly addressed the moisture reduction and drying processes, nor have they fully analyzed the impact of drying temperature and time on the oil yield and quality.

MATERIALS AND METHODS:

The study was conducted on *M.I* nuts of 246 (Keauhou) cultivar, harvested 220-235 days after nut set from an *M.I* plantation in Lam Dong Province, Vietnam. The nuts were stored at a temperature of 30-35^{o}C and under low humidity conditions.

Harvesting and Oil Extraction Method: *M.I* nuts were harvested 15 to 30 days prior to their natural abscission. The moisture reduction and drying process was carried out using a moisture reduction and ripening dryer system with circulating hot air. The heating process was initiated at 40°C and gradually increased to 60°C over a period of 3 hours. During this period, the temperature increased slowly, and the moisture exhaust vent was partially opened. After that, the temperature was maintained at 60°C for 50 hours and the moisture exhaust vent was fully opened during this stage. Kernel samples were then collected for evaluation; if the quality criteria were met, the temperature was further raised from 40°C to 90°C at a rate of 10°C every 30 minutes. Subsequently, the drying temperature was maintained at 90°C for 30 minutes. The moisture exhaust vent was closed during this stage. This stage is considered critical, as it marks the onset of oil formation within the kernels. Oil was extracted using an Akira oil press, model JMO01, with a power capacity of 500 W. The pressing temperature was controlled to ensure the crude oil output

did not exceed 70°C. The crude oil was then filtered continuously three times over 8-12 hours using a settling-filtration system. The residue was further pressed using a mechanical press to recover the remaining oil.



(a) (b)

Figure 2: Diagram and system for moisture reduction and convective drying: (a) The moisture exhaust vent is closed, (b) The moisture exhaust vent is open.

Method for Determining Oil Yield: Determine the initial mass (m_0) of the *M.I* kernel material. After oil extraction, the mass of the oil obtained is recorded as m_1 (g); Weigh the remaining residue to determine the mass of the residue (m_2), and calculate the mass of oil lost during the process using the formula: $m_3 = m_0 - m_1 - m_2$, where m_2 is the mass of the residue (g) and m_3 is the mass of oil lost (g); Oil yield is calculated according to the formula: $Y_{oil} = \frac{m_1}{m_1 + m_3}.100\%$ (Silva *et al.*, 2008).

Method for Determining the Sensory Characteristics of M.I Oil: The sensory properties of *M.I* oil were assessed according to ISO 6658:2017. Color was evaluated by pouring the oil into a glass cup with a diameter of 50 mm and height of 100 mm. The oil layer was at least 50 mm high and observed against a white background. Odor was assessed by spreading a thin layer of oil on glass or rubbing a small amount into the palm and smelling. Taste was determined by direct tasting. Clarity was evaluated by pouring 100 mL of oil into a colorless glass tube (30 mm diameter), left undisturbed at 20°C for 24 hours, and observed with reflected light on a white background.

Microbiological Analysis of M.I Oil: (1) *Coliforms*: ISO 4832:2006; (2) *Escherichia coli*: ISO 16649-3:2015; (3) *Salmonella spp.*: ISO 6579-1:2017; (4) *Staphylococcus aureus*: ISO 6888-3:2003; (5) Total yeast and mold count: ISO 21527-2:2008; (6) Total aerobic mesophilic bacteria: ISO 4833-1:2013.

Determination of Physicochemical Indices and Oil Quality: (1) Moisture and volatile content: ISO 662:2016; (2) Refractive index at 20°C: ISO 280:1998; (3) Acid value: ISO 660:2009; (4) Iodine value: ISO 3961:2018; (5) Peroxide value: ISO 3960:2017; (6) Insoluble impurities: ISO 663:2007; (7) Oxidative stability: Metrohm Rancimat 743/892 (ISO 6886:2016).

Method for Determining the Chemical Composition of M.I Oil: The components and concentrations in *M.I* oil were analyzed using gas chromatography-mass spectrometry (GC-MS) at the KLAMAG laboratory, University of Science, Vietnam National University, Hanoi, Vietnam.

Method for Evaluating the Bioactivity of the Oil: Antioxidant activity was assessed via EC_1 (µM $FeSO_4$/g extract), ABTS radical scavenging activity (mg/mL), and TEAC (mg Trolox/g extract); Skin-whitening potential was tested by determining the inhibitory effect on the enzyme Tyrosinase.

RESULTS AND DISCUSSION:

Analysis results of sensory, microbiological, physicochemical, and quality parameters of *M.I* oil

The sensory evaluation results of *M.I* oil revealed that the oil has a bright yellow color, a characteristic pleasant aroma, a rich and nutty taste, and a clear liquid appearance. The oil contained no impurities, showed no turbidity, and exhibited no sedimentation at the bottom of the glass tube.

The microbiological analysis results showed that no *Coliforms*, *Escherichia coli*, *Salmonella spp.*, Staphylococcus aureus, yeasts, molds, or aerobic microorganisms were detected. This indicates that the oil sample was extracted through a clean and hygienic process and stored under optimal conditions, ensuring high quality and safety for human health.

Physicochemical and quality indices of *M.I* oil: The density of the obtained *M.I* oil was 0.88 $g \cdot cm^{-3}$; Moisture and volatile matter were detected only in trace amounts, at a very low level of <0.033%, indicating that the oil extraction method was efficient and yielded a highly pure product. The refractive index of the *M.I* oil sample in this study was measured at 1.4674, consistent with the findings of Winston *et al.* (1943) (range: 1.4657–1.4681), Carvajal *et al.* (2010) (1.4607). This indicates that the oil is pure, unoxidized, and unadulterated. The acid value was determined to be 0.1 mg KOH/g fat. This very low value indicates minimal hydrolysis (low free fatty acid content), high oil quality, and proper storage conditions. As such, the oil is suitable for use in high-end cosmetics and functional foods. The iodine value was found to be 75.5 g I_2/100 g fat, indicating a moderately high level of unsaturation in fatty acids. However, this also suggests that *M.I* oil is more stable than oils with very high iodine values and is less prone to oxidation. The oil still contains beneficial unsaturated fatty acids such as omega-3, omega-6, omega-7, and omega-9, which are nutritionally valuable and beneficial for the skin. The peroxide value analysis showed that the oil contained no peroxides (0 meq/kg), indicating that it was fresh, unoxidized, and

suitable for use in anti-aging cosmetics and nutrient-rich food products. These results reflect the effectiveness of the storage conditions, convective circulating drying, and extraction processes.

Oil extraction yield and lipid content in *M.I* kernels

Table 1: Initial weight of *M.I* kernel, extracted oil weight, and residue mass.

Sample	*M.I* kernel Mass (g)	Oil mass (g)	Residue mass (g)	Oil loss Mass (g)	Yield (%)
S1	4002.3	2991.5	876.2	134.6	95.69
S2	3999.6	2995.2	873.5	130.9	95.81
S3	4003.1	2996.6	879.1	127.4	95.92
S4	3998.5	2993.8	874.3	130.4	95.83
S5	4001.7	2998.1	875.9	127.7	95.91

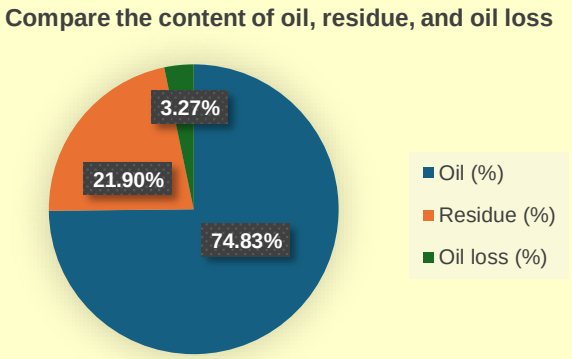


Figure 3: Comparison of oil content, residual cake, and oil loss.

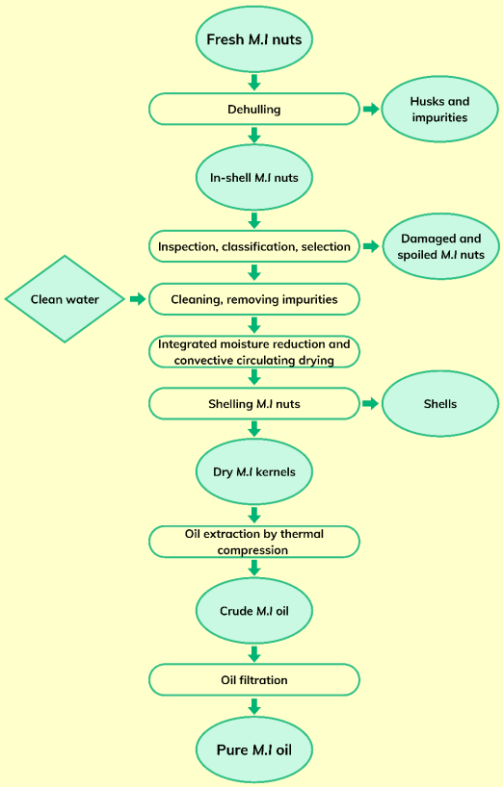


Figure 4: Processing flowchart for converting *M.I* nuts into *M.I* oil.

The results presented in **Table 1** and **Figure 3** indicate that the oil content in *M.I* kernels is approximately 78%. The oil extraction process from *M.I* kernels achieved a high yield, comparable to the lipid content reported by Laohasongkram *et al.* (2011) and Navarro *et al.* (2018). The average extraction yield of the three samples was 95.8%, which is higher than those reported in the studies by Silva *et al.* (2008) and Navarro *et al.* (2018). Additionally, a substantial amount of oil and press cake was recovered from the input material. These findings reflect the effectiveness of the optimized oil extraction process, which combined moisture reduction and convective hot-air drying.

The harvesting and oil extraction procedures achieved high efficiency due to the timing of harvest, which was carried out approximately 15 days after the kernel had fully developed within the shell. This stage represents the point at which the kernel reaches its full size, highest sweetness, and begins transitioning into the lipid accumulation phase. Harvesting at this time helps minimize enzymatic degradation processes that would otherwise reduce oil quality.

Two different methods were applied in the oil extraction process. Method 1 (M1): After being washed, *M.I* nuts were sun-dried and then placed in a conventional thermal dryer. The dried *M.I* nuts were subsequently subjected to thermal pressing at 170°C, with no temperature control of the extracted oil. Method 2 (M2): After washing, *M.I* nuts were directly processed in a combined moisture reduction and convective circulating drying system. The dried *M.I* nuts were also pressed at 170°C, with the temperature of the extracted oil being maintained at 70°C. The maximum total mass of M.I kernels in the drying chamber was 600 kg. The results are presented in **Table 2**, **Table 3,** and **Figure 5**.

Table 2: Moisture content, drying temperature, and drying time of *M.I* nuts processed using the two methods, M1 and M2.

Parameter	M1	M2
Initial moisture content of *M.I* nuts (%)	23.40	23.40
Moisture content after sun-drying (%)	5.70	-
Drying temperature (°C)	60	40-90
Drying time (hours)	90	56
Moisture content after drying (%)	0.68	0.09
Oil extraction yield (%)	75.40	95.80

Table 3: Moisture content (MC) and temperature (t) over drying time of *M.I* nuts using Method 1 (M1) and Method 2 (M2).

Drying time (hours)	t (°C) – M1	MC (%) – M1	t (°C) – M2	MC (%) – M2
0	30	5.70	40	23.40
1	60	4.81	50	21.03
3	60	4.05	60	17.09
53	60	2.52	60	4.05
53	60	2.52	40	3.26
53.5	60	2.26	50	2.58
54	60	2.04	60	2.02
54.5	60	1.83	70	1.06
55	60	1.64	80	0.53
55.5	60	1.52	90	0.27
56	60	1.44	90	0.03
60	60	1.27	-	-

In M1, moisture content decreased more slowly and required a longer drying duration. In M2, the use of a recirculating hot air flow with stable and well-controlled temperature resulted in a faster and more uniform moisture reduction, reaching the desired level within just 12 hours.

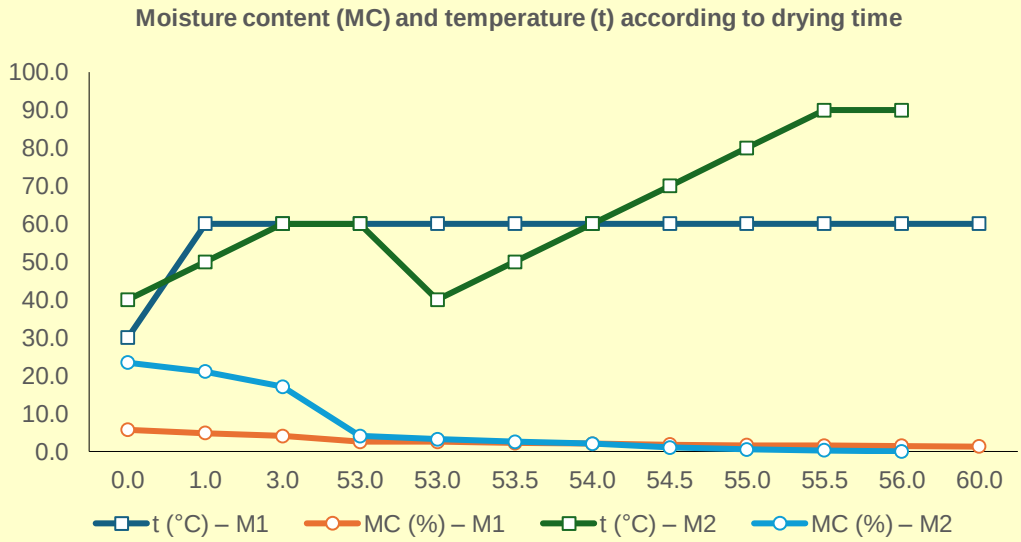


Figure 5: Changes in moisture content and temperature during the drying process of *M.I* nuts.

For the M1 method, the temperature stabilized at 60°C after the initial phase, and the moisture content gradually decreased to below 1.0%. In contrast, for the M2 method, the temperature increased to 60°C and 90°C in 2 stages, resulting in a faster moisture reduction that stabilized earlier at a lower level of 0.03%.

Immediately after harvest, fresh *M.I* nuts were subjected to rapid moisture reduction to prevent unwanted oxidation and fermentation reactions. The moisture reduction and drying processes

were performed simultaneously using circulating hot air, which helped shorten the processing time. The moisture reduction was carried out in a hot air chamber (40–90°C) to quickly reduce the moisture content of the seeds prior to the drying phase for macadamia kernel maturation. In the circulating convection drying process, convective heat transfer was enhanced by forcing the hot air to circulate evenly through the *M.I* nut surface using a fan. With higher airflow speed, the convective heat transfer coefficient (h) increased, resulting in faster heat transfer. As a result, heat was quickly and evenly applied to the inside of the *M.I* nuts, and moisture was efficiently removed, reducing drying time and preventing damage to the cell structure. Additionally, the circulating convection drying method helps distribute heat evenly, minimizing overheating and preventing the degradation of oil, as *M.I* oil consists of unsaturated fatty acid chains, which are prone to oxidation or decomposition at high temperatures. The convection drying method allows temperature control, keeping it below the threshold that would cause oil degradation. Therefore, compared to sun drying (which has fluctuating temperatures and is uncontrollable) or conventional drying (which involves uneven high temperatures), convection drying helps maintain lipid structure stability, leading to higher oil yield and quality.

Moreover, the heat pressing phase was carried out at 170°C, and the output temperature was controlled to not exceed 70°C to prevent changes in the properties and composition of the oil, thus avoiding the destruction of compounds within the oil. The result was a high oil yield, retention of many compounds, and ensuring stability and safety for use in functional foods or cosmetics.

This process is effective in extracting a significant amount of oil from the raw material, which is an important economic factor in production, opening up potential applications for large-scale production. The process is environmentally friendly, minimizing processing time, energy consumption, and the use of harmful organic solvents, contributing to the reduction of emissions and pollution. This is a sustainable development trend in post-harvest processing technologies today.

Chemical composition analysis of *M.I* oil

The chemical composition analysis of *M.I* oil is presented in **Table 4** and **Figure 6**. The analysis results indicated that the saturated fatty acid content was 16.8%. The unsaturated fatty acid content accounted for 83.2%, significantly higher than that of saturated fatty acids. This demonstrates that the oil extraction process effectively retained a high proportion of unsaturated fats. Fatty acid composition analysis of *M.I* oil revealed the presence of several important fatty acids.

Table 4: Acid composition in *M.I* oil.

Name of acids	Compositions (%)	
	M1	M2
α-Linolenic acid (C18:3n3, Omega-3)	0.26	0.138
Linoleic acid (C18:2n6, 9,12-Octadecadienoic acid, Omega-6)	0.98	1.95
Oleic acid (C18:1n9, 9-Octadecenoic acid, Omega-9)	57.9	58.6
Lauric acid (C12:0, Dodecanoic acid)	0.082	0.063
Myristic acid (C14:0, Tetradecanoic acid)	0.61	0.611
Palmitic acid (C16:0, Hexadecanoic acid)	9.69	8.87
Palmitoleic acid (C16:1n7, Z-9-Hexadecenoic acid, Omega-7)	19.33	20.1
Margaric acid (C17:0, Heptadecanoic acid)	-	0.03
Stearic acid (C18:0, Octadecanoic acid)	3.98	3.36
Arachidic acid (C20:0, Eicosanoic acid)	2.88	2.71
Eicosenoic acid (C20:1, 9-Eicosenoic acid)	2.69	2.44
Behenic acid (C22:0, Docosanoic acid)	0.98	0.783
Lignoceric acid (C24:0, Tetracosanoic acid)	0.36	0.337
Erucic acid (C22:1, cis-13-Docosenoic acid)	0.23	-

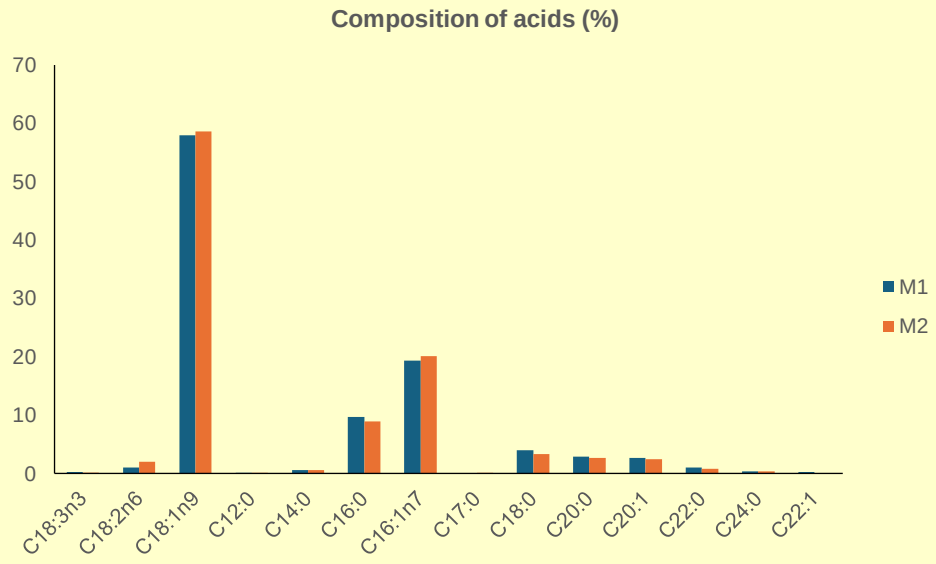


Figure 6: Comparison of fatty acid composition in *M.I* oil.

Omega-3 accounted for 0.138%, which is relatively low compared to other oils rich in Omega-3. Therefore, *M.I* oil is not considered a primary source of Omega-3. However, despite its low concentration, Omega-3 still plays an important role in the oil. Omega-6 was present at 1.95%, a moderate level that is lower than in sunflower oil and soybean oil. Nonetheless, it is important to maintain a balance with Omega-3 to avoid pro-inflammatory effects.

Omega-9 was the most abundant fatty acid, comprising 58.6% of the total fatty acid content in *M.I* oil. Omega-9 is known for its ability to lower LDL cholesterol and raise HDL cholesterol, thus

supporting cardiovascular health. The high Omega-9 content is a notable characteristic of *M.I* oil, making it suitable for healthy dietary regimens.

Palmitoleic acid was also present at a significant level of 20.1%, contributing to the uniqueness of *M.I* oil. Palmitoleic acid is a monounsaturated fatty acid with anti-inflammatory properties and benefits for skin health. It has also been studied for its potential in supporting lipid metabolism and improving insulin sensitivity. Therefore, the use of *M.I* oil or isolated palmitoleic acid from *M.I* oil holds promising potential for future applied research.

Several other fatty acids were also identified, including arachidic acid (2.71%), which enhances oil stability and shelf life; eicosenoic acid (2.44%), which supports skin and hair health; behenic acid (0.783%), known for its skin and hair-softening properties; and lignoceric acid (0.337%), which plays a role in maintaining cell membrane structure and product stability.

Table 5: Comparison of *M.I* oil recovery yields between methods M1 and M2.

Parameter	M1	M2
Number of samples (n)	5	5
Oil extraction yield (%)	82.3	95.8
Standard deviation (SD)	± 1.5	± 0.9
Mean difference (%)	-	+13.5
p-value (Independent t-test)	-	$p = 6.6 \times 10^{-5}$

The results shown in **Table 5** indicate that sun-drying is highly dependent on weather conditions and may lead to microbial spoilage and lipid oxidation. In contrast, the combination of moisture reduction and controlled convective drying allows for effective control of both temperature and moisture content, helping to preserve kernel structure and enhance oil release efficiency during hot pressing. The difference of approximately 13.5% represented a significant industrial and economic advantage, especially at large production scales. Additionally, the p-value < 0.01 indicated statistical significance.

Table 6: Comparison of *M.I* oil quality parameters between the M1 and M2 methods.

Quality Parameters	M1	M2
Color	Light yellow, slightly turbid	Clear bright yellow
Flavor	Slightly burnt odor	Mild characteristic aroma
Peroxide value (meq O_2/kg)	1.21 ± 0.15	0
Acid value (mg KOH/g oil)	0.41 ± 0.02	0.10 ± 0.02
Iodine value (g I_2/100g oil)	70.5 ± 0.24	75.5 ± 0.25
Moisture and volatile matter content (%)	0.12 ± 0.01	≈ 0
Unsaturated fatty acid content (%)	79.5 ± 0.3	83.2 ± 0.2
Oxidative stability (Rancimat, h)	8.3 ± 0.4	10.3 ± 0.6

The comparative analysis of quality parameters between M1 and M2 samples reveals notable differences in both physicochemical and sensory characteristics, as indicated in **Table 6**. In terms of appearance, M2 exhibited a clearer and brighter yellow color, whereas M1 appeared slightly turbid. This visual clarity of M2 is likely indicative of better processing conditions or filtration efficiency. Correspondingly, M2 also displayed a more pleasant and mild characteristic aroma, in contrast to the slightly burnt odor detected in M1, suggesting reduced thermal degradation during the extraction process.

Chemically, M2 demonstrated superior quality as evidenced by a peroxide value of 0 meq O_2/kg, reflecting an absence of primary oxidation products. In comparison, M1 had a measurable peroxide value (1.21 ± 0.15 meq O_2/kg), indicating initial stages of lipid peroxidation. The acid value, an indicator of free fatty acids resulting from hydrolysis, was also significantly lower in M2 (0.10 ± 0.02 mg KOH/g oil) than in M1 (0.41 ± 0.02 mg KOH/g oil), confirming its higher degree of freshness and stability.

The iodine value of M2 (75.5 ± 0.25 g I_2/100g) was slightly higher than that of M1 (70.5 ± 0.24 g I_2/100g), indicating a greater degree of unsaturation. This observation is consistent with the higher unsaturated fatty acid content recorded for M2 (83.2 ± 0.2%) compared to M1 (79.5 ± 0.3%). Moreover, M2 exhibited nearly negligible moisture and volatile matter content, which not only enhances oxidative stability but also improves shelf life. This is further supported by the Rancimat oxidative stability test, where M2 showed longer induction time (10.3 ± 0.6 h) than M1 (8.3 ± 0.4 h), highlighting its greater resistance to oxidation.

Collectively, these results suggest that the M2 extraction method yields a higher-quality macadamia oil in terms of both physicochemical integrity and functional properties, potentially making it more suitable for food, cosmetic, or nutraceutical applications.

Evaluation of antioxidant and anti-tyrosinase

Table 7: Antioxidant activities of *M.I* samples.

Mẫu	EC_1 (μM $FeSO_4$/g)	TEAC (mg Trolox/g)	ABTS – IC_{50} (mg/mL)
L-Ascorbic acid	238.3	124.0	0.059
M1	212.4	0.26	42.6
M2	261.3	0.42	23.7

The antioxidant activities of *M.I* samples are shown in **Table 7**. The antioxidant activities of *M.I* samples (M1 and M2) revealed noticeable differences. Sample M2 exhibited a higher EC_1 value (261.3 μM $FeSO_4$/g) compared to M1 (212.4 μM $FeSO_4$/g), suggesting a greater ferric reducing power. Despite their low TEAC values (0.26 and 0.42 mg Trolox/g for M1 and M2, respectively),

M2 showed improved performance, indicating a modestly better radical scavenging potential. Furthermore, the ABTS – IC_{50} of M2 (23.7 mg/mL) was significantly lower than that of M1 (42.6 mg/mL), confirming its relatively stronger antioxidant capacity through a more effective inhibition of the ABTS•⁺. However, both oil samples demonstrated much weaker activity than the positive control, L-ascorbic acid, across all assays.

The relatively high ABTS–IC_{50} values observed in *M.I* samples can be attributed to several interrelated factors. Firstly, the hydrophobic nature of *M.I* limits the interaction between its antioxidant constituents and the ABTS•⁺ radical, which exists in an aqueous environment during the assay. Secondly, the oil contains relatively low levels of potent hydrophilic antioxidants, such as polyphenols or ascorbate derivatives, resulting in insufficient radical scavenging activity. Thirdly, while certain lipid-soluble components may exhibit strong reducing power in electron transfer-based assays (e.g., FRAP), they may not effectively neutralize the ABTS•⁺ radical due to differences in reaction mechanisms. Finally, the oil matrix itself may physically interfere with the assay system by forming emulsions or layers that reduce the accessibility of active compounds to the radical species. These combined factors help explain the weaker antioxidant performance of macadamia oil in the ABTS assay compared to hydrophilic reference standards.

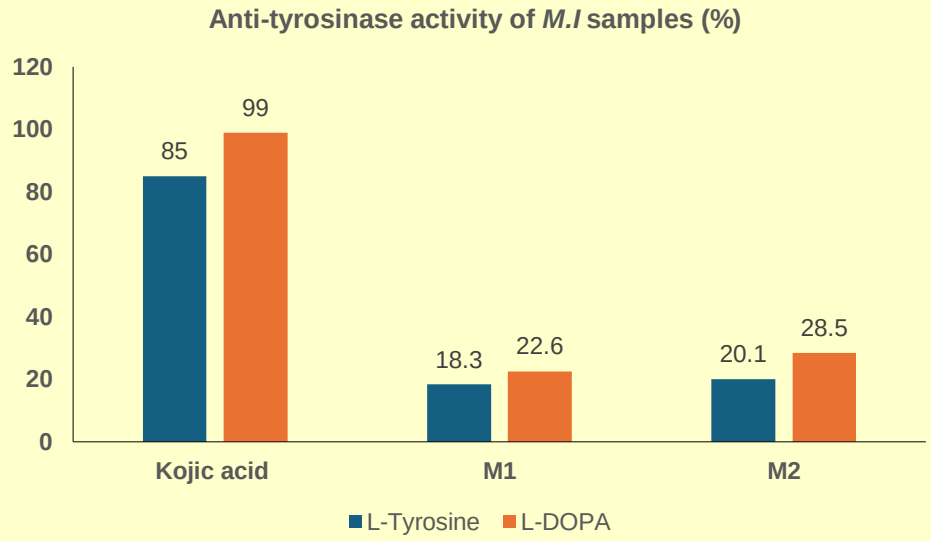


Figure 7: Tyrosinase inhibition by Kojic acid and *M.I* samples when the substrates were L-Tyrosine (A) and L-DOPA (B).

The tyrosinase inhibitory activity of the *M.I* samples is presented in **Figure 7**. Tyrosinase is a key enzyme involved in the complex biochemical pathway of melanin synthesis. Therefore, any compound capable of inhibiting tyrosinase is considered to have potential for skin-whitening applications. Tyrosinase catalyzes the oxidation of L-tyrosine to L-DOPA, which is subsequently

converted to L-dopaquinone and ultimately to melanin. As shown in the figure, both M1 and M2 samples exhibited tyrosinase inhibitory activity, with M2 consistently outperforming M1. Specifically, M2 showed 20.1% inhibition when L-tyrosine was used as the substrate, compared to 18.3% for M1. When L-DOPA was used, the inhibitory effect increased to 28.5% and 22.6% for M2 and M1, respectively. Although the activities were significantly lower than that of the positive control, kojic acid, the results suggest that macadamia oil, particularly M2, contains bioactive compounds with potential skin-whitening properties through partial suppression of melanin biosynthesis

CONCLUSION:

M.I oil extracted through the method combining convective hot air drying and thermal pressing demonstrated high yield and superior quality. Results indicated that *M.I* kernels contain approximately 78% oil, with an oil recovery efficiency of 95.8%. Furthermore, the oil possesses a rich nutritional profile and significant bioactive properties, offering great potential for applications in the food, cosmetic, and pharmaceutical industries. Specifically, *M.I* oil was found to be free from microbial and fungal contamination, with extremely low volatile content (<0.033%). The acid value was low at 0.1 mg KOH/g fat, while the iodine value was relatively high at 75.5 g I_2/100 g fat. The peroxide value was 0 meq/kg, and the oxidative stability reached 10.3 hours (Rancimat test). In addition, unsaturated fatty acid residues accounted for 83.2% of the total fatty acid content, notably including a high proportion (20.1%) of palmitoleic acid, along with other important fatty acid residues that contribute to the oil's functional properties. The evaluation of the bioactivity of *M.I* oil revealed that the oil extracted using the process developed in this study possesses relatively strong antioxidant capacity. However, its performance is limited in polar solvent environments such as water. In addition, it demonstrated a moderate tyrosinase inhibitory activity (20.1%), suggesting its potential application in natural and health-safe skin-whitening cosmetic products.

CONFLICT OF INTEREST:

The authors declare that there are no conflicts of interest related to this research.

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