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The Effect of Cultivation Conditions on Sacha Inchi (*Plukenetia volubilis* L.) Seed Production and Oil Quality (Omega 3, 6, 9)

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Abstract: Sacha Inchi (*Plukenetia volubilis* Linneo, Euphorbiaceae) is known as a Peruvian seed containing a high level of unsaturated fatty acids, such as α-linolenic acid (Omega-3), linoleic acid (Omega-6), and oleic acid (Omega-9). These essential fatty acids are important functional foods due to their benefits for human health. Considering its benefits, it is necessary to find the right cultivation conditions to develop Sacha Inchi in Indonesia, where it has not been widely cultivated. This study aimed to determine the adaptability of Sacha Inchi to different cultivation conditions and the effects of these conditions on seed production and oil quality. Sacha Inchi plants were cultivated under three different cultivation conditions (open area, mixed cultures, and agroforestry) and the seeds were harvested monthly to determine the seed production and oil quality. The results showed that seed production in the open area was higher than in other conditions. The highest oil yield from monthly harvesting was found in mixed cultures. Interestingly, the level of Omega-3 content in the agroforestry condition was higher compared to other conditions. The level of Omega-6 and Omega-9 content in the open area was higher than in mixed cultures and agroforestry. However, the content of unsaturated fatty acids in the three different cultivation conditions was not significantly different, being 91.88% in the open area, 92.53% in mixed cultures, and 92.97% for agroforestry. In conclusion, the cultivation of Sacha Inchi under open areas is recommended due to its seed productivity which will affect the total oil production.

Keywords: Sacha Inchi; seed production; cultivation conditions; Omega-3; Omega-6; Omega-9; essential fatty acids

1. Introduction

Dietary lipids are required by the human body since they are an important component of all living cells. Humans can synthesize all lipids except those that are long-chain fatty acids (FAs), which are grouped into three omega-families: Omega-3, Omega-6, and Omega-9 [1]. Omega-3 and Omega-6 are polyunsaturated fatty acids (PUFAs), whereas the majority of the Omega-9 FAs are monounsaturated fatty acids (MUFAs) [2]. Alpha-linolenic acid (ALA) and linoleic acid (LA) are members of the Omega-3 and Omega-6 families, respectively, and are essential FAs as they cannot be produced by mammalian cells and must be obtained from the food in sufficient proportions [3]. Oleic acid (OA) is a member of the Omega-9 family and a non-essential FA which can be produced naturally by the body in the presence of enough Omega-3 and Omega-6 [4].

PUFAs have been found to have an effect in preventing cardiovascular, autoimmune, and inflammatory illness by decreasing blood triglycerides and cardiac arrhythmias, as well as enhancing thrombocyte function and regulating cytokine production [3]. The Omega-3 PUFAs are commonly found in fish oil tablets, which are employed as an immune nutrition supplement [3]. MUFAs have benefits in reducing cardiovascular disease, the occurrence of Parkinson's and Alzheimer's disease, and cancer [5]. MUFAs have previously been shown to be a beneficial factor in the development of dietary programs for obesity, cardiovascular disease, type 2 diabetes, and sepsis [6–9]. A recent study showed that the ratio of PUFA to MUFA (PUFA/MUFA) intake is related to the level of visceral adiposity index (VAI) and cardiometabolic index (CMI) of postmenopausal women [10]. The PUFAs and MUFA may be found in a variety of seed foods, as well as from fish oil, including from vegetable oils that can be obtained from Sacha Inchi oil [11,12]. The advantage of PUFAs and MUFA from vegetables, including Sacha Inchi plants, is that they have a less unfavorable odor than fish oil, are easier to develop in terms of production system and technology, and are low cost.

The Sacha Inchi plant (*Plukenetia volubilis* L.) is a member of the Euphorbiaceae family which originated from South America, a native to the Amazon region including part of Peru and northwestern Brazil [13]. It has been cultivated in the lowlands of the Peruvian Amazon and, for generations, the indigenous people have utilized it in traditional cuisine; it has been a staple in the diets of various local populations in the region [14–16]. Sacha Inchi is also known as the mountain peanut, Inca nut, or Inca Inchi and bears a star-shaped fruit capsule [13,17]. Sacha Inchi seeds contain nutritional elements such as edible oil (45% of dry weight), protein (27%), tocopherols (137 mg/100 g), and phytosterols (75 mg/100 g) [16,18]. Sacha Inchi oils have a large amount of PUFAs (about 77.5–84.4%), MUFAs (about 8.4–13.2%), and a small proportion of saturated fatty acids (about 7.9–9.1%) [12–14,16,19]. The ratio of Omega-6/Omega-3 in Sacha Inchi oil ranges from 0.81 to 1.09, which is considered to be an ideal ratio of functional food for human health [20–22]. The Omega-6/Omega-3 fatty acid ratio in edible oils is crucial in the formulation of functional foods to treat or prevent cardiometabolic illness, heart disease, hypertension, and diabetes [23–25]. A recent study concluded that low levels of PUFA and Omega-3 in the diet may cause changes in biochemical parameters and metabolic syndrome-related indicators [10].

The essential fatty acids alpha-linolenic acid (C18:3 *n*-3, Omega-3, ALA) and linoleic acid (C18:2 *n*-6, Omega-6, LA) are abundant in Sacha Inchi oils. ALA serves as a precursor to synthesis of eicosapentaenoic acid (EPA; 20:5 Omega-3) and docosahexaenoic acid (DHA; 22:6 Omega-3) in the human body, which are important to prevent cardiovascular disease, have a protective effect in mood disorders, and support cognitive function in children [26]. Intake of ALA and LA is necessary for children's healthy growth and development. In Indonesia, the majority of children have PUFA consumption levels that are below than the Food and Agriculture Organization (FAO) and World Health Organization (WHO) recommended dietary limits, particularly for ALA. Indonesian children consume only 40% of the recommended intake level of ALA and 67% of the total essential fatty acids that are recommended by FAO/WHO [27]. The nutrient deficiencies of ALA (Omega-3) and LA (Omega-6) may cause stunting and obesity [28–31]. The nutrient deficiencies in ALA (Omega-3) and LA (Omega-6) might be tackled by developing Sacha Inchi plants in Indonesia to fulfill the requirements for essential fatty acids of Indonesian children. Sacha Inchi oil has excellent nutritional properties and a high potential for industrialization in producing functional food [32].

Sacha Inchi plants normally grow under high-light conditions with an altitude ranging from 200–1500 masl and its seeds typically germinate at the optimal temperature between 25 to 35 °C [33,34]. Considering the need for Omega-3 and Omega-6 and agroclimatic conditions, therefore, it is necessary to establish an experimental plot for cultivating Sacha Inchi plants in Indonesia. As a first step, an experimental plot was established in the experimental garden of the Natural Product Laboratory, SEAMEO BIOTROP, Bogor, West Java, Indonesia, as a species trial for evaluating the adaptability of Sacha Inchi in different cultivation conditions. Bogor is located at an altitude of 300 masl, has an average monthly temperature of 26 °C, and annual precipitation of 3000 mm. Indonesian farmers practice the cultivation conditions of an open area, mixed cultures, or agroforestry, which may affect the productivity and quality of their agricultural products. To date, the Sacha Inchi plant is not a well-known species to the Indonesian farmers, nor are its uses and derivative products. This study aims to determine the adaptability of Sacha Inchi to Indonesia's agro-climatic conditions by evaluating the effect of cultivation conditions on seed production and oil quality.

2. Materials and Methods

2.1. Plant Materials

The Sacha Inchi (*Plukenetia volubilis* L.) seeds were obtained from the farmers in Sukabumi, West Java, Indonesia, which were originally imported from Peru by a Korean expert. The seeds were stratified by soaking in warm water for 1 h and, subsequently, in cold water for 24 h to break the seed coat dormancy. The seeds were then germinated on the germination media, which contained 100% cocopeat, and were covered with black plastic (under dark conditions). The seedlings were transplanted into polybags containing a mixed growing medium of cocopeat, husk charcoal, and compost (1:1:1, volume/volume (*v*/*v*)). One-month-old seedlings which had three pairs of leaves were selected and planted in the field.

2.2. Site Selection, Land Preparation, and Planting Method

Site selection was done by considering the flatness of the land, type of vegetation coverage (open area or no vegetation, mixed cultures, agroforestry), and accessibility, to facilitate maintenance and data recording. The land preparation was done manually. Herbicide was applied to eliminate the weeds. The planting distance was 2 m × 4 m. The seedlings were planted in planting pits with the size of 60 cm in depth, length, and width (60 cm × 60 cm × 60 cm). The planting pits were filled with growth medium that contained husk charcoal, compost, and topsoil (1:3:3, *v*/*v*). After planting, two-meter stakes were installed in the field with a distance of 4 m between each stake along the planting area, and each stake was connected with ropes to direct the vines of the Sacha Inchi plants.

The area of 0.16 ha was divided into three different cultivation conditions: agroforestry area, mixed cultures area, and open area. The agroforestry cultivation was performed under stands of teak (*Tectona grandis*) and jabon (Burflower-tree, *Neolamarckia cadamba*) aged 13 years, with a canopy density of 70%; it covered an area of 758 m^2 which had 91 Sacha Inchi plants. The mixed cultures cultivation was performed by planting Sacha Inchi seedlings in between papaya (*Carica papaya*) and cassava (*Manihot esculenta*) plants aged 6 months, with a canopy density of 30%; it covered an area of 432 m^2 which had 54 Sacha Inchi plants. The open area 448 m^2 had 56 Sacha Inchi plants and no additional plants.

The soil properties of the experimental site were medium C-organic (2.3%), low total N (0.185%), medium C/N ratio (12.5), high available P_2O_5 (41.31 ppm), high available K_2O (90.90 ppm), low cation exchange capacity (CEC) (9.25 cmol/kg), low soil pH H_2O (4.3), sand (14.6%), loam (20.9%), and clay (63.4%). Soil properties improvement was done by adding a soil amendment made of charcoal, compost, and topsoil.

Watering was applied in the first week after planting due to the dry season. The weeds were removed manually. Fertilizer was applied in the first week of planting containing 50 g NPK fertilizer (15:15:15) per plant. The vines were routinely directed to avoid the overgrowth of branches. Pruning was performed to remove the dried/dead branches.

2.3. Experimental Design and Analysis of Variance

The experiment was performed in the experimental garden of the Natural Product Laboratory, SEAMEO BIOTROP, Bogor, which has an altitude of 300 masl and high precipitation with an annual average precipitation of 3000 mm. The soil type is alluvial. A completely randomized design was used in this experiment. The three different cultivation conditions were considered as the treatments. Twenty-five plants were selected randomly for each cultivation condition as the samples for data recording. Analysis of variance (ANOVA) was done by using SAS 9.1 version followed by the least significant difference (LSD) test.

2.4. Seed Production

Data collection was focused on productivity under different cultivation conditions. Observations were made on first flowering, fruit maturity, pests and diseases, and pollinators. Data on the number of fruits per plant for each harvesting time, the fresh weight of fruit per plant, the dry weight of fruit per plant, and the weight of seeds per plant were recorded. The mature fruits which had a dark brown color were harvested monthly. Monthly harvesting was performed in the middle of the month, from August to November 2021. The fruits were air-dried for 2–4 weeks and then seeds were extracted from the fruit pod by cracking the seed pods or seed capsules gently using a small hammer. The seeds were collected separately according to each treatment to obtain the seed production of each cultivation condition.

2.5. Oil Quality

To obtain the oil, Sacha Inchi seeds from the September, October, and November 2021 harvesting were pooled and grouped according to the cultivation conditions to achieve a sufficient quantity for oil quality analysis. The seed kernels were separated gently from their shells (seedcoat) manually by using a small hammer. The kernels (endosperm as food store) were collected and air-dried to decrease moisture content to 9–12%. The kernels then were pressed by using the cold press method to obtain Sacha Inchi oil. Prior to laboratory analysis for oil quality, the Sacha Inchi oil was filtered by using Monyl No. 500/197T-42 08M (PT. Indesso, Indonesia) to minimize the water content and debris. The 200 milliliters (mL) of Sacha Inchi oil from each cultivation condition were subjected to analysis of the oil quality using standardized methods developed by PT. Saraswanti Indo Genetech (SIG) Laboratory, Bogor, Indonesia. The parameters and methods of the oil content analysis are listed in Table 1.

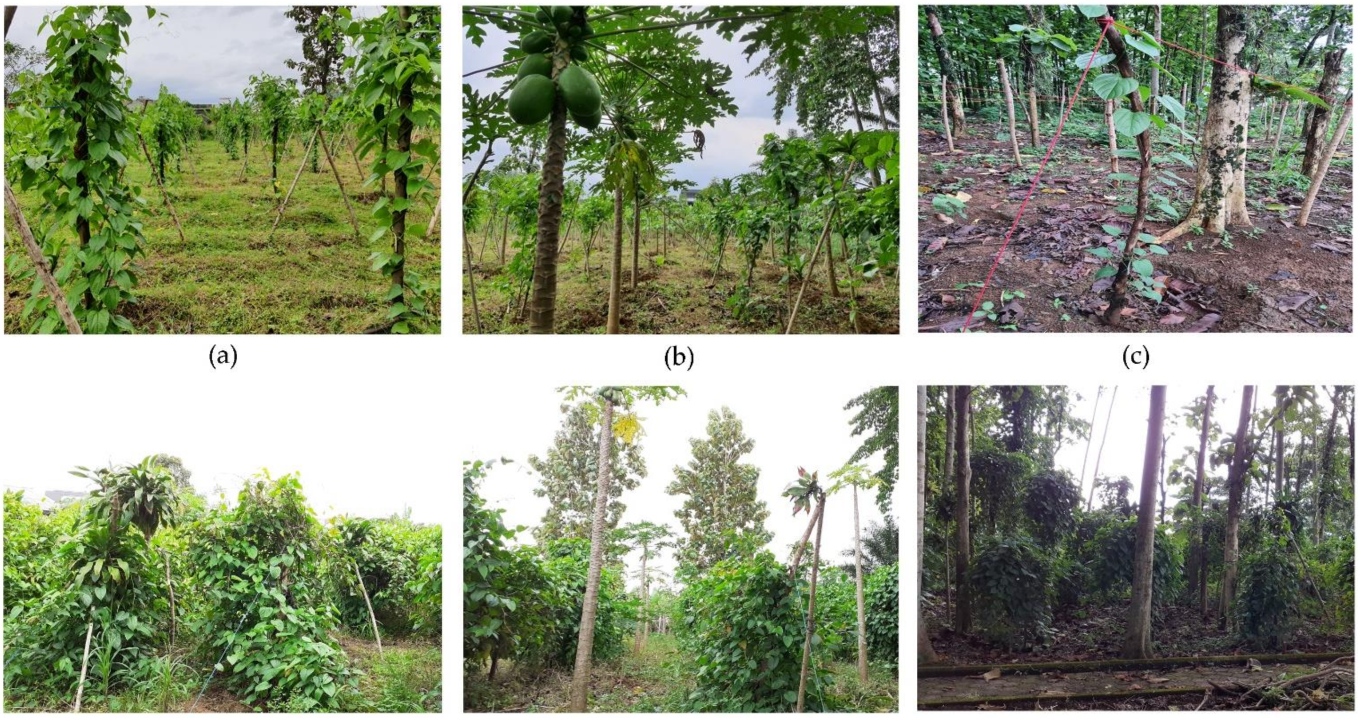
Table 1. The parameters, unit, and method for oil quality analysis.

No.	Parameter	Unit	Method
1	Omega-3	%	18–6–1/MU/SMM-SIG (GC)
2	Omega-6	%	18–6–1/MU/SMM-SIG (GC)
3	Omega-9	%	18–6–1/MU/SMM-SIG (GC)
4	Unsaturated fat	%	18–6–1/MU/SMM-SIG (GC)
5	Saturated fat	%	18–6–1/MU/SMM-SIG (GC)
6	Total fat	%	18–8–19/MU/SMM-SIG
7	Energy from fat	Kcal/100 gr	Calculation
8	Total energy	Kcal/100 gr	Calculation
9	Ash content	%	SNI 01–2891–1992 point 6.1
10	Protein content	%	18–8–31/MU/SMM-SIG (KjelTech)
11	Carbohydrate	%	FAO 2003 point 2.3
12	Moisture content (Karl Fischer)	%	18–11–44/MU/SMM-SIG

3. Results and Discussion

3.1. The Adaptability of Sacha Inchi

Sacha Inchi seedlings were planted under three different cultivation conditions (open area, mixed cultures, and agroforestry). Sacha Inchi plants grew well under those three different cultivation conditions, in terms of leaf color and size (green or dark green, normal size), and were able to flower and produce seeds (Figure 1). The ability of Sacha Inchi plants to produce viable seeds was an indicator of successful adaptation to three different cultivation conditions and Bogor climate, although seed production is different. It is necessary to mention that we did not find any significant pests or diseases, or indeed pollinators, during the cultivation of Sacha Inchi.



(a) (b) (c) (d) (e) (f)

Figure 1. Sacha Inchi plants in experimental garden of Natural Product Laboratory, SEAMEO BIOTROP, Bogor. Growth performance of Sacha Inchi plants at the first month after planting (**a**–**c**) and six months after planting (**d**–**f**). Sacha Inchi plants in the open area (**a**,**d**), mixed culture (**b**,**e**), and agroforestry (**c**,**f**).

A recent study in Central Java, Indonesia, discovered 75 arthropod phylum families on Sacha Inchi plants, most of which were located on the leaf. Just 8% of them were pests, 10% were natural enemies, and 85% were pollinators and decomposers [35]. The lack of pests and diseases, which was found in this study, could be advantageous for developing Sacha Inchi in Bogor, West Java, Indonesia, but also a disadvantage for the lack of pollination agents of Sacha Inchi. Sacha Inchi is an allogamous species that exhibited a minor level of selfing (4.3%) in a crossbreeding experiment [36]. Sacha Inchi is a monoecious plant that has one or two female flowers and about 60 male flowers (Figure 2a–c) [37]. Elsewhere, Sacha Inchi flowers about 3–5 months after planting, while fruiting takes place approximately 8–9 months after planting [38]. Under our experimental plot conditions, Sacha Inchi plants flower about three months after planting and seeds mature about four months after planting (Figure 2d). This result suggests that the cultivation of Sacha Inchi in Bogor has the potential to produce Sacha Inchi seeds in a shorter time. It is also possibly due to the high content of phosphorous and potassium in the experimental site.

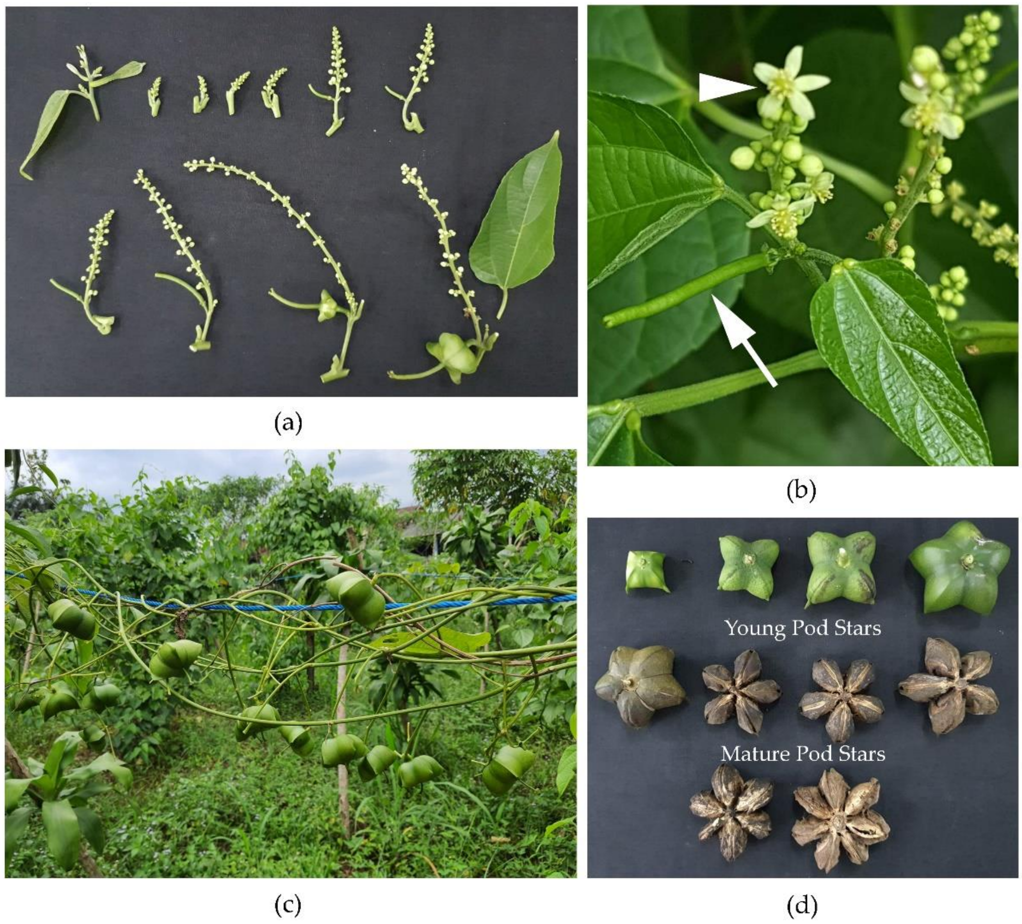


Figure 2. Sacha Inchi flowers and fruits. (**a**) Sacha Inchi flower development. (**b**) Pistillate female (white arrow) and staminate male flower (white head arrow). (**c**) Sacha Inchi plants were fruiting at 3–4 months after planting. (**d**) Young and mature fruit pod stars.

3.2. Seed Production of Sacha Inchi

Prior to evaluating the monthly harvesting, the first harvesting was done to collect seed production and to synchronize the fruit production for each cultivation condition. The mature fruits from the first harvesting out of 25 plants for each cultivation condition were harvested by cutting with scissors and grouped according to the conditions. It was found that Sacha Inchi plants that were grown under open areas produced a significantly higher number of fruit pods, fresh weight of fruit, air-dried weight of fruit, and air-dried seed weight than for mixed cultures and agroforestry (Table 2). Overall, seed production in the open area, mixed cultures, and agroforestry was 123.02 gr/plant, 55.04 gr/plant, and 40.07 gr/plant, respectively. It means the Sacha Inchi plant is more productive in the open areas than in the other conditions.

Table 2. Sacha Inchi first harvesting data.

Conditions	Number of Fruit Pods (*n*)	Fresh Weight of Fruit Pods (gr/plant)	Air-Dried Weight of Fruit Pods (gr/plant)	Air-Dried Seeds (gr/plant)
Open Area	45.60 ± 20.26 a	229.57 ± 113.86 a	197.35 ± 103.13 a	123.02 ± 59.49 a
Mixed cultures	25.08 ± 11.83 b	94.01 ± 55.51 b	92.69 ± 53.52 b	55.04 ± 32.46 b
Agroforestry	19.28 ± 9.59 b	64.96 ± 47.36 b	63.92 ± 46.19 b	40.07 ± 30.32 b

Data are presented as mean ± SD, mean values followed by the same small letters in the same column indicate significant difference among the treatments at $p < 0.05$.

To maintain the continuity of seed production of Sacha Inchi, the interval between harvesting needs to be considered. Therefore, monthly harvesting was performed to evaluate the consistency of seed production. Monthly harvesting was performed a month after the first harvesting, which was then called the first month of harvesting. Table 3 shows that under the open area condition, the number of fruits was higher than mixed cultures and agroforestry in the first monthly harvesting. However, the number of fruits then gradually decreased in the next monthly harvestings; a fluctuating number of fruits was exhibited in mixed cultures and agroforestry. These fluctuated results were also shown in the weight of air-dried seeds. The air-dried seed weight was higher in open areas than in mixed cultures and agroforestry, at about 178.95–273.95 gr/plant, 67.05–188.81 gr/plant, and 35.73–55.61 gr/plant, respectively. Seed production decreased in the third month of harvesting but, in total, the seed production in the open area was still higher than in mixed cultures and agroforestry, at 643.94 gr/plant, 357.43 gr/plant, and 146.49 gr/plant, respectively. These differences are also consistently shown for the number of fruit pods, fresh weight of fruit pods, and air-dried weight of fruit pods parameters.

These results suggest that monthly harvesting could provide good results for seed production. By considering the results from all the parameters, the open area exhibited the highest results, then followed by mixed cultures and agroforestry, whether in the first harvesting or monthly harvesting. The decrease of seed production in the agroforestry condition is due to light reduction and nutrient competition. Sacha Inchi requires full sunshine to grow and flower [33]. Shade delayed the initial flowering which decreased the number of fruits [33]. The high production of seed in the open area showed that the monoculture system improves the seed production of Sacha Inchi. A previous study also showed that monoculture using dry-season irrigation significantly increased the fruit and total biomass of Sacha Inchi [39].

3.3. Oil Yield and Oil Quality of Sacha Inchi

Research on the oil yield and oil quality of the Sacha Inchi plant (*Plukenetia volubilis* L.) in Indonesia has never been done. Most research on Sacha Inchi has been performed in Peru, Ecuador, Venezuela, Suriname, Colombia, Brazil, and Bolivia. The Sacha Inchi plant is a little-known oilseed crop endemic to the Amazon basin, where it has been used by people since the Incan era.

The quantity of Sacha Inchi oils can be reflected in its oil yield after cold pressing. The factors affecting oil yield could be oil content, seed water content, and pressing technology [40–42]. Oilseed content in general is affected by the interaction between genetic and environmental factors [43,44]. The existence of seed water content affects the oil quality (clearness of the oil yield) [42], while the pressing technology could affect the oil yield due to differences in the pressure strength [41]. In this study, the seed water content has been decreased to 9–12% but it was pressed manually using human strength which may have affected the oil yield (Figure 3c,d). The oil yield in the open area, mixed cultures, and agroforestry area were 22%, 26.3%, and 17.2%, respectively (Table 4). The oil yield in the agroforestry area was the lowest compared to the other conditions. The canopy of the trees in the agroforestry area might reduce the light intensity and light quality for Sacha Inchi plants which may affect the photosynthetic activity and kernel size as food storage, and in turn, will affect the oil content [33,45].

Table 3. Sacha Inchi monthly harvesting.

Conditions	Number of Fruit Pods (*n*)				Fresh Weight of Fruit Pods (gr/plant)			
	September 2021	October 2021	November 2021	Total	September 2021	October 2021	November 2021	Total
Open Area	64 ± 147.74 a	55 ± 22.19 a	38 ± 19.82 a	157 ± 159.14 a	426.71 ± 247.47 a	751.76 ± 299.62 a	427.59 ± 252.45 a	1606.06 ± 530.23 a
Mixed cultures	14 ± 8.37 b	37 ± 17.86 b	24 ± 15.77 b	75 ± 21.04 b	153.02 ± 102.43 b	449.45 ± 204.26 b	283.64 ± 200.00 b	886.1 ± 263.75 b
Agroforestry	7 ± 6 b	15 ± 21.77 c	11 ± 6.80 c	34.96 ± 23.69 c	81.71 ± 64.54 b	124.68 ± 125.88 c	95.62 ± 75.94 c	302.02 ± 217.49 c
Conditions	**Air-Dried Weight of Fruit Pods (gr/plant)**				**Air-Dried Seeds (gr/plant)**			
	September 2021	**October 2021**	**November 2021**	**Total**	**September 2021**	**October 2021**	**November 2021**	**Total**
Open Area	319.97 ± 188.42 a	467.49 ± 190.57 a	312.93 ± 164.22 a	1100.39 ± 375.51 a	178.95 ± 108.29 a	273.95 ± 109.26 a	191.04 ± 129.13 a	643.94 ± 229.87 a
Mixed cultures	113.37 ± 74.03 b	316.95 ± 150.87 b	191.16 ± 129.13 b	621.48 ± 181.37 b	67.05 ± 42.7 b	188.81 ± 89.15 b	101.57 ± 74.03 b	357.43 ± 111.84 b
Agroforestry	55.38 ± 40.19 b	87.2 ± 82.28 c	82.86 ± 53.49 c	225.44 ± 136.79 c	35.73 ± 26.43 b	55.12 ± 50.28 c	55.61 ± 35.04 c	146.49 ± 85.74 c

Data are presented as mean ± SD, mean values followed by the same small letters in the same column indicate significant difference among the treatments at $p < 0.05$.

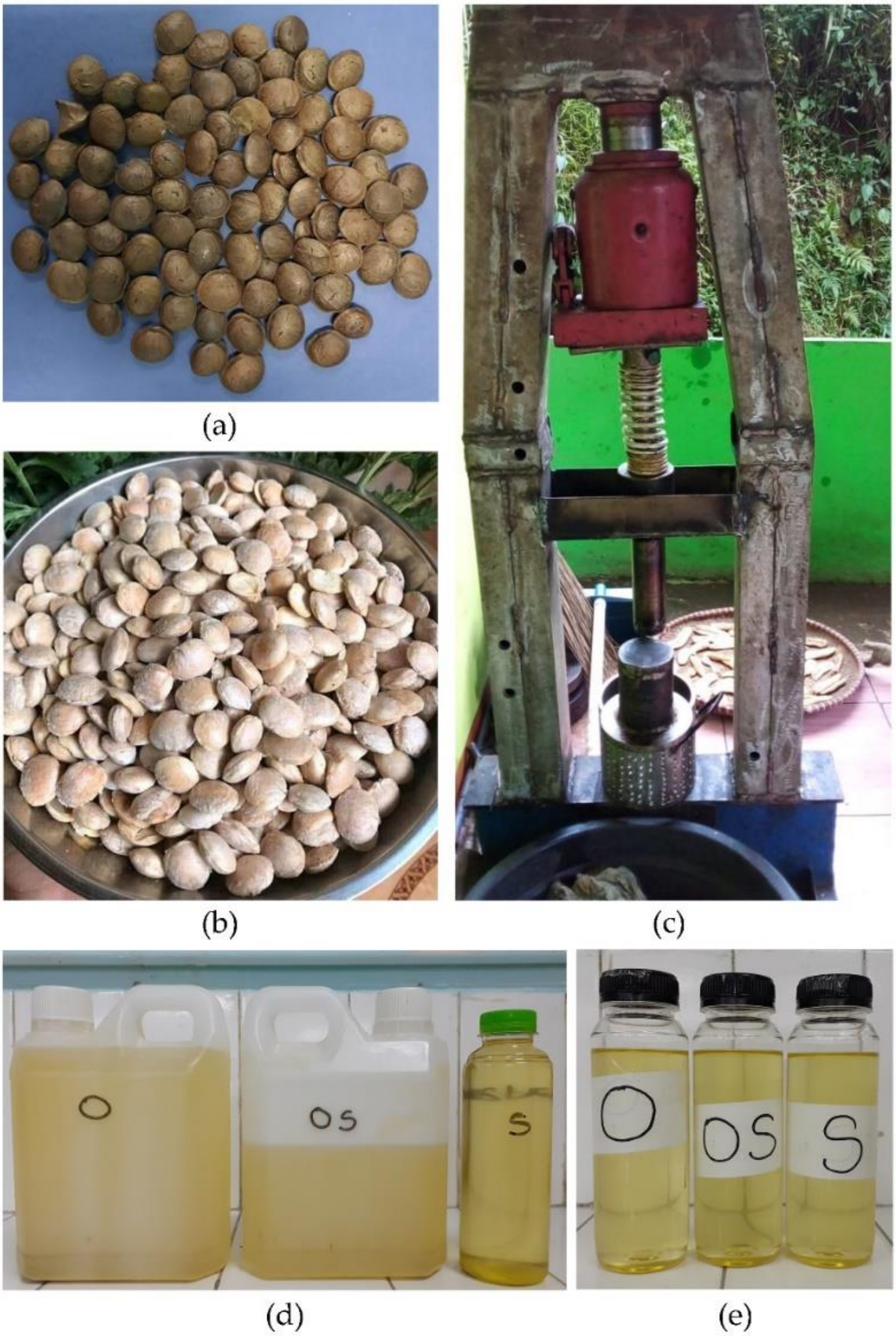


Figure 3. Sacha Inchi oil extraction. (**a**) Sacha Inchi seeds with shell and (**b**) kernel or seeds without the shell. (**c**) Sacha Inchi oil extraction by using a cold-press machine. (**d**) Sacha Inchi oil before filtering and (**e**) after filtering, for oil quality analysis. (**d**,**e**) O: Open area; OS: Mixed cultures; S: Agroforestry.

Table 4. Sacha Inchi oil yield.

Conditions	Oil Yield (%)	
	Based on Seed Weight with Shell	Based on Seed Weight without Shell
Open Area	13	22
Mixed cultures	17.7	26.3
Agroforestry	11.3	17.2

The quality of Sacha Inchi oil was analyzed using standardized procedures. The oil contains 91.88–92.97% unsaturated fatty acid, of which approximately 42.67–46.34% is Omega-3 (alpha-linolenic acid) and approximately 37.37–39.18 % is Omega-6 (linoleic acid), while approximately 9.03–9.82 % is Omega-9 (C18:1 *n*-9, Oleic acid) (Table 5). The Omega-3 content in agroforestry was higher than in mixed planting and in open areas but the total oil production in the open area was higher than in mixed planting and in the agroforestry area due to its seed production. The organoleptic test showed low total energy from fat (899.3 Kcal/100 g), very low ash content (<0.02%), very low protein content (<0.04%), zero carbohydrates, and very low moisture content (0.08%). Technically the use of Monyl filter No. 500/197T-42 08M (PT. Indesso, Indonesia) minimized the water content and debris, thereby increasing the Sacha Inchi oil quality.

Table 5. Sacha Inchi oil content analyzed with the standard method.

No.	Parameter	Unit	Content		
			O	OS	S
1	Omega-3 (alpha-linolenic acid)	%	42.67	43.95	46.34
2	Omega-6 (linoleic acid)	%	39.18	38.9	37.37
3	Omega-9 (oleic acid)	%	9.82	9.44	9.03
4	Unsaturated fat	%	91.88	92.53	92.97
5	Saturated fat	%	8.04	7.4	6.95
6	Total fat	%	99.92	99.93	99.92
7	Energy from fat	Kcal/100 gr	899.3	899.4	899.3
8	Total energy	Kcal/100 gr	899.3	899.4	899.3
9	Ash content	%	<0.02	<0.02	<0.02
10	Protein content	%	<0.04	<0.04	0.04
11	Carbohydrate	%	0	0	0
12	Moisture content (Karl Fischer)	%	0.08	0.07	0.08

Note: O: Open area; OS: Mixed cultures; S: Agroforestry.

The lipid content of the large seeds is around 45–50%, with Omega-3 (alpha-linolenic acid) accounting for roughly 35.2–50.8% and Omega-6 (linoleic acid) accounting for around 33.4–41.0%; these PUFAs are needed by the human body as essential fatty acids [16,46,47]. The seeds also have antioxidant effects and contain 22–30% protein. Sacha Inchi has garnered increased interest in recent years due to its outstanding nutritional content and strong agronomic features, and cultivation is expanding. When it comes to today's global concerns, reforming our food systems is critical to providing food security, mitigation of climate change, and malnutrition alleviation [46]. Furthermore, the content of polyunsaturated fatty acids in Sacha Inchi oil is higher than with the known fish oil, which normally contains 11–35% Omega-3 and 0.9–12% Omega-6 [48]. The production and processing of fish oil are also costly, with removal of color pigments, contaminants (dioxins, furans, and/or polyaromatic hydrocarbons), and volatile components responsible for the oil's odor and flavor [12]. When compared to fish oils, the cultivation of Sacha Inchi and the use of its oil as a plant-based Omega-3 fatty acids' source might provide a sustainable, renewable, and affordable source of Omega-3 [12].

The chemical content of the unsaturated fatty acids Omega-3, Omega-6, and Omega-9 in Sacha Inchi seeds planted in Bogor was higher than for those planted in Peru [49]. Sacha Inchi (*Plukenetia volubilis* L.) is a highly promising crop, primarily due to the nutritional composition of the seeds as a superfood. With regard to the seed production, oil yield, and oil quality, it is suggested to plant the Sacha Inchi plants in open areas and in other geographic positions in Indonesia to provide functional food from oilseeds for alleviation of malnutrition of Indonesian children.

4. Conclusions

Sacha Inchi (*Plukenetia volubilis* L.) is a promising plant for producing functional food due to its Omega-3 (42.67–46.34%) and Omega-6 (37.37–39.18%) which are essential fatty acids, and Omega-9 (9.03–9.82%), with the total unsaturated fatty acids amounting to 91.88–92.97%. Sacha Inchi adapted successfully to the Bogor environment. Seed and oil production in open areas was better than in mixed cultures and agroforestry.

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