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EFFECT OF PRETREATMENT AND PRESSING METHOD ON OIL YIELD FROM SACHA INCHI SEEDS

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Abstract

Sacha inchi seeds contain large amounts of oil and have many applications in food and medicine. The aim of this study was to evaluate the effectiveness of different pressing methods and their parameters on oil recovery efficiency. The results obtained using dehulled seeds pressed by conventional pressing method showed the highest efficiency of 78.35 ± 0.10 % at a pressing capacity of 20 kW and a screw speed of 42 rpm. In hot pressing of roasted seeds at 155 ± 5 °C, the efficiency was 79.37 ± 0.08 % at a pressing capacity of 21 kW and a screw speed of 44 rpm. When the seeds were treated with alkali and cold pressed, the highest oil recovery efficiency was 83.14 ± 0.22 % at a pressing capacity of 19.5 kW and a screw speed of 40 rpm. The oil obtained by all three methods contained saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), and polyunsaturated fatty acids (PUFA), with the omega 3-6-9 fatty acid group accounting for 93.35 to 93.65 % of the total fatty acids, indicating the high quality of the oil. The cold pressing method combined with alkaline treatment provides the highest oil recovery efficiency and has the potential for industrial application compared to other pressing methods.

Keywords: Sacha inchi; fatty acids; oils; pressing power; screw speed.

ВПЛИВ ПОПЕРЕДНЬОЇ ОБРОБКИ ТА СПОСОБУ ПРЕСУВАННЯ НА ВИХІД ОЛІЇ З НАСІННЯ САЧІ ІНЧІ

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Анотація

Насіння сачі інчі містить велику кількість олії і має багато застосувань у харчовій та медичній промисловості. Метою цього дослідження була оцінка ефективності різних методів пресування та їх параметрів на ефективність вилучення олії. Результати, отримані під час використання очищеного насіння, пресованого традиційним методом, показали найвищу ефективність – 78.35 ± 0.10 % за потужності пресування 20 кВт і швидкості шнека 42 об/хв. В ході гарячого пресування обсмаженого насіння за температури 155 ± 5 °С ефективність становила 79.37 ± 0.08 % за потужності пресування 21 кВт і швидкості обертання шнека 44 об/хв. Після обробки насіння лугом і холодному пресуванні найвища ефективність вилучення олії становила 83.14 ± 0.22 % за потужності пресування 19.5 кВт і частоті обертання шнека 40 об/хв. Олія, отримана всіма трьома методами, містила насичені жирні кислоти (НЖК), мононенасичені жирні кислоти (МНЖК) і поліненасичені жирні кислоти (ПНЖК), до того ж група жирних кислот омега 3-6-9 становила 93.35–93.65 % від загальної кількості жирних кислот, що свідчить про високу якість олії. Метод холодного віджиму в поєднанні з лужною обробкою забезпечує найвищу ефективність вилучення олії і має потенціал для промислового застосування в порівнянні з іншими методами віджиму.

Ключові слова: Саха інчі; жирні кислоти; олії; сила пресування; швидкість шнека.

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Introduction

Sacha inchi (Inca inchi or Inca nut), scientifically known as *Plukenetia volubilis* L., originates from the Amazon rainforest in tropical South America, particularly in Venezuela, Bolivia, Ecuador, and Peru [1]. The seed harvest time is about 244–250 days from planting [2]. Sacha inchi seeds contain 25–27 % protein and 41–54 % oil, of which about 85 % are fatty acids [3–6]. Sacha inchi oil has great potential for application in the food, pharmaceutical, and biodiesel industries [7; 8]. Polyunsaturated fatty acids (PUFAs) in the oil help prevent diseases such as arthritis, cancer, coronary heart disease, diabetes, hypertension, hyperactivity disorder, memory loss, and skin diseases, thereby improving health [9]. In particular, omega-3 and omega-6 fatty acids account for a high proportion, between 47–51 % and 34–37 %, respectively These are essential fatty acids, which the body cannot synthesize and must obtain from food [10; 11]. Although the body can synthesize omega-9 fatty acids, the proportion is not high [12]. Therefore, Sacha inchi oil is a highly nutritious oil suitable for many consumers, especially those who abstain from animal products. Additionally, Sacha inchi seeds are rich in omega-3-6-9 fatty acids, making them a viable alternative to the fatty tissue of deep-sea fish. This breakthrough contributes to ecological stability and conservation of rare fish species on the brink of extinction [13–16].

Currently, vegetable oil is obtained by various methods such as pressing and solvent extraction. Among these, traditional pressing and hot pressing are the most popular due to their simple technology and low investment cost. However, they come with disadvantages such as high residual oil in the residue. Additionally, some components in the oil, such as antioxidants or minerals, can easily change properties due to the heat generated during the pressing process. Adjusting the pressing parameters for plant materials is particularly complex because it depends on their structure and chemical composition. Therefore, to increase recovery efficiency and obtain high-quality oil, it is especially important to evaluate the effectiveness of different pressing methods and raw material pretreatments. This is the main reason we conducted this experiment.

Materials and methods

Materials and chemicals

The Sachi inchi tree, which originated from the Krong Buk district in Dak Lak province, Vietnam, was 4 years old. The seeds used for this study were harvested from the October 2023 crop. Ripe fruits were yellow-brown or dark brown in color, free from insects and physical damage.

All chemicals used in the analysis, including potassium hydroxide, ethanol, phenolphthalein, potassium iodide, sodium thiosulfate, sodium hypochlorite, and hydrochloric acid, all met analytical standards by Sigma Aldrich.

Sacha inchi seed processing process

Sacha inchi fruits were dried at 55 ± 5°C for 4 hours. The seed samples in Fig. 1. included: (S0) whole seeds; (S1) peeled seeds; (S2) peeled seeds treated by soaking in a 2% sodium hydroxide solution for 30 minutes (at a ratio of 1 part solid to 8 parts liquid, w/v), then rinsed with clean water several times to remove the alkali, naturally drained for 20 minutes, and freeze-dried at 8 ± 2 °C; and (S3) peeled seeds that were roasted at 80 ± 2.5 °C for 36 ± 2 minutes and cooled naturally. After preprocessing, the seed samples were packed into 2 kg bags made of polyethylene. The bags were sealed and stored at 5 ± 1 °C for the research process.

Fig 1. Sacha inchi seed samples

Note: (S0) whole seed, (S1) shelled seed, (S2) shelled seed treated with 2% NaOH, and (S3) shelled seed roasted

Processing of Sacha inchi oil

Sacha inchi seeds were fed into the inlet of the screw press (Guangxin YZLXQ140XC-8, China). The press allows adjustment of the pressing power (P) from 18.5 to 22 kW and the screw speed (ω) from 32 to 46 rpm. The seeds were compressed and rubbed against the tube wall, which broke the seed structure and increased the

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temperature. The oil escaped through the slots on the machine body. Then the oil was vacuum-filtered to separate the sediment and to collect pure oil.

Traditional pressed oil (E1): Seed material (S1) was fed into the feed port of the screw press. The fatty oil in the seeds was pushed out through the slots on the screw body to the receiving tray held at a temperature of 63 ± 2 °C. The oil was roughly filtered to separate the residue and cooled down to 3 ± 1 °C for 3 hours to precipitate the residue [17]. The oil was then transferred to the vegetable oil filter (Hai Minh HMLD1500, Vietnam) using specialized oil filter paper with a diameter of 0.45 µm. With a filtering pressure of 1.5 kW, pure oil was collected using method (E1).

Cold pressed oil (E2): Before pressing, the seed sample (S2) was cooled down to 3.5 ± 0.5 °C [17]. During pressing, the fat in the seed was pushed out and flowed through the slots on the screw shaft down to the receiving tray held at an average temperature of 48 ± 2°C. The refining steps were similar to method (E1).

Hot pressed oil (E3): The seed sample (S3) was placed into the press, and the heating mode of the pressing cage was adjusted to 155 ± 5 °C. The pressed oil flowed into the receiving tray held at a temperature of 84 ± 2 °C. The refining steps were similar to method (E1).

Determination of nutritional composition in Sacha inchi seeds

Seed samples (S1), (S2), and (S3) were analyzed for the following parameters: moisture (FAO FNP 14/7 p.205-1986), total protein content (FAO FNP 14/7 p.221-1986), total fat content (FAO FNP 14/7 p.212-1986), carbohydrate (US-FDA 21 CFR 101.9), and ash (FAO FNP 14/7 p.228-1986) [18; 19].

Determination of hardness of grain samples

Using the agricultural grain hardness tester GWJ-1 (Top Instruments, China), we determined the hardness of each Sacha inchi grain. The hardness values are expressed as N.

Determination of the structure of Sacha inchi seeds

Using scanning electron microscopy (SEM) techniques with different magnifications, the sample was divided into three parts: the first part consisted of intact particles; the second part was machined along the grain length; and the third part consisted of cross-sectional particles. The imaging results were obtained using S-4800 high-resolution SEM device (Hitachi, Japan) with an acceleration voltage of 10 kV.

Determination of oil recovery efficiency

The formula for calculating has been presented as follows:

$$H\ (\%) = \frac{A}{B} \times 100$$

where A is the actual amount of oil obtained after refining (in grams), and B is the total fat content of the seed sample (in grams).

Determination of some physical and chemical properties of oil

Physicochemical parameters of oil, such as density, kinematic viscosity, melting point, refractive index, acid value, peroxide value, iodine value, saponification value, free fatty acid content, moisture content, and aflatoxin content were measured according to CODEX STAN 210:1999 [20], AOCS Ja10-87 (2009) [21], ISO 6321:2002 [22], ISO 6320 [23], AOCS Method Cd 3d-63 (2009) [24], AOCS Method Cd 8-53 (1997) [25], AOCS Method Cd 1-25 (2009) [26], AOCS Method Cd 3-25 (2009) [27], AOCS Method Cd 3d-63 (2009) [24], AOCS Ca 2c-25 (2009) [28], and IS (Irish Standard) EN EN. 15662 (2018) [29], respectively.

Determination of fatty acid composition in Sacha inchi oil

The basic fatty acid composition of Sacha inchi oil was determined by Gas chromatography according to the AOCS Ce 2- 66 [30] and AOAC 996.06 methods [31]. The samples were methylated using a fast method, and the transesterification of neutral lipids was carried out via alkali catalysis in the presence of anhydrous methanol (transmethylation) with NaOH as a reagent. The fatty acid composition was determined using an Agilent Technology 7890A gas chromatograph (Agilent Technologies, California, American) with operating parameters set according to the running method. The chromatographic separation was conducted on a 100 m × 0.25 mm ID, 0.2 mm HP-88 column. A 0.5 µL sample was filtered, and a 0.1 µL sample volume was injected into a capillary gas chromatograph equipped with a split-mode/non-linear injection system and a fused silica capillary column coated with different stationary phases. The temperature was maintained at 100 °C for 5 min, then increased at a rate of 3 °C/min to 205 °C and held at this temperature for 40 min. The total analysis time was 48 min. Fatty acids were identified by comparing the retention times of the standard mixture with those of the fatty acids and by comparison with the spectral library.

Data processing

Experimental results were analyzed by one-way analysis of variance (ANOVA), and significant differences between mean values from triplicate analyses at ($p < 0.05$) were determined by Fisher's least significant difference (LSD) test using Statgraphics Centurion 19-X64 software (StatPoint Technologies, Inc., Warrenton, VA, USA). The values obtained are expressed as mean ± standard deviation (SD).

Results and discussion

Characteristics of Sacha inchi seeds

The results in Table 1 show that the highest total protein content in sample (S1) reached 26.52 ± 0.42 %, and the lowest was sample (S3) at 26.13 ± 0.52 %, which were approximately the same. The highest total fat content was in sample (S3) at 53.78 ± 0.21 %, and the lowest was in sample (S2) at 53.74 ± 0.18 %, also approximately the same. In 2014, these values are consistent with a publication by Niu et al. [32] when they studied Sacha inchi seeds (*Plukenetiia volubilis* L.) originating from South America.

Table 1

Basic nutrient composition and hardness of Sacha inchi seeds

Target	Sacha inchi seeds (%)		
	(S1)	(S2)	(S3)
Grain moisture (%)	6.0^{B} ± 0.50	6.4^{C} ± 0.55	4.5^{A} ± 0.35
Grain hardness (N)	53.5^{B} ±3.2	52.3^{A} ± 3.7	58.4^{C} ± 2.2
Total protein content (%)	26.52 ± 0.42	26.47 ± 0.45	26.13 ± 0.52
Total fat content (%, w/w)	53.74 ± 0.19	53.74 ± 0.18	53.78 ± 0.21
Ash (%, w/w)	4.15 ± 0.08	4.15 ± 0.10	4.18 ± 0.11
Carbohydrate content (%, w/w)	9.59^{B} ± 0.10	9.14^{A} ± 0.07	11.41^{C} ± 0.06

Note: ^{A,B,C} mean that represent statistically significant differences between seed samples (S1), (S2), and (S3) in rows ($p < 0.05$) respectively.

Additionally, there was a significant difference ($p > 0.05$) in the protein content, total fat content, or total ash content among the three seed samples. This finding indicates that even though the Sacha inchi seeds were processed differently, the content of these components did not change.

However, changing the seed treatment method will alter some other components such as moisture and carbohydrate content. The analysis results show that the moisture content of sample (S3) had the lowest value of 4.5 ± 0.35 %, while sample (S2) had the highest value at 6.4 ± 0.55 %. This difference indicates that the alkaline treatment destroys the outer layer of the seed coat, and the proteins on the seed surface are partially denatured, hindering the process of moisture loss on the seed surface.

The results also indicate that the hardness of the samples is different ($p < 0.05$). The roasted seed sample (S3) had the highest hardness, while the sample (S2) treated with 2 % NaOH had the lowest hardness. This decrease in hardness can be explained as follows: in the caustic solution, NaOH molecule dissociates into Na^+ and OH^- ions. The seed coat is mostly polyphenol, and polyphenol molecules contain many •OH radicals that tend to release H^+ to react with OH– ions of the caustic solution to form H_2O molecules. In radicals that have lost H^+, [•O] becomes more flexible and easily reacts with Na^+ to form •ONa radicals, increasing water solubility. Soaking Sacha inchi seeds in alkali removes the thin outer coat of the seeds. This study is similar to the study of Nguy et al. [17], which indicated that the hardness of the seeds is related to the choice of oil extraction method. Therefore, determining the hardness of Sacha inchi seeds will help in choosing a highly effective oil extraction method.

Observation of the longitudinal section (Fig. 2a) shows that the three grain samples (S1, S2, S3) all have a honeycomb structure but exhibit different levels of uniformity. Sample (S1) has the best uniformity, while sample (S3) has the worst. When observing the cross section, it appears quite rough (Fig. 2b), most notably in sample (S3). The edge layer of the cross section of sample (S1) has a stacked fiber structure (Fig. 2c), whereas in sample (S2), this fiber layer is absent, and the outer surface is quite rough compared to sample (S3).

From the image results, it is evident that the different sample treatments significantly affect the grain surface structure, creating areas with uneven structure. The external forces acting on these areas are different, which easily leads to local stresses that break the bonded arrays. These forces help to break down the various grain structures, resulting in increased collection efficiency and improved oil properties.

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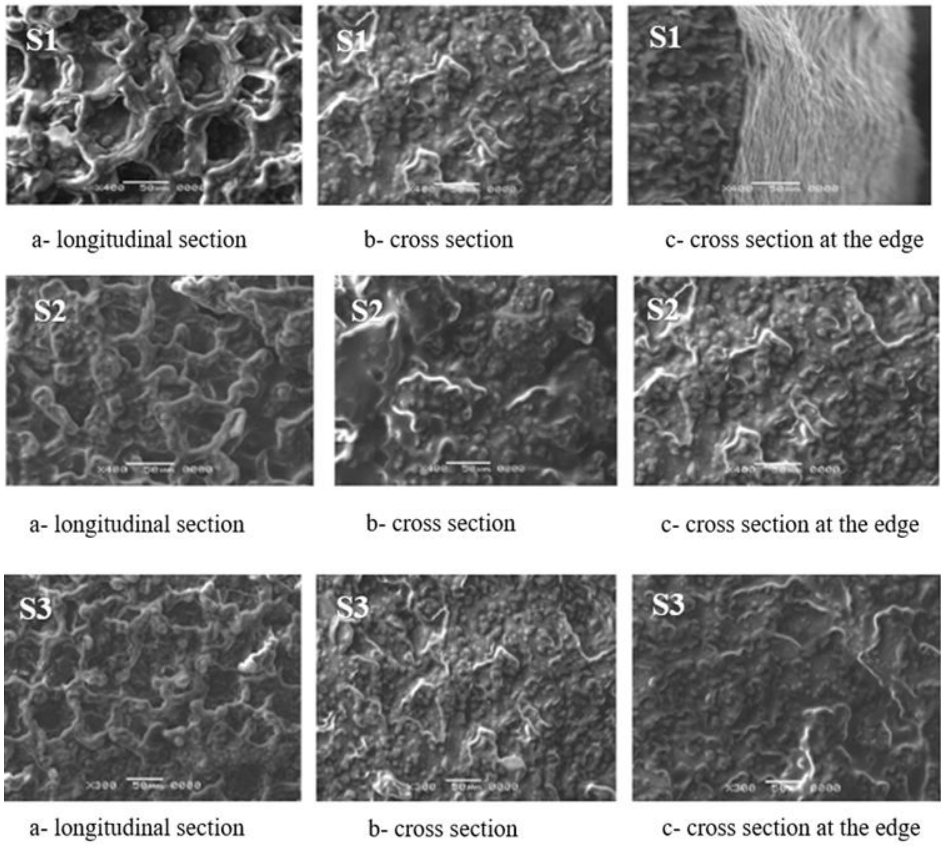

Fig. 2. Cross-sectional structure of Sacha inchi seed sample

Effect of different seed samples on Sacha inchi oil yield

The survey results in Table 2 show that when using sample (S1) at a pressing capacity of 20 kW to press oil by the traditional method (E1), the oil recovery efficiency reaches the highest value compared to samples (S2) and (S3) with 77.35 %. According to the results in Table 3, sample (S2) showed the suitability of cold pressing method (E2) achieving the highest oil recovery efficiency compared to samples (S1) and (S3) at 83.14 %, with a pressing capacity of 19.5 kW. According to the results in Table 4, sample (S3) is the most suitable for hot-pressing method (E3), with the highest oil recovery efficiency compared to samples (S1) and (S2), 78.41 %, at a pressing capacity of 21 kW. Increasing the pressing capacity does not lead to an increase in oil recovery efficiency, indicating that the pressing capacity for each different type of seed is different and that the oil pressing methods should be adjusted accordingly. Additionally, sample (S2) has the lowest hardness, which results in lower pressing capacity. This property is an advantage of the alkali treatment of the sample and the cold pressing method.

Table 2

Effect of different seed samples on yield of Sacha inchi by method (E1)

Pressing capacity (kW)	Oil recovery efficiency by E1 method (%)		
	S1	S2	S3
18.5	$67.45^{Ac} \pm 0.19$	$58.35^{Aa} \pm 0.18$	$62.46^{Ab} \pm 0.17$
19	$70.87^{Bc} \pm 0.22$	$61.57^{Ba} \pm 0.20$	$65.89^{Bb} \pm 0.21$
19.5	$74.54^{Cc} \pm 0.15$	$63.34^{Ca} \pm 0.16$	$69.56^{Cb} \pm 0.17$
20	$77.35^{Dc} \pm 0.22$	$68.15^{Da} \pm 0.22$	$72.37^{Db} \pm 0.21$
20.5	$77.35^{Dc} \pm 0.17$	$68.15^{Da} \pm 0.18$	$72.37^{Db} \pm 0.18$
21	$77.34^{Dc} \pm 0.21$	$68.14^{Da} \pm 0.21$	$72.36^{Db} \pm 0.20$
21.5	$77.33^{Dc} \pm 0.18$	$68.13^{Da} \pm 0.20$	$72.35^{Db} \pm 0.18$
22	$77.35^{Dc} \pm 0.11$	$68.15^{Da} \pm 0.13$	$72.37^{Db} \pm 0.12$

Note: $^{A, B, C, D}$ represent statistically significant differences in columns ($p < 0.05$)
$^{a, b, c}$ represent statistically significant differences across rows ($p < 0.05$).

Table 3

Effect of different seed samples on the yield of Sacha inchi by method (E2)

Pressing capacity (kW)	Oil recovery efficiency by E2 method (%)		
	S1	S2	S3
18.5	57.45^{Aa} ± 0.08	70.31^{Ac} ± 0.09	59.32^{Ab} ± 0.08
19	60.87^{Ba} ± 0.22	73.21^{Bc} ± 0.17	62.43^{Bb} ± 0.21
19.5	64.54^{Ca} ± 0.15	83.14^{Cc} ± 0.15	65.14^{Cb} ± 0.13
20	67.35^{Da} ± 0.11	83.14^{Cc} ± 0.12	68.51^{Db} ± 0.10
20.5	67.35^{Da} ± 0.11	83.13^{Cc} ± 0.11	68.15^{Db} ± 0.09
21	67.34^{Da} ± 0.10	83.12^{Cc} ± 0.08	70.41^{Eb} ± 0.11
21.5	67.33^{Da} ± 0.11	83.14^{Cc} ± 0.09	70.41^{Eb} ± 0.10
22	67.35^{Da} ± 0.10	83.14^{Cc} ± 0.08	70.41^{Eb} ± 0.07

Note: $^{A, B, C, D, E}$ represent statistically significant differences in columns ($p < 0.05$)
$^{a, b, c}$ represent statistically significant differences across rows ($p < 0.05$)

In addition, oil extraction efficiency depends on certain characteristics of the seeds, such as their internal structure and hardness. These characteristics determine the change in pressing capacity for each method. Based on the results above, we chose the cold pressing method (E2) with seed sample (S2) at a pressing capacity of 19.5 kW, then the hot pressing method (E3) with seed sample (S3) at a pressing capacity of 21 kW, and finally the traditional pressing method (E1) with seed sample (S1) at a pressing capacity of 20 kW for the following experiments.

Table 4

Effect of different seed samples on yield of Sacha inchi by method (E3)

Pressing capacity (KW)	Oil recovery efficiency by E3 method (%)		
	S1	S2	S3
18.5	61.45^{Ab} ± 0.10	59.35^{Aa} ± 0.09	67.32^{Ac} ± 0.08
19	64.87^{Bb} ± 0.22	62.57^{Ba} ± 0.20	70.43^{Bc} ± 0.21
19.5	69.54^{Cb} ± 0.15	64.34^{Ca} ± 0.16	73.14^{Cc} ± 0.13
20	71.35^{Db} ± 0.13	67.15^{Da} ± 0.12	75.51^{Dc} ± 0.10
20.5	71.35^{Db} ± 0.10	67.15^{Da} ± 0.12	76.15^{Ec} ± 0.09
21	71.34^{Db} ± 0.21	67.14^{Da} ± 0.21	78.41^{Fc} ± 0.20
21.5	71.33^{Db} ± 0.18	67.13^{Da} ± 0.19	78.41^{Fc} ± 0.17
22	71.35^{Db} ± 0.11	67.15^{Da} ± 0.13	78.41^{Fc} ± 0.15

Note: $^{A, B, C, D, E, F}$ represent statistically significant differences in columns ($p < 0.05$)
$^{a, b, c}$ represent statistically significant differences across rows ($p < 0.05$)

Effect of screw speed on Sacha inchi oil recovery efficiency

The results in Table 5 show that when the screw speed increases, the efficiency changes accordingly. However, this increase stops at the optimal screw speed value at which the oil recovery efficiency is the highest. Specifically, oil recovery by method (E2) had a pressing capacity of 19.5 kW at a screw speed of 40 rpm, achieving the highest efficiency level of 83.14 %. For method (E3), the pressing capacity was 21 kW with a screw speed of 44 rpm, achieving the highest efficiency of 79.37 %. Lastly, method (E1) had a pressing capacity of 20 kW with a screw speed of 42 rpm, achieving the highest efficiency of 78.35 %.

Table 5

Effect of screw speed on Sacha inchi oil extraction efficiency by different methods

Screw speed (rpm)	Oil recovery efficiency (%)		
	E1	E2	E3
32	71.47^{Aa} ± 0.14	74.11^{Ab} ± 0.15	72.03^{Aa} ± 0.10
34	72.07^{Ba} ± 0.20	75.23^{Bb} ± 0.12	72.24^{Aa} ± 0.21
36	73.14^{Ca} ± 0.15	76.31^{Cb} ± 0.08	73.29^{Ba} ± 0.18
38	75.78^{Da} ± 0.05	77.48^{Db} ± 0.10	76.39^{Ca} ± 0.25
40	77.35^{Ea} ± 0.25	83.14^{Eb} ± 0.22	78.41^{Da} ± 0.13
42	78.35^{Fa} ± 0.10	83.13^{Eb} ± 0.15	78.68^{Ea} ± 0.10
44	78.32^{Fa} ± 0.18	83.14^{Eb} ± 0.13	79.37^{Fa} ± 0.08
46	78.35^{Fa} ± 0.02	83.11^{Eb} ± 0.05	79.36^{Fa} ± 0.06

Note: $^{A, B, C, D, E, F}$ represent statistically significant differences in columns ($p < 0.05$)
$^{a, b, c}$ represent statistically significant differences across rows ($p < 0.05$)

For each different pressing method, when increasing screw speed, the oil recovery efficiency does not increase significantly and even tends to decrease due to high resistance of the pulp and slow pulp drainage, causing blockage [33]. Additionally, the results show that the cold

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pressing method (E2) gives higher efficiency than the hot pressing and traditional methods. This finding is consistent with the study of Nguy et al. [17], who extracted oil from areca nut seeds using the same method. The cold pressing method yields more oil, and the pressing force is lower compared to other methods due to lower hardness of the seeds (S2) compared to other types of seeds Table 1. The uneven structure of the seeds leads to the appearance of uneven stresses when subjected to an external force, making it easier to break the seeds (S1) and (S3).

Properties of Sacha inchi oil

Values such as refractive index (40 °C), melting temperature, and oil density (25 °C) were not significantly different ($p > 0.05$) between pressing methods in Table 6. Meanwhile, kinematic viscosity (25 °C) varied with the oil collection method; hot pressed oil viscosity (E3) was higher than the other two methods because an increased screw temperature leads to the thermal denaturation and degradation of other components in the seeds, such as protein. At high temperatures, additional components with properties similar to fat, such as wax, gum, and phosphatide, also liquefy and mix into the oil, increasing its viscosity [34].

Table 6

Physical properties of Sacha inchi oil obtained from different methods

Physical indicators	Oil pressing method		
	E1	E2	E3
Oil moisture (%)	$0.003^{B} \pm 0.0001$	$0.0032^{B} \pm 0.0003$	$0.0025^{A} \pm 0.0003$
Kinematic viscosity (cP)	$84.3^{A} \pm 0.52$	$84.2^{A} \pm 0.45$	$87^{B} \pm 0.20$
Refractive index	1.4778 ± 0.0152	1.4779 ± 0.0162	1.4781 ± 0.0148
Melting temperature (°C)	51.5 ± 0.5	51.5 ± 0.2	51.7 ± 0.6
Specific gravity of oil (g/L)	0.9188 ± 0.0150	0.9190 ± 0.0210	0.9187 ± 0.0180

Note : $^{A, B}$ represent statistically significant differences across rows ($p < 0.05$).

In addition, Sachi inchi oil obtained from different pressing methods had refractive index and specific gravity values as follows: 1.4778 and 0.9188 g/L (E1); 1.4779 and 0.9190 g/L (E2); and 1.4781 and 0.9187 g/L (E3), respectively. These values were not affected by the pressing method. Compared with other popular oils, such as soybean oil (Glycine max (L.) Merr) with values of 1.4773 and 0.9170 g/L, olive oil (Olea europaea) with values of 1.4706 and 0.9089 g/L, and sesame seed oil (Sesamum indicum L.) with values of 1.4739 and 0.9172 g/L, there were no significant difference [35].

Table 7

Summary table of fatty acid composition of Sacha inchi oil obtained by different methods

Group	Composition of characteristic fatty acids	Sacha inchi oil sample (%)		
		E1	E2	E3
SFA	Palmitic acid (C16:0)	3.4703	3.4057	3.4703
	Margaric acid (C17:0)	0.0818	0.0790	0.0819
	Stearic acid (C18:0)	2.2943	2.2605	2.2942
	Arachidic acid (C20:0)	0.2963	0.2970	0.2963
	Heneicosylic acid (C21:0)	0.0736	-	0.0736
MUFA	Palmitoleic acid (C16:1)	0.0562	-	0.0562
	Oleic acid (C18:1-n9) – (omega-9)	7.6719	7.7634	7.6719
	Cis-11-eicosenoic acid (C20:1-n9)	0.3029	0.2432	0.3029
PUFA	Polyunsaturated fatty acids (C18:2 -trans)	0.0705	0.0652	0.0705
	Linoleic acid (C18:2-n6) – (omega-6)	36.4149	35.7947	36.4149
	Linolenic acid (C18:3-n3) – (omega-3)	49.2675	50.0914	49.2675
Toxin	Total aflatoxin (B1B2G1G2), (μg/kg)		-	

The results of Table 7 indicate that Sacha inchi oil contains many types of fatty acids. The amount of saturated fatty acids (SFA) was 6.22 % in oil extraction by methods (E1) and (E3) and 6.04% by method (E2). This result is consistent with the fact that method (E2) has a lower oil outlet temperature compared to methods (E1) and (E3), making it more difficult to extract some large molecular fatty acids. The components of polyunsaturated fatty acids, including MUFA and PUFA, were almost the same. Notably, the content of omega-3, omega-6, and omega-9 components is quite high, especially omega-3 and omega-6, which belong to the group of unsaturated fatty acids. Polyunsaturated fatty acids are common fatty acids that humans need to absorb from certain foods to help the body synthesize prostaglandins, which are essential for easy blood circulation and preventing cardiovascular diseases [36].

The analysis of Table 7 also shows that the omega-3 content varied depemding on the pressing method. The omega-3 content was 49.27 % for method (E1), 50.09 % for method (E2), and 40.27 % for method (E3). The omega-6 content was 36.41% for method (E1), 35.79 % for method (E2), and 36.41 % for method (E3). The omega-9 content was 7.67 % for method (E1), 7.76% for method (E2), and 7.67 % for method (E3). Method (E2) yielded higher omega-3 and omega-9 content, but the omega-6 content was lower compared to methods (E1) and (E3). The previous research results of Niu et al. [32] and Norhazlindah et al. [37] showed similar findings, with omega-3 and omega-6 content reaching 47–51 % and 34–37 %, respectively. This result is similar to the oil extraction by our pressing method (E2). Thus, the pressing method has a significant effect on the omega 3-6-9 composition.

In addition, the analysis of results of Sacha inchi oil did not detect the toxin aflatoxin, which is known to be one of the most powerful causes of liver cancer. Oral adsorption of aflatoxin with a total amount of 2.5 mg in 90 days can lead to liver cancer after more than 1 year [38]. Therefore, Sacha inchi oil extracted by the above methods does not have any effect on the liver with prolonged use.

Table 8

Physicochemical parameters of Sacha inchi oil obtained by different methods

Physical and chemical index	Unit	Sacha inchi oil obtained from different methods		
		E1	E2	E3
Free fatty acids like oleic acid	%FFA	$0.550^B \pm 0.01$	$0.503^A \pm 0.012$	$0.620^C \pm 0.01$
Acid value (AV)	mg KOH/g	$1.197^C \pm 0.369$	0.813A ± 0.045	1.393B ± 0.028
Peroxide value (PV)	meq O_2 /kg	1.203A ± 0.006	1.187A ± 0.006	1.383B ± 0.012
Iodine value (IV)	g I_2/100g	102.57B ± 0.006	103.59A ± 0.014	102.49B ± 0.012
Saponification value (SV)	mg KOH/g	182.12B ± 0.03	181.17A ± 0.12	182.14C ± 0.1

Note: ^{A,B,C} represent statistically significant differences across rows ($p < 0.05$).

The results of Table 8 show that the lowest AV was in the oil obtained from the pressing method (E2), which proves that the oil pressing method affects the AV index of the oil. All these values are lower than the results of Muangrat et al. [39], who reported the acid value from 1.94 to 5.9 mg KOH/g of the same oil. The peroxide value (PV) for the three methods were 1.203 (E1), 1.187 (E2), and 1.383 (E3), which was also lower than the study of Muangrat et al. [39], where values ranging from 1.94 to 2.27 meq O_2/kg were obtained. Notably, the oil obtained by method (E2) is less susceptible to oxidation than by the other two pressing methods because pressing methods (E1) and (E3) generate heat, resulting in higher output temperatures of 63 °C and 84 °C, respectively, which may lead to oxidation reactions, especially at the double or triple bond positions of unsaturated fatty acids, thereby increasing the peroxide index.

The IV index helps classify oils according to their level of unsaturation: dry oils with IV > 150 g I_2/100 g (including linseed and tung oils); semi-dry oils with IV between 125–150 g I_2/100g (including soybean oil and sunflower oil); and non-drying oils with IV < 125 g I_2/100g (including rapeseed oil, olive oil, and coconut oil) [40]. In this study, Sacha inchi oil had an IV of 102.49 g I_2/100g (E3), 102.57 g I_2/100g (E1), and 103.59 g I_2/100g (E2), all classifying them as non-drying oils. Our research results are aligned with those of Muangrat et al. [39], who reported IV between 102.66 – 104.05 g I_2/100g for Sacha inchi oil.

The SV index of the oil obtained by method (E2) was 181.17 mg KOH/g, which is lower than that of method (E1) at 182.12 and method (E3) at 182.14 mg KOH/g. This research result is lower than the reported SV by Muangrat et al. [39], which ranged from 182.18 to 195.11 mg KOH/g. This shows that Sacha inchi oil contains many long-chain fatty acids, from C16 and above in Table 7.

In general, the oil obtained by method (E2) has better quality because the free fatty acid content, acid value, and peroxide value are lower than those obtained from methods (E1) and (E3). Additionally, the results of the physicochemical properties of Sachi inchi oil in this study are quite similar to those of Muangrat et al. [39] for saponification value but superior to them for acid, peroxide, and iodine values. This superiority entirely depends on the pressing method, pretreatment, and raw material source.

Conclusion

The oil pressing efficiency of the three methods was significantly affected by the pressing capacity and screw speed. In particular, the cold pressing method (E2), with a capacity of 19.5 kW and a screw speed of 40 rpm, was more effective than

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the traditional pressing methods (E1) and hot pressing (E3), providing the highest recovery efficiency of 83.14 %. The quality indices such as AV, PV, IV, and SV were 0.813 mg KOH/g, 1.187 meq O_2/kg, 103.59 g I_2/100g, and 181.17 mg KOH/g, respectively. Additionally, all three methods yielded a high omega 3-6-9 ratio, making the oil suitable foruse in the food, pharmaceutical, and cosmetic industries.

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