International Journal of Academic Health and Medical Research (IJAHMR)
ISSN: 2643-9824
Vol. 10 Issue 6 June - 2026, Pages: 73-78

Optimization of Screw Press Extraction Parameters for Oil Recovery from Sacha Inchi (Plukenetia volubilis L.) Seeds Cultivated in Vietnam

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ABSTRACT: *Sacha inchi (Plukenetia volubilis L.) has drawn growing interest as a plant-based source of omega-3 fatty acids, yet systematic data on the mechanical extraction of oil from seeds cultivated in Vietnam remain limited. This study examined how three screw press parameters — pre-heat temperature (75–120°C), seed particle size (1–5 mm), and screw rotation speed (40–80 rpm) — affect oil yield and quality using seeds harvested in Daklak Province. Experiments followed a sequential one-factor-at-a-time (OFAT) design. Fatty acid composition was determined by GC-MS; acid, iodine, and peroxide values were measured by standard methods; and antioxidant activity was evaluated by the DPPH radical scavenging assay. The combination of pre-heating at 90°C, a particle size of 3–5 mm, and a screw rotation speed of 70 rpm yielded the highest extraction efficiency (91.54%). Below 90°C, incomplete seed softening limited oil expression; above 100°C, marginal yield gains were offset by oil darkening and off-odour development. Fine particles (< 2 mm) failed to generate adequate back-pressure within the barrel, while speeds exceeding 70 rpm shortened material residence time and increased frictional heat loss. Under the optimised conditions, the crude oil exhibited an iodine value of 176.37 g I_2/100 g, an acid value of 2.29 mg KOH/g, a peroxide value of 8.95 meq O_2/kg, and a DPPH IC_{50} of 90.58 mg/mL. The fatty acid profile was dominated by α-linolenic acid (ω-3; 39.5%) and linoleic acid (ω-6; 34.4%), with an ω-6/ω-3 ratio of 0.87. These results provide a practical reference for the mechanical processing of Vietnamese-grown Sacha inchi and support the oil's potential as an omega-3-rich functional food ingredient.*

Keywords: *Sacha inchi oil, Plukenetia volubilis; screw press extraction; process optimization; polyunsaturated fatty acids; DPPH antioxidant activity; iodine value.*

1. INTRODUCTION

Sacha inchi (*Plukenetia volubilis* L.), commonly known as Inca peanut or Mountain peanut [1], is a perennial woody climber of the family *Euphorbiaceae* native to the Amazonian lowlands of Peru. Cultivation has since expanded beyond Peru to Ecuador and Colombia, with principal export markets in the United States, Japan, and the European Union.

Sacha inchi was introduced to Vietnam in 2012, where it is colloquially referred to as *"dầu núi"* (lit. "mountain oil") or *"dầu sao"* (lit. "star oil"), the latter derived from the distinctive star-shaped fruit capsule. The species has been classified as a novel medicinal plant in Vietnam and is currently cultivated in the Central Highlands provinces (Tay Nguyen) and northern mountainous regions, including Son La, Hoa Binh, and Vinh Phuc [2].

Sacha inchi seeds have a high lipid content (35–60%), with a predominance of unsaturated fatty acids and minimal saturated fat [1]. Research conducted by the Vietnam Academy of Agricultural Sciences reported that domestically cultivated Sacha inchi yielded an oil content of 47.7% [3]. The unsaturated fatty acid fraction constitutes approximately 84% of total lipids, with a saturated fraction of only 9% and a polyunsaturated-to-saturated ratio of approximately 7:1 [4]. The predominant fatty acid is α-linolenic acid (ω-3, C18:3), accounting for 46.8–50.8% of total fatty acids, followed by linoleic acid (ω-6, C18:2) at 33.4–36.2% and oleic acid (ω-9, C18:1) at 8.7–9.6% [5]. The ω-6/ω-3 ratio in Sacha inchi oil ranges from 0.83 to 1.09, a range considered favourable for human nutrition [6].

Sacha inchi-derived products have found applications across the food, pharmaceutical, and cosmetic industries. In traditional and modern medicine, the oil is used for skin care, wound healing, treatment of insect bites, and management of dermal infections. Products based on Sacha inchi have demonstrated antibacterial, anti-inflammatory, and anti-ageing activity, and several formulations have been patented [7]. The favourable fatty acid profile and reported bioactivities support the potential of Sacha inchi oil as a high-value functional food ingredient.

Despite growing interest in mechanical extraction of Sacha inchi oil, systematic data on the effect of screw press operating parameters on oil recovery and quality from Vietnamese-grown seeds remain limited. The present study therefore aimed to determine how pre-heat temperature, seed particle size, and screw rotation speed affect extraction efficiency and oil quality in seeds sourced from Daklak Province, Vietnam.

2. MATERIALS AND METHODS

2.1. Raw Materials and Equipment

Dried Sacha inchi seeds were purchased from Tan Xuan Village, Ea Toh Commune, Krong Nang District,

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Daklak Province, Vietnam. Shells were removed by hand; damaged or discoloured kernels were discarded. The remaining kernels were ground using a laboratory disc mill and sieved into three particle size fractions (1–2 mm, 2–3 mm, and 3–5 mm). Ground material was stored in sealed polyethylene bags at room temperature (25 ± 2°C) prior to processing.

2.2. Experimental Design

A sequential one-factor-at-a-time (OFAT) approach was used: each variable was optimised independently while the remaining parameters were held constant, and the optimised value was carried forward to the next stage.

- Pre-heat temperature: Seeds of 3–5 mm particle size were pressed at a fixed screw speed of 70 rpm (preliminary default settings) at four pre-heat temperatures: 75, 90, 105, and 120°C.
- Seed particle size: Three particle size fractions (1–2 mm, 2–3 mm, and 3–5 mm) were pressed at the optimised pre-heat temperature and a fixed screw speed of 70 rpm.
- Screw rotation speed: Five speeds (40, 50, 60, 70, and 80 rpm) were evaluated at the optimised pre-heat temperature and particle size.

2.3. Analytical Methods

against a blank prepared by replacing the extract with 1 mL of ethanol

The percentage DPPH radical scavenging inhibition was calculated as:

$$\% \text{ Inhibition} = \frac{[A0 - A1]}{A0} \times 100$$

where A_0 represents the absorbance of the control (without sample) and A_1 represents the absorbance of the test sample. The IC_{50} value (the concentration required to scavenge 50% of DPPH radicals) was derived from the dose-response curve.

2.3.2. Fatty Acid Composition (GC-MS)

2.3.1. Antioxidant Activity (DPPH Radical Scavenging Assay)

The antioxidant capacity of the extracted oil was assessed using the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging method [4]. The assay is based on the ability of antioxidant compounds to donate hydrogen atoms to DPPH radicals, resulting in decreased absorbance at the characteristic wavelength and a concomitant colour change from deep purple to pale yellow. Lower absorbance values indicate greater free radical scavenging capacity.

The phenolic fraction was isolated by liquid–liquid partitioning of 10 g of Sacha inchi oil with 10 mL of n-hexane and 10 mL of methanol/water (80:20, v/v). The mixture was homogenised using a vortex mixer for 3 min and centrifuged at 5,500 rpm for 15 min. The lower methanol/water phase, which is enriched in polar phenolic compounds, was collected and diluted with methanol to concentrations ranging from 10 to 100 mg/L for antioxidant determination.

DPPH scavenging activity was determined as follows: 5 mL of DPPH solution (0.08 mM in ethanol) was added to test tubes containing 1 mL of phenolic extract at each concentration (10–100 mg/L). Mixtures were incubated in the dark for 30 min, after which absorbance was measured at 517 nm

Following extraction, the crude oil was transferred to 100 mL amber glass bottles with screw caps to minimise exposure to light and air. After centrifugal clarification, the clarified oil was submitted to an accredited analytical laboratory for fatty acid composition analysis by gas chromatography–mass spectrometry (GC-MS) according to standard AOAC methods.

3. RESULTS AND DISCUSSION

3.1. Proximate Composition of Raw Sacha Inchi Seed

The proximate analysis of the Sacha inchi seed kernels is presented in Table 1.

Table 1. Proximate composition of Sacha inchi seed kernels

Parameter	Value
Moisture content (%)	5.21 ± 0.04
Total ash (%)	2.76 ± 0.02
Crude fat content (%)	54.41 ± 0.72
Crude protein content (%)	31.30 ± 0.49

Note: Values are expressed as mean ± SD (n = 3). dw = dry weight basis.

The moisture content of the raw kernels was 5.21%, which falls well within the recommended range for oilseed storage (below 13%), thereby reducing the risk of microbial proliferation and enzymatic hydrolysis of triacylglycerols. The crude fat content (54.41%) and crude protein content (31.30%) are consistent with previously reported values for Sacha inchi seeds of Peruvian origin (54% lipid, 33% protein) [8]. Compared with values reported by the Vietnam Institute of Nutrition for domestically cultivated seeds (47.7% oil, 27.5% protein) [3], the present samples exhibited higher values for both parameters, which may be attributable to differences in cultivar, edaphic conditions, climate, or analytical methodology.

3.2. Effects of Processing Parameters on Extraction Efficiency

3.2.1. Effect of Pre-heat Temperature

Extraction efficiency increased progressively with pre-heat temperature (Figure 1). At 75, 90, 105, and 120°C, oil yields of 76.55%, 87.80%, 89.60%, and 90.30% were recorded, respectively. In screw press operation, heat reduces the viscosity of the oil and softens the seed matrix, facilitating oil release under mechanical compression. At 75°C, incomplete softening of the seed kernels limited oil expression.

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Figure 1. Effect of pre-heat temperature on the extraction efficiency of Sacha inchi (*Plukenetia volubilis L*.) oil by screw press.
Note: Data points represent mean values (n = 3). The dashed vertical line indicates the selected optimal temperature (90°C). Triangular markers (▲) denote conditions associated with quality degradation (darkening and off-odour development).

Above 100°C, incremental gains in extraction efficiency were marginal, while the crude oil exhibited visible darkening and development of off-odour, indicative of thermal degradation of pigments and volatile compounds. A pre-heat temperature of 90°C was therefore selected as the optimal condition, representing the most favourable balance between extraction efficiency and oil quality. This finding is consistent with the results of Muangrat et al. (2018) [4].

3.2.2. Effect of Seed Particle Size

Seed particle size had a pronounced effect on extraction efficiency (Figure 2). Oil yields of 58.54%, 67.04%, and 91.27% were obtained for the 1–2 mm, 2–3 mm, and 3–5 mm fractions, respectively, with the coarsest fraction yielding substantially higher recovery.

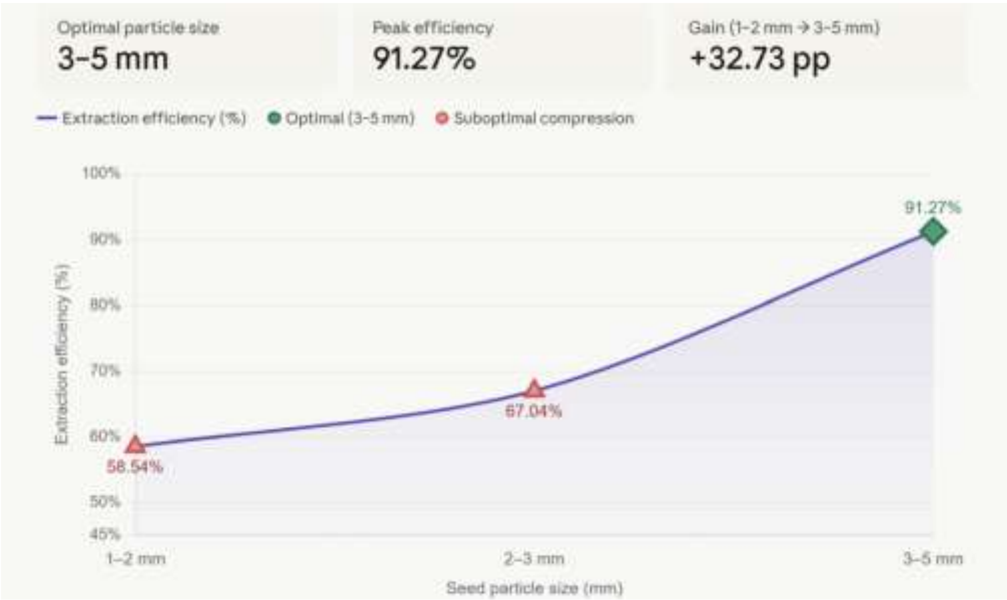

Figure 2. Effect of seed particle size on the extraction efficiency of Sacha inchi (Plukenetia volubilis L.) oil by screw press.
Note: Data points represent mean values (n = 3). The filled circle (●) indicates the optimal particle size fraction (3–5 mm), which yielded the highest extraction efficiency (91.27%). Triangular markers (▲) denote fractions associated with suboptimal barrel compression. Extraction efficiency increased by 32.73 percentage points from the 1–2 mm to the 3–5 mm fraction.

The superior performance of the 3–5 mm fraction is attributed to adequate back-pressure generation within the screw press barrel. Very fine particles (≤2 mm) tend to compact excessively or pass through barrel clearances without generating sufficient resistance against the screw flights, resulting in inadequate compression and poor oil expression. In contrast, coarser particles maintain a permeable cake structure that allows progressive compression and sustained pressure build-up along the barrel. Uneven friction distribution associated with fine feed material further contributes to inefficient heat transfer and reduced yield.

3.2.3. Effect of Screw Rotation Speed

Extraction efficiency as a function of screw rotation speed is shown in Figure 3. Oil yield increased progressively from 75.70% at 40 rpm to a maximum of 91.54% at 70 rpm, followed by a decline to 83.30% at 80 rpm.

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ISSN: 2643-9824
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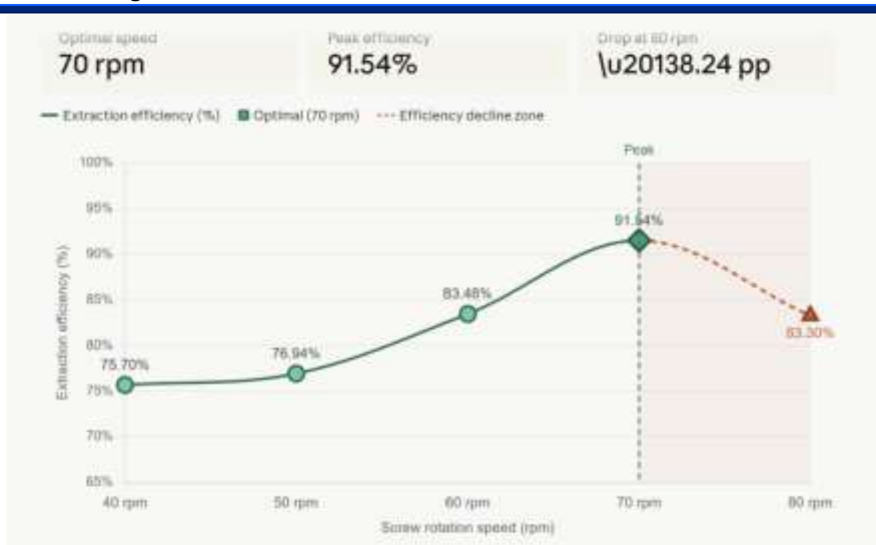

Figure 3. Effect of screw rotation speed on the extraction efficiency of Sacha inchi oil.
Note: Data points represent mean values (n = 3). The filled diamond (◆) indicates the optimal speed (70 rpm; 91.54%). The shaded region and dashed line denote the efficiency decline zone above 70 rpm, attributed to reduced residence time and increased frictional heat generation.

Screw rotation speed governs two interrelated parameters: material residence time within the barrel and the magnitude of compressive force applied to the seed cake. At speeds below 70 rpm, insufficient compressive force limited oil expression despite adequate residence time. At 70 rpm, the combination of compressive force and residence time was optimal for maximum oil recovery. At 80 rpm, reduced residence time and excessive frictional heat generation resulted in incomplete oil expression and thermal stress on the oil. A comparable optimum rotation speed has been reported for screw press extraction of other oilseeds [9].

3.3. Compositional Analysis and Quality Assessment of the Extracted Oil

3.3.1. Fatty Acid Profile

The fatty acid composition of the Sachi oil extracted under optimal conditions was determined by GC-MS (Table 2).

Table 2. Fatty acid composition of Sacha inchi oil

Fatty acid	Content (% of total fatty acids)
C16:0 (palmitic acid)	6.72
C18:0 (stearic acid)	4.77
C18:1 (oleic acid, ω-9)	13.20
C18:2 (linoleic acid, ω-6)	34.40
C18:3 (α-linolenic acid, ω-3)	39.50

The oil was characterized by a high proportion of unsaturated fatty acids, with ω-3 (α-linolenic acid) constituting 39.5%, ω-6 (linoleic acid) 34.45%, and ω-9 (oleic acid) 13.2%. The resulting ω-6/ω-3 ratio was approximately 0.87, which is consistent with previously reported values ranging from 0.81 to 1.12 [5]. This ratio is considered nutritionally favorable for human health, as a balanced ω-6/ω-3 intake is associated with reduced cardiovascular risk and improved neurological function [6]. The high unsaturated fatty acid content further supports the development of Sacha inchi oil as a functional food ingredient and a source of plant-based omega-3 supplementation.

3.3.2. Acid Value

The effect of pre-heat temperature on the acid value of the extracted oil is presented in Table 3.

Table 3. Effect of pre-heat temperature on acid value

Pre-heat temperature (°C)	Acid value (mg KOH/g oil)
75	2.06 ± 0.05
90	2.29 ± 0.08
105	2.40 ± 0.07
120	2.72 ± 0.12

Note: Values are expressed as mean ± SD (n = 3). Particle size: 3–5 mm; screw speed: 70 rpm.

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The acid value increased progressively with rising pre-heat temperature, from 2.06 mg KOH/g at 75°C to 2.72 mg KOH/g at 120°C. Heat speeds up hydrolysis of triacylglycerols, especially when oxygen is present, freeing fatty acids through oxidative cleavage of carboxyl groups [10]. The increase was modest, though, and all values stayed within the range reported by Muangrat et al. (2018) [4].

3.3.3. Iodine Value

The influence of screw rotation speed on the iodine value is shown in Table 4.

Table 4. Effect of screw rotation speed on iodine value

Rotation speed (rpm)	Iodine value (g I_2/100 g oil)
40	173.77 ± 1.01
50	172.78 ± 2.00
60	172.17 ± 1.58
70	176.37 ± 1.55
80	174.58 ± 1.60

Note: Values are expressed as mean ± SD (n = 3). Pre-heat temperature: 90°C; particle size: 3–5 mm.

Iodine values stayed between 172–176 g I_2/100 g oil. Values above 170 are typical of oils rich in linolenic and linoleic acids and show that the degree of unsaturation was not altered by extraction conditions. Such oils have high nutritional value but need proper storage to limit oxidation.

3.3.4. Antioxidant Capacity (DPPH IC_{50})

The effect of pre-heat temperature on the antioxidant capacity of the oil is presented in Table 5.

Table 5. Effect of pre-heat temperature on antioxidant capacity (DPPH IC_{50})

Pre-heat temperature (°C)	DPPH IC_{50} (mg/mL)
75	43.77 ± 1.89
90	90.58 ± 2.31
105	158.53 ± 0.61
120	170.21 ± 0.84

Note: Values are expressed as mean ± SD (n = 3). Higher IC_{50} values indicate lower antioxidant capacity. Particle size: 3–5 mm; screw speed: 70 rpm.

IC_{50} values increased progressively with rising pre-heat temperature, from 43.77 mg/mL at 75°C to 170.21 mg/mL at 120°C, indicating progressive degradation of heat-sensitive antioxidant compounds, including phenolics, tocopherols, and phytosterols. Since a higher IC_{50} means weaker radical scavenging, these numbers show that heat progressively destroys the phenolics, tocopherols, and phytosterols responsible for antioxidant activity, especially phenolic antioxidants, tocopherols, and phytosterols, which are progressively destroyed at temperatures exceeding 90°C.

From a purely antioxidant standpoint the lowest possible temperature would be best. In practice, 90°C is a reasonable compromise, yielding an IC_{50} of 90.58 mg/mL while maintaining extraction efficiency above 87%.

4. CONCLUSION

Sacha inchi (*Plukenetia volubilis* L.) is a lipid-rich oilseed, with the raw material analyzed in this study containing approximately 54% crude fat. Pressing at 90°C with 3–5 mm particles and a screw speed of 70 rpm recovered 91.54% of the available oil.

The crude Sachi oil obtained under these optimized conditions exhibited the following quality characteristics: an iodine value of 176.37 g I_2/100 g, an acid value of 2.06 mg KOH/g, a peroxide value of 8.95 meq O_2/kg, and a DPPH radical scavenging IC_{50} of 90.58 mg/mL. All quality indices met the requirements for food-grade and pharmaceutical applications. The oil contained a high proportion of unsaturated fatty acids, confirming the oil's value as a plant-based omega-3 source for functional foods and nutraceuticals.

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