



## Physico-Chemical Properties of Sacha Inchi (*Plukenetia volubilis* L.) Seed Oil from Vietnam

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Sacha inchi (*Plukenetia volubilis* L.) seed oil was studied for physico-chemical characteristics and chemical composition. Through gas chromatography-flame ionization (GC-FID) process, the fatty acid composition in the oil was analyzed, revealing that the oil is rich in linoleic acid (42.62 %), linolenic acid (36.32 %) and oleic acid (11.64 %). The tocopherol level in the oil was also high ( $7.7 \pm 0.005$  mg/Kg), revealed by high-performance liquid chromatography/ultraviolet-visible detector (HPLC/UV-VIS). The physico-chemical properties of the oil were also examined, including viscosity (88-92 cP), acid value ( $2.05 \pm 0.005$  mg KOH/g), saponification content ( $183.5 \pm 1.45$  mg KOH/g) and iodine value ( $192.4 \pm 1.55$  g I<sub>2</sub>/100 g). The results also indicated that sacha inchi is a health beneficial oil due to the high contents of essential fatty acids ( $\omega$ -3,  $\omega$ -6 and  $\omega$ -9).

**Keywords:** Physico-chemical properties, Fatty acid composition, Sacha inchi oil, *Plukenetia volubilis* L.

### INTRODUCTION

Sacha inchi (*Plukenetia volubilis* L.) belonging to the Euphorbiaceae family is also known as the Inca nut or sacha peanut [1]. The local trees has adapted to elevated locations of between 200 and 1500 m above sea level [2]. Sacha inchi is a plant with enormous commercial value and is widely cultivated in South and Central America, as well as in Vietnam, Thailand and China. The sacha inchi fruit is star-shaped with diameter ranging from 2 to 4 cm. The fruit bears a unique shape with expanded middle part and squashed star edges. When the fruit ripens, the colour of sacha inchi seeds changes from green to blackish brown [3] and sacha inchi oil exhibited darker colour. Sacha inchi seeds are rich in proteins (20-25 %) including fundamental amino acids such as tryptophan, lipids such as  $\omega$ -3,  $\omega$ -6 and  $\omega$ -9, minerals and vitamin E. In addition, sacha inchi seeds exhibited significantly higher lipid level (97.2 %) [4] in comparison with that in chia seeds (26.7-35.0 %) [5] and soybeans (16.5-17.5 %) [6]. In the sacha inchi seeds, the level of monounsaturated and polyunsaturated fatty acids varies from 8.5-13.4 % and 78-85 %, respectively [1,4]. The Amazons of Peru usually prepare different meals using oil obtained from

seeds. Sacha inchi oil is one of the vegetable oils having beneficial physico-chemical features and good visual properties including taste and flavour. Also, due to the high level of fatty acids and a favourable  $\omega$ -6/ $\omega$ -3 rate, sacha inchi oil plays a significant role in the production of functional food. Especially, the  $\alpha$ -linolenic acid can be transformed into docosahexaenoic (DHA) acids and eicosapentaenoic (EPA) serving as alternatives to fish oil with the absence of the fish odour [7].

Although sacha inchi is attracting scientific attention as a promising alternative source for different useful components. To our best of knowledge, little is explored about the composition of Vietnamese sacha inchi oil. Previous studies reported that sacha inchi oil is abundant in unsaturated fatty acids, making up nearly 90 % of the oil. In particular, levels of essential fatty acids discovered in another study including  $\alpha$ -linolenic,  $\alpha$ -linoleic acid and oleic acid were reported to constitute 82 % of the entire oil content [4]. Sacha inchi oil is also rich in  $\beta$ -carotene and tocopherols [8]. Another beneficial feature of the sacha inchi oil is the proportion of  $\omega$ -6/ $\omega$ -3. To be specific, the  $\omega$ -6/ $\omega$ -3 proportion in sacha inchi oil varied between 0.80 and 1.10 [8] which closely approximates equal proportions recognized as health beneficial [9]. Individually,  $\omega$ -3 and  $\omega$ -6

could also prevent disorders such as obesity, cardiovascular syndrome, heart disease and cancer [10]. Such richness in essential acid content has made sacha inchi oil applicable for manufacture of food supplements. Other applications of sacha inchi oil could range from skin treatment, including treatment of insect bites, infection and skin hardness [11], to in cosmetic products to prevent skin tightening and to kill bacteria [12].

In this study, the chemical composition and physico-chemical characteristics of the sacha inchi seed oil (cultivated in Vietnam) was evaluated. This fundamental characterization will establish the foundation for the future development of sacha inchi oil.

## EXPERIMENTAL

Sacha inchi oil was extracted from cleaned, dried, dehulled and crushed seeds of *P. volubilis* by screw pressing extraction method using a mechanical oil presser model Anyang 6YL-68 (Henan, China). The extracted oil was then filtered and dried completely. The extraction oil yield was 47.5 %. The extracted oil was transferred into dark bottles and stored at -20 °C for further use.

**Physico-chemical characteristics:** Various physico-chemical characteristics of the sacha inchi oil were examined including protein content (AOAC 945.01-Kjeldahl method) [13]; total lipid content (AOAC method (920.39)) [13]; viscosity at 20 °C (Brookfield RVDV-E machine, USA); refractive index (AOCS method); density; FFA value (ISO 660:1996); acid value (ISO 660:1996); saponification value (ISO 3657:2002); moisture (ISO 662:1998); peroxide value; iodine value; unsaponification value (ISO 3596:2000). These characterizations were performed in triplicate.

**Fatty acid composition:** The fatty acid was analyzed by using a flame ionization detector (GC-FID). First, the fatty acids were converted to fatty acid methyl esters (FAMES) by incubating a mixture containing 100 mg sacha inchi oil and 2 mL of sodium methylate in methanol for 15 min at 100 °C. Following that, 1 mL of boron trifluoride-methanol (20 % BF<sub>3</sub>) was added and the mixture was heated at 100 °C for another 15 min. Then 1 mL of water and 1 mL of *n*-hexane were introduced into the mixture, followed by centrifugation. The resulted FAMES was transferred into a vial and kept at 4 °C. The study was carried by an Agilent-6820 gas chromatograph. Each unit was analyzed in triplicate. Data examination was carried out by using Agilent Cerity method.

**Statistical analysis:** All studies were completed in triplicate. The result of the different parameters was expressed as mean ± standard deviation (SD). The study was examined by Statgraphics Centurion XV software.

## RESULTS AND DISCUSSION

**Physico-chemical characteristics:** Physico-chemical characteristics of sacha inchi oil are summarized in Table-1. Sacha inchi oil had the slightly higher density (0.90-0.921 g/cm<sup>3</sup> at 25 °C) than that of soybean and corn oil [14]. The refractive index of sacha inchi oil (1.5) was also slightly comparable to that of soybean (1.473), sunflower (1.470) and olive (1.467) [8].

TABLE-1  
PHYSICO-CHEMICAL CHARACTERIZATION  
OF SACHA INCHI OIL

Parameter	Sachi oil	Unit
Protein content	0	%
Viscosity at 20 °C	88 ± 2.55	cP
Refractive index	1.525 ± 0.002	n <sup>40</sup>
FFA value	3.0	%
Acid value	2.05 ± 0.005	mg KOH/g oil
Saponification value	183.5 ± 1.45	mg KOH/g oil
Moisture	3.5 ± 0.55	%
Iodine value	192.4 ± 1.55	g I <sub>2</sub> /100 g oil
Peroxide value	1.78 ± 0.068	meqO <sub>2</sub> /kg oil
Unsaponification matter	5.5 ± 0.005	g/kg
Vitamin E	7.7 ± 0.005	mg/Kg

Chemical properties of the sacha inchi oil include oxidative stability and fatty acid profile. Oxidative level is reflected by iodine value, acid value and saponification value. Viscosity at 20 °C and iodine value of sacha inchi oil were 88-92 cP and 192.4 ± 1.55 g I<sub>2</sub>/100 g oil, respectively. The high iodine content of the sacha inchi oil (192.4 ± 1.55 g I<sub>2</sub>/100 g oil) suggested that the oil chains are slightly rich in unsaturated fatty acids [15]. The iodine level of sacha inchi oil was significantly higher than that of sunflower (127 g I<sub>2</sub>/100 g), soybean (132 g I<sub>2</sub>/100 g) and corn (116 g I<sub>2</sub>/100 g) [16]. The acid value of sacha inchi oil is 2.05 ± 0.005 mg KOH/g oil, lower than that of olive oil (about 6.0 mg KOH/g oil). Saponification value of sacha inchi oil, at 183.5 ± 1.45 mg KOH/g, was similar to that of the olive oil of 185 mg KOH/g. Tocopherols (vitamin E) are lipid-soluble composites that are broadly present in vegetable oils. Tocopherols have multiple vital purposes in the human body and are acknowledged as a powerful substance that could slow down the oxidation and antioxidative process [17]. Total tocopherols in sacha inchi oil were 7.7 ± 0.005 mg/Kg. The total γ-tocopherol and tocopherol value constituted in sacha inchi seeds are higher than peanuts, cashews and hazelnuts [1]. The refractive index, FFA value, moisture, unsaponification matter of sacha inchi oil were 1.525 ± 0.002 n<sup>40</sup>, 3.0 %, 3.5 % and 5.5 ± 0.005 g/kg, respectively.

**Fatty acid composition:** In order to evaluate nutritional property and stability of fats and oils, we analyze the composition of the sacha inchi oil and compare that with compositions of other vegetable oils from previous studies. The fatty acid profile distribution of sacha inchi oil was presented in Table-2. The results revealed that dominant saturated fatty acids recognized in sacha inchi oil were stearic acid (3.8 %), palmitic acid (4.9 %) and arachidic acid (0.12 %). The total of saturated fatty acid composition of sacha inchi oil (10 %) was significantly lower than those in commonly used vegetable oils such as coconut oil (80 %) and olive oil (15 %). The content of monounsaturated fatty acid compositions in sacha inchi oil accounted for 12 % of total content and is largely dominated by oleic acid whose content reached 11.64 % of total content, higher than that found in coconut oil (7.5 %) and much lower than in olive oil (70 %). The polyunsaturated fatty acid in sacha inchi oil was 78 %, significantly higher than that in commonly used vegetable oils such as coconut oil (8 %) and olive oil (15 %). To be specific, the major essential polyunsaturated fatty acids found in sacha inchi oil are linoleic acid (42.62 %) and

TABLE-2  
COMPOSITION OF FATTY ACIDS IN SACHA INCHI OIL

Fatty acid composition	Sachi oil
Saturated fatty acid (%)	
Myristic acid (C14:0)	0.02
Palmitic acid (C16:0)	4.80
Heptadecanoic acid (C17:0)	0.11
Stearic acid (C18:0)	3.70
Arachidic acid (C20:0)	0.12
Docosanoic acid (C22:0)	0.03
Lignoceric acid (C24:0)	0.02
Monounsaturated fatty acid (%)	
Palmitoleic acid (C16:1)	0.06
Oleic acid (C18:1)	11.64
Eicosenoic acid (C20:1)	0.29
Erucic acid (C22:1)	0.02
Polyunsaturated fatty acid (%)	
Linoleic acid (C18:2)	42.62
Linolenic acid (C18:3)	36.32
Eicosapentaenoic acid (EPA) (C20:5)	0.02
Docosahexaenoic acid (DHA) (C20:6)	Not detected
	MDL = 0.01

linolenic acid (36.32 %). These results are contrasted with the composition found in olive oil, which is characterized by high content of monounsaturated fatty acids and balanced content of polyunsaturated fatty acids and were consistent with results of Fares *et al.* [15] where content of linoleic acid in sachu inchi oil was found to overwhelm those in olive oil. The study also found that oleic acid in the sachu inchi oil only made up 11.6 % of total fatty acids, which is consistent with present results and is significantly lower than the value in olive oil (> 70 % of total fatty acids) [18,19]. In comparison with the results of Wedyan *et al.* [17] who profiled and compared chemical compositions of olive pomace harvested in different locations in Jordan, sachu inchi oil showed higher content in linoleic and linolenic acid and lower content in oleic acid and palmitic acid.

Among reported constituents, linoleic acid (18:2) is vital in human diet, playing an important function in the inhibition of vascular disorders and of heart attack [20]. Comparing with sunflower oil, the amount of linoleic acid in sachu inchi was little. Naz *et al.* [18] showed that the content of linoleic acid (18:2) in deodorizer distillates of sunflower oil (DDSFO) was higher than that in sachu inchi oil (53.26 % versus 42.62 %). The same study also indicated that DDSFO exceeded sachu inchi oil in terms of palmitic acid and oleic acid contents (9.62 % versus 4.80 % and 4.80 % versus 30.12 %) but linolenic acid in DDSFO was much lower than in sachu inchi oil (0.61 % versus 36.32 %). In another comparative study, sunflower oil in Mediterranean was found to contain MUFAs with higher content and PUFAs with lower content than in sachu inchi oil (28.30 % versus 12.01 % and 62.40 % versus 78.96 % respectively) [21]. In general, the fatty acid composition in sachu inchi oil is characterized by high proportion of PUFAs, in which C18:2 and C18:3 are predominant components.

In comparison with linseed oil, sachu inchi oil is constituted by lower concentrations of oleic acid (18.51 % versus 53.21 %) and linolenic acid (11.64 % versus 36.32 %) and a higher concentration of linoleic acid (42.62 % versus 17.25 %) [22]. Although linseed is a major source of fatty acids relating to  $\omega$ -3 including  $\alpha$ -linolenic acid and linoleic acid [23], both

of these acids only attained approximately 73 % of total linseed oil content which were lower than that in sachu inchi oil (about 78.94 %). In a comparative study of linseed oil and sachu inchi oil, it was found that composition of linseed oil was similar to that of sachu inchi oil in terms of n-3 linolenic acyl and that sachu inchi oil included a large proportion of n-6 linoleic acyl groups.

Regarding poly-unsaturated fatty acid composition, Socrates and Marleny [24] compared and demonstrated that olive oil contained saturated fatty acids in large quantity, at 24 %, followed by corn oil and sunflower oil, at 8 %, approximating the proportion of 8.8 % found in Vietnamese sachu inchi oil. These levels are larger than those presented by other sachu inchi oil studies. Stroher *et al.* [23] suggested that due to the incentive to reduce *trans*-fatty acids of the food industry, daily consumption of saturated fatty acids has been growing, causing imbalance in fatty acid intake. This promotes sachu inchi oil, having the low content of saturated fatty acids, as a preferred option for daily diet.

In comparison with sachu inchi oil from Xishuangbanna (China), Vietnamese sachu inchi oil exhibited higher contents of oleic acid (11.64 % versus 9.29 %) and linoleic acid (42.62 % versus 39.57 %). However, linolenic acid (C18:3) of the Vietnamese sachu inchi oil was lower than that in Chinese sachu inchi oil (36.32 % versus 43.52 %). The portion of stearic acid and palmitic acid in sachu inchi oil from China were equivalent to those of the sachu inchi oil from Vietnam. Chirinos *et al.* [4] revealed that nearly 90 % of the fatty acids in sachu inchi oil is composed of unsaturated fatty acid methyl esters, in which L (C18:2,  $\omega$ 6) and  $\alpha$ -Ln (C18:3,  $\omega$ 3) acids were highest in proportions, at approximately 36 and 50 %, respectively.

In comparison with Peruvian sachu inchi oils, which were characterized by high contents of unsaturated fatty acids (94 %) and linolenic acid ( $\omega$ -3) (55 %) [4,25], Vietnamese sachu inchi oil demonstrated a higher content of linoleic acid (C18:2) (42.62 % versus 34.08 %) and a lower content of linolenic acid (C18:3) (34.08 % versus 42.62 %). This suggests that the Vietnamese sachu inchi oil can be used as a natural substance in nutraceutical applications. Total content of linolenic and linoleic acid in Vietnamese sachu inchi oil was approximately 79 % (36.32 % linolenic acid and 42.62 % of linoleic acid), which is slightly higher than that in Guillén *et al.* [21] (42.62 and 34 %, respectively) and is consistent with data on Chinese and Peruvian sachu inchi oil in terms of prevalence of these two acids. The fatty acid level of sachu inchi oil detected in this research is in accordance with those described by other works [4,6,20,26]. Even though sachu inchi oil is frequently promoted as a nutritional addition due to the large content of healthy polyunsaturated fatty acids, particularly  $\omega$ -3 and  $\omega$ -6, high  $\omega$ -6/ $\omega$ -3 ratio, caused by excessive consumption of  $\omega$ -6, has been shown to increase the risk of pathogenesis of many diseases [20]. Hence,  $\omega$ -3 fatty acid consumption is also necessary for human health [27]. Through present results, it is observed that the  $\omega$ -3,  $\omega$ -6 and  $\omega$ -9 fatty acid in Vietnamese sachu inchi oils were relatively balanced in ratio, showing the contents of 36.34, 42.62 and 11.95 %, respectively (Table-3).

## Conclusion

Seeds of sachu inchi was characterized by their extracted oil. The oil is mainly composed of neutral lipids, carrying major

TABLE-3  
COMPOSITION OF THREE OMEGA  
FATTY ACIDS OF SACHA INCHI OIL

Fatty acid	%
Omega 3 ( $\omega$ -3)	
Linolenic acid (ALA) (C18:3)	36.32
Eicosapentaenoic acid (EPA) (C20:5)	0.02
Omega 6 ( $\omega$ -6)	
Linoleic acid (LA) (C18:2)	42.62
Omega 9 ( $\omega$ -9)	
Oleic acid (C18:1)	11.64
Eicosenoic acid (C20:1)	0.29
Erucic acid (C22:1)	0.02

amounts of essential fatty acids such as  $\omega$ -3,  $\omega$ -6 and  $\omega$ -9, which reached 36.34, 42.62 and 11.95 % of total fatty acids, respectively. This makes sacha inchi seeds suitable ingredients for production of medicinal products such as tablets of vital fatty acids. In addition, the tocopherol content in the oil was also high ( $7.7 \pm 0.005$  mg/Kg). The physico-chemical properties of the oil were also determined, including viscosity (88-92 cP), acid index ( $2.05 \pm 0.005$  mg KOH/g), iodine index ( $192.4 \pm 1.55$  g I<sub>2</sub>/100 g) and saponification number ( $183.5 \pm 1.45$  mg KOH/g). Due to the high content of linoleic acid, it is suggested that sacha inchi oil is a valuable source of  $\omega$ -6 fatty acids. Additionally, sacha inchi oil could also serve as an alternative source for  $\omega$ -3 polyunsaturated fatty acids, assisting the balancing of  $\omega$ -3/ $\omega$ -6 fatty acid consumption. Sacha inchi oil also contain various phytosterols (stigmasterol and  $\beta$ -sitos-terol), tocopherols ( $\gamma$ - and  $\delta$ -tocopherols) and total phenolic composites. The presence of total phenolic composites and tocopherols might emphasize the role of sacha inchi oil as an antioxidant and as an important ingredients to facilitate the oxidative balance.

### CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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