Nutrition Composition of Sacha Inchi (*Plukenetia Volubilis L.*)

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Abstract **- We investigated the macronutrient, selected mineral and fatty acid composition of Sacha inchi (SI) (*Plukenetia volubilis* L.) seeds harvested from the grounds of Crops for the Future, Malaysia. Macronutrient analysis was carried out on both fresh and roasted (160°C for 6 mins) SI seeds. Both fresh and roasted seeds were rich in crude fat (56.2%, 49.8%) and crude protein (23.8%, 25.0%) respectively. Fatty acid and some selected minerals analyses were carried out for the roasted SI seeds. Fatty acid analysis showed that the 18.6% of saturated fat was mainly made up of palmitic (4.64%) and stearic (12.9%) acids. The polyunsaturated fat amounted to 81.3% and was contributed mainly by linolenic (35.9%) and linoleic (44.8%) acids. The main minerals found were potassium (5179 mg/kg), phosphorus (3868 mg/kg), magnesium (3439 mg/kg) and calcium (1142 mg/kg). Comparison with other crops highlights SI's potential as a plant source of omega -3 and omega-6 fatty acids, its macronutrient and mineral contents.**

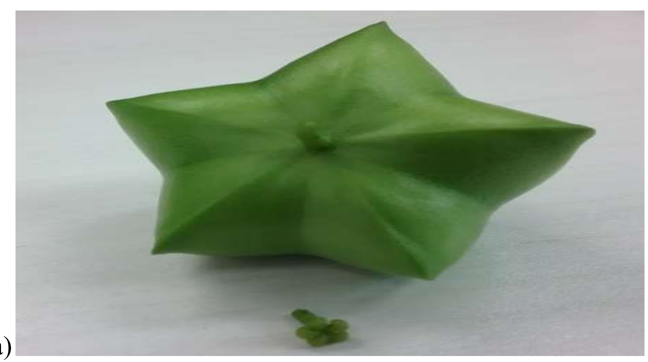
Key words: **Sacha inchi, Nutritional profile, Underutilised crop, Proximate composition, Fatty acids, Mineral, *Plukenetia volubilis***

I. INTRODUCTION

There are approximately 30,000 known plant species documented for human use of which 7000 plant species have been identified as food sources with less than 20 species providing most of the world's food and only three crops (rice, wheat and maize) accounting for ca. 60% of the calories consumed [1]. A diverse diet of plants and plant products such as fruits, vegetables and nuts are regarded as beneficial to human health [2]. Many currently underutilised crops or orphan crops have the potential to improve the nutritional quality of diets [3],[4]. These underutilised crops can also provide valuable traits for the purpose of improving agricultural diversity, climate change mitigation, land degradation and reducing external inputs that contribute to the carbon footprint of agriculture [1],[4],[5].

Sacha inchi (SI) (*Plukenetia volubilis* L.) is native to the Amazon rainforest of Peru, Ecuador, Brazil and other parts of South America [6],[7],[8]. In recent years, the nut plant has spread to other countries [5],[7],[9]. SI has been established in parts of South East Asia notably in Thailand, Vietnam and Malaysia [10],[11]. The seed has many common names including 'Inca Inchi', 'Inca Peanut', 'Mountain Peanut', 'Sacha Peanut', 'Supua', 'Ticazo', 'Sacha Maní', 'Maní del Inca', 'Maní Del Monte' or 'Maní Jibaro' [7],[8],[12],[13],[14].

Different parts of the plants have different chemical constituents, some with high nutritional values. It is a perennial climbing plant with star shaped fruit containing lenticular seeds in fours, fives or sixes. The fruit starts out green and turns brownish black when ripe. Each lenticule contains one white cotyledon with a hard, dark coloured nutlike seed coat (Fig. 1). SI seeds have been reported to contain a high content of omega 3, 6 and 9 essential fatty acids which are not common in other vegetable oils [10]. Studies show SI can contain omega-3 linolenic acid (45%-53%), omega-6 linoleic acid (34-39%) and non-essential omega-9 (6%-10%) [6], [8], [11], [12], [13], [14], [15]. It is also noted for its highly digestible protein (24%-33%) rich with essential amino acids [6],[12],[14],[16]. The heart-shaped leaves are also regarded as nutritious and constitute a source of terpenoids, saponins, and phenolic compounds (flavonoids). They are edible when cooked [5],[11],[13],[17].

a) 

b) 

c) d) e) f)

Fig. 1. Visual appearance of sacha inchi, a) green pod, b) & c) matured four and six lenticular pods, d) fresh seeds e) roasted seeds f) shell and seed with seed coat

Fatty acid composition is known to have a positive influence on human health as it is linked to the prevention of various diseases like arthritis, cardiovascular disease, high blood pressure, diabetes and inflammatory skin diseases [7],[15],[18],[19]. Due to these properties, SI is attractive in the food, cosmetic, horticultural, nutraceutical and pharmaceutical industries [5],[13],[20],[21]. The nutritional composition of SI makes it a potential alternative source of plant-based protein and fatty acid especially for people with dietary restriction (e.g. vegan) or limited resources to access animal protein.

Despite some published nutritional analysis of SI, to the best of our knowledge, there is a paucity of published data from Malaysia. The aim of this study was to investigate the macronutrients, selected minerals and fatty acid composition of SI seeds harvested from the grounds of Crops For the Future Research Centre, Malaysia.

II. MATERIAL AND METHODS

A. *Raw material*

Mature pods of SI were harvested from multiple plants growing at Crops For the Future Research Centre (CFFRC), Semenyih Selangor, Malaysia (2.946900 N latitude, 101.872814 E longitude). Sampling consisted of harvesting approximately 200 g of pods at fortnightly intervals in January and February 2020.

B. *Sample preparation*

The pods (≈ 800 g) were cleaned to remove dirt and other foreign materials before cracking open to expose the dark coloured seeds. The seed coat was removed leaving the light coloured seed. The extracted seeds were divided into two batches for analysis – i) fresh seeds and ii) roasted seeds. For batch ii), the extracted seeds were roasted in an oven at 160°C for 6 mins [17]. The prepared batches were stored in labelled airtight containers in a desiccator before analysis. Triplicate samples of both batches were analysed for moisture, crude protein, crude fat, crude fibre and total ash using standard methods [22]. Carbohydrate content was determined by difference and the caloric value estimated by summing the multiplied values for crude protein, fat and carbohydrate by their respective factors (4,9,4). Mineral content and fatty acid profiles were determined for the roasted seeds in accordance with AOAC methods by an ISO/IEC 17025 accredited laboratory, UNIPEQ, Malaysia.

C. *Analytical methods*

1) *Moisture:* Approximately 5 g of fresh sample was dried in an oven at 105 °C for 16 h or until a constant weight was achieved.
2) *Crude Protein*: A semi-automated Kjeldahl method was used in the determination of protein by measuring the nitrogen content in the sample. The three steps involved, i) manual digestion, ii) automatic distillation and iii) titration. Approximately 2g of sample was mixed with 20 ml concentrated sulphuric acid (> 98 % H_2SO_4) and catalyst before digestion (Gerhardt, KI 11/26) for 2 hours or until the solution became clear/colourless. Digested samples were distilled with a mixture of 50 ml deionised water and 70 ml 32 % sodium hydroxide (NaOH) into 60 ml 2% boric acid (H_3BO_3) for 4 min using automatic distillation equipment (Gerhardt, Vapodest 400). Finally, the distillate was titrated against standardized 0.1 M hydrochloric acid (HCl) using an automatic titrator (Metrohm, 877 Titrino plus) to determine nitrogen percentage. Protein was calculated by multiplying by 6.25.

3) *Crude Fat:* Fat was determined using a semi-continuous solvent extraction method or Soxhlet method using a classic Soxhlet apparatus from Gerhardt. Approximately 2g of dried sample was wrapped in a filter paper and inserted into a cellulose thimble and then placed in an extraction chamber. 200ml of petroleum ether was added into a pre-dried and weighed boiling flask with 2-3 pieces of boiling stones. The samples were refluxed for three hours. Once complete the boiling flask was placed in a water bath (approximately 70°C) to evaporate the solvent leaving behind the fat residue. The boiling flask was then dried in an oven at 105°C for an hour. The fat content was measured by the weight difference of the boiling flask at the end of the drying process.
4) *Crude Fibre*: Determination of indigestible fibre using Fibrebag System (Gerhardt). Four steps were involved, i) de-fat and rinse 2g of the sample using petroleum ether, ii) acid digestion using 0.13 mol/L H_2SO_4 (to remove free sugar and starch) and iii) alkaline digestion using 0.23 mol/L NaOH (to remove protein and carbohydrate). The samples were digested over a heating mantle for 30 min and rinsed with hot water twice after each digestion process, iv) drying and ashing of the sample - the samples were dried overnight at 105°C and incinerated in a muffle furnace at 550°C for 4h.
5) *Ash:* Ash was determined by incinerating 5g of the samples in a muffle furnace at 550°C for 4 h.
6) *Carbohydrate:* Carbohydrate was obtained from difference calculation, 100 – (sum of percentage in moisture, ash, protein and fat).
7) *Energy:* The total energy content was determined by the sum of fat, protein and carbohydrate multiplied with factors 9.0, 4.0 and 4.0 respectively, the result was expressed in kilocalories per 100 g sample.

III. RESULT AND DISCUSSION

A. Proximate composition

The proximate composition data of SI fresh and roasted seeds are presented in Table 1. The moisture content in the fresh seeds was low because the harvested sample material was already nearly air dry before analysis. The value was slightly higher compared to that of the raw seeds reported by Gutiérrez et al. [14] but comparable with the value reported by Hidalgo et al. [23]. The moisture in the roasted seeds was naturally lower due to the roasting process. The protein values obtained were in a similar range (21%-30%) to that found by Kodahl [9]. The fat content in fresh SI (56.2%) was higher than in SI roasted (49.8%) and both values were higher compared to those reported by Gutiérrez et al. [14] and Hidalgo et al. [23]. However, the total fatty acids reported through fatty acid profiling gave a similar value (42%) (Table 2). The difference with other sources may be due to different reagents used in oil extraction [14]. The fibre content in roasted SI (23.88%) was higher than that fresh SI (13.03%) and the value in raw seeds reported by Hidalgo et al. [23] (18%). The ash content in both fresh SI (2.59%) was lower than the value reported by Gutiérrez et al. [14] but similar to that of Hidalgo et al. [23]. The carbohydrate content has the least information available [9]. The values for both fresh and roasted samples were different but lower than the value reported by Gutiérrez et al. [14]. However, Ruiz et al. [16] estimated the value to be 12.1%. As presented in Table 1, the energy content in fresh (643.63 kcal/100g) roasted (635.25 kcal/100g) samples were similar.

B. Fatty acid composition

Table 2 presents the important fatty acids in SI. The total fatty acid content of the roasted seeds was in the reported range of 33.4% - 54.3% reported by Wang et al. [24]. The saturated fatty acids (SFA) obtained in this study was higher than the range (6.8%-9.1%) estimated by Kodahl [9] because of the high value of stearic acid (12.89%) measured. Previous reported values for stearic acid were in the range of 3% - 4% [9],[23],[25]. In addition, the monounsaturated fatty acids (MUFA) were low compared to the commonly obtained values due to the missing oleic acids value. This fatty acid was estimated to be between 8.4% and 10.7% based on previous studies [9] but Hidalgo et al. [23] obtained a higher value (17.12%). This suggests that the range of oleic acids is still unknown, and the cause has yet to be determined. Plant variation, soil, climate and crop management may have been contributing factors. Palmitic acid content was on par with the range of values found by others. The polyunsaturated acids (PUFA) content i.e. linoleic and alpha-linolenic acids were commonly reported to be high in SI [9]. The values obtained in this study were in the range reported by Kodahl [9] although the value of omega-6 fatty acids (44.82%) was higher than those of the omega-3 (35.89%) - a difference from other reported previous studies [8], [12], [14], [15], [18], [21], [23],[25].

C. Mineral composition

The mineral composition in roasted SI was compared with that of roasted seeds from Kim and Joo [17] (Table 3). Most of the values were similar except for the calcium, sodium and phosphorus concentrations. The potassium concentration was the highest (5178.87 mg/kg) similar to the previous studies done on raw seeds [14],[26]. This was followed by phosphorus (3867.83 mg/kg) which was reported to be the highest by Kim and Joo [17]. The calcium concentration was lower (1142.23 mg/kg) compared to that of the roasted seeds reported by Kim and Joo [17] but almost similar to the raw seed value (1263.2 mg/kg) reported in the same study. They deduced that the difference may be due to the roasting process but in this study, even with the roasting process the concentration was still lower. Kim and Joo [17] did not obtain any value for sodium but this study reported a considerably higher amount (39.83 mg/kg) compared to Gutiérrez et al. [14] (15.4 mg/kg). Traces of selenium were also found in the roasted SI

TABLE I

Proximate composition of SI seeds

Component	SI Fresh*	SI Roasted*	Gutiérrez et al. [14]	Hidalgo et al. [23]
Moisture (%)	6.75 ± 0.08	0.73 ± 0.03	3.30	6.72
Crude protein (%)	23.63 ± 0.72	25.46 ± 0.54	24.70	29.78
Crude fat (%)	56.20 ± 0.83	49.77 ± 0.46	42.00	42.03
Crude fibre (%)	13.03 ± 1.92	23.88 ± 2.65	ND	18.00
Ash (%)	2.59 ± 0.02	2.68 ± 0.05	4.00	2.90
Carbohydrate (%)	10..83 ± 0.13	21.36 ± 0.1	30.90	ND
Energy (kcal/100g)	643.64 ± 4.42	635.25 ± 2.22	ND	ND

*Data from this study; values in this study are expressed as mean ± standard deviation (n = 3; ND - No data

TABLE 2

Fatty acid composition of SI seeds

Component	SI Roasted*	Souza et al. [25]	Hidalgo et al. [23]	Kodahl [9]
Total Fatty Acid (g/100g)	41.60 ± 3.02	48.52	42.03	ND
SFA (% in fat)	18.56 ± 1.47	7.20	9.38	6.80 - 9.10
MUFA (% in fat)	0.19 ± 0.08	8.52	17.12	8.40 - 13.20
PUFA (% in fat)	81.26 ± 1.55	77.73	73.51	77.50 - 84.40
Palmitic (C16:0) (% in fat)	4.64 ± 0.12	4.21	5.44	4.70 - 5.70
Stearic (C18:0) (% in fat)	12.89 ± 1.97	2.99	3.94	3.00 - 3.70
Oleic (C18:1 n-9) (% in fat)	0.00 ± 0.00	8.52	17.12	8.40 - 10.70
Linoleic (C18:2) (% in fat)	44.82 ± 0.89	33.85	34.67	33.40 - 41.00
α-Linolenic (C18:3) (% in fat)	35.89 ± 0.8	43.88	38.84	35.20 - 50.80

*Data from this study; values in this study are expressed as mean ± standard deviation (n = 3; ND - No data

TABLE 3

Minerals composition of SI seeds

Component	SI Roasted*	Kim and Joo [17]**
Calcium (Ca) (mg/kg)	1142.23 ± 27.89	2291.70 ± 7.0
Iron (Fe) (mg/kg)	44.37 ± 2	47.80 ± 0.6
Potassium (K) (mg/kg)	5178.87 ± 171.22	4789.10 ± 14.0
Magnesium (Mg) (mg/kg)	3438.70 ± 215.43	3667.50 ± 32.1
Sodium (Na) (mg/kg)	39.83 ± 15.31	0.00 ± 0.00
Manganese (Mn) (mg/kg)	11.20 ± 0.5	11.90 ± 0.2
Phosphorus (P) (mg/kg)	3867.83 ± 173.35	5442.70 ± 42.8

* Data from this study; ** Data from the roasted seeds

Table 4

Nutrient comparison of SI and some commercially available nuts /seeds (Serving size: 28g)

Nut / Seed	Sacha*	Almond[1]	Brazil Nut[1]	Cashew Nut[1]	Chest-nut[1]	Hazel-nut[1]	Macada-mia[1]	Peanut[1]	Pecan[1]	Pista-chio[1]	Walnut[1]
Energy (kcal)	180.2	162.0	187.0	157.0	70.0	178.0	204.0	161.0	196.0	159.0	183.0
Carbohydrate (g)	3.1	6.0	3.3	8.6	15.0	4.7	3.9	4.6	3.9	7.7	3.8
Protein (g)	6.7	5.9	4.1	5.2	0.9	4.2	2.2	7.3	2.6	5.7	4.3
Fat (g)	15.7	14.0	19.0	12.4	0.6	17.2	21.5	14.0	20.4	12.9	18.3
Fibre (g)	3.6	3.5	2.1	0.9	1.5	2.8	2.4	2.4	2.7	3.0	1.9
SFA (g)	2.2	1.1	4.6	2.2	0.1	1.3	3.4	1.8	1.8	1.7	1.7
MUFA (g)	0.0	8.8	6.8	6.8	0.2	12.9	16.7	6.9	11.6	6.6	2.5
PUFA (g)	9.5	3.5	6.9	2.2	0.3	2.3	0.4	4.4	6.1	4.1	13.2
Omega-3 (g)	4.2	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.3	0.1	2.5
Omega-6 (g)	5.2	3.5	6.9	2.2	0.2	2.2	0.4	4.4	5.9	4.0	10.7

* Data from this study; [1]Source: [27]

D. Nutrient comparison of SI nuts

SI contains a high amount of PUFA, second only to walnut (Table 4). The walnut has higher omega-6 content compared to omega-3. SI on the other hand provides a higher amount of omega-3 (4.2g) in a 28 g serving. It also provides a good amount of omega-6 (5.2g). SI has less carbohydrate compared with some other nuts but is high in protein. It also has a higher fibre content compared to others.

Underutilised crops have the potential to mitigate food and nutritional insecurity, including “hidden hunger” [1] by enriching diets with nutritionally diverse foods while simultaneously making food and food culture more varied and interesting. Here we have compared roasted SI with bambara groundnut [28] and lablab bean [29],[30] classified as underutilised crops (Table 5). Both crops have recently gained interest due to their potential to improve nutritional availability and biodiversity. The protein content is similar for all three crops. There is a significant difference in fat content with SI recording almost 50 times more; this contributes to the higher energy level. The higher fat content also contributes to the higher PUFA in SI with linoleic and α-linolenic acids in a range which has been recorded to have a positive influence on human health, linking it to prevention of cardiovascular and high blood pressure [12],[13],[15]. SI also has higher essential minerals such as calcium (1142.23 ± 27.89 mg/kg), magnesium (3438.70 ± 215.43 mg/kg) and phosphorus (3867.83 ± 173.35 mg/kg) compared to the other crops.

IV. CONCLUSION

SI, an underutilised crop, has unexplored potential. Analysis of SI seeds collected from CFFRC, Malaysia had excellent nutritional composition with high content of crude protein (23.80%) and crude fat (56.20%). The fatty acids analysis indicated high omega-3 (35.89%) and omega-6 (44.82%%). The data obtained from this study is comparable with other studies. The SI seeds also contained essential minerals such as iron, magnesium and calcium. Comparing SI’s nutrition profile, especially the fatty acid content, with other commercialised crops draws attention to its potential as a plant source of omega-3 and omega-6 alongside its macronutrient and minerals content. These properties may create opportunities for developing highly valued food and pharmaceutical products for human health.

Data Availability Statement

All datasets generated for this study are included in the article material.

Authors Contributions

Gomathy Sethuraman: Validation, Investigation, Resources, Data Curation, Writing – Original Draft. Nur Marahaini Mohd Nizar: Resources, Data Curation, Writing -Review and Editing. Fatin Nadia Muhamad: Resources, Data Curation. Ebrahim Jahanshiri: Funding acquisition, Project Administration. Peter J. Gregory: Conceptualization, Supervision, Writing-Review and Editing. Sayed Azam-Ali: Funding acquisition, Project Administration

Table 5

Nutrient comparison with other reported underutilised crop

Component	SI Roasted*	Bambara groundnut (*Vigna subterranea* (L.) Verdc.) Yao et al. [28]	Lablab bean (*Lablab purpureus* (L.))
Energy (kcal/100g)	635.25 ± 2.22	348.6***	352.42 ± 2.66
Moisture (%)	0.73 ± 0.03	11.7 ± 0.1	8.47 ± 0.52[1]
Crude protein (%)	25.00 ± 0.89	18.8 ± 0.2	23.95 ± 0.16[1]
Crude fat (%)	49.77 ± 0.46	1.4 ± 0.3	1.02 ± 0.06[1]
Crude fibre (%)	23.88 ± 2.65	ND	ND[1]
Ash (%)	2.68 ± 0.05	2.9 ± 0.0	3.5 ± 0.07[1]
Carbohydrate (%)	21.37 ± 0.1	65.2**	61.86 ± 0.79[1]
Total Fatty Acid (g/100g)	41.60 ± 3.02	ND	1.10[1]
SFA (% in fat)	18.56 ± 1.47	37.88	ND[1]
MUFA (% in fat)	0.19 ± 0.08	23.46	ND[1]
PUFA (% in fat)	81.26 ± 1.55	37.34	ND[1]
Palmitic (C16:0) (% in fat)	4.64 ± 0.12	20.57 ± 0.42	2.96 ± 0.34[1]
Stearic (C18:0) (% in fat)	12.89 ± 1.97	7.12 ± 0.18	0.76 ± 0.07[1]
Oleic (C18:1 n-9) (% in fat)	0.00 ± 0.00	22.61 ± 0.06	1.1 ± 0.10[1]
Linoleic (C18:2) (% in fat)	44.82 ± 0.89	35.92 ± 0.17	9.5 ± 1.1[1]
α-Linolenic (C18:3) (% in fat)	35.89 ± 0.8	1.3 ± 0.13	1.95 ± 0.31[1]
Calcium (Ca) (mg/kg)	1142.23 ± 27.89	302.0 ± 1.6	99.0 ± 0.02[2]
Iron (Fe) (mg/kg)	44.37 ± 2	88.0 ± 0.6	63.0 ± 0.01[2]
Potassium (K) (mg/kg)	5178.87 ± 171.22	ND	5970.0 ± 0.01[2]
Magnesium (Mg) (mg/kg)	3438.70 ± 215.43	1360.0 ± 2.0	104.0 ± 0.01[2]
Sodium (Na) (mg/kg)	39.83 ± 15.31	ND	57.4 ± 0.02[2]
Manganese (Mn) (mg/kg)	11.20 ± 0.5	ND	16.4 ± 0.01[2]
Phosphorus (P) (mg/kg)	3867.83 ± 173.35	3358.0 ± 5.9	2850.0 ± 0.02[2]
Selenium (Se) (mg/kg)	0.10 ± 0.01	ND	ND

* From this study; ** calculated as 100 – (sum of percentage in moisture, ash, protein and fat) of the data; *** calculated as sum of fat, protein and carbohydrate multiplied with factors 9.0, 4.0 and 4.0 of the data; [1]Hossain et al. [30]; [2]Ademola & Abioye [29]; ND - No data

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