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Research Article

Characterization of Oils and Solid Residues Obtained from *Bauhinia variegata L.* and *Pachira glabra pasq.* Seeds Through the Solvent Extraction Method

Ulrich Cabrel Kenmegne Tebe[1, *], Julius Kewir Tangka[1], Brice Martial Kamdem[2], Kunmi Joshua Abioye[3]

[1]Laboratory of Renewable Energies, Department of Rural Engineering, Faculty of Agronomy and Agricultural Sciences, the University of Dschang, Dschang, Cameroon

[2]Department of Mechanical Engineering, Ecole de Technologie Supérieure, Université du Québec, Montréal, Canada

[3]Department of Chemical Engineering, Universiti Teknologi PETRONAS, Perak, Malaysia

Abstract

Vegetable oils derived from non-edible seeds are excellent sources for producing biodiesel which serves as an alternative to fossil fuels. In this study, products viz vegetable oils and solid residues obtained from solvent extraction method of *Bauhinia variegata* and *Pachira glabra* seeds were characterized according to standard norms to evaluate their energy potential. The oils obtained have a free fatty acid content of 2.31 wt% and 13.6 wt%, a kinematic viscosity of 12.45 and 3.24 mm^2/s, an iodine value of 17.26 and 12.37 (g of I_2/100g of oil), a saponification value of 207.57 and 183.03 (mg of KOH/g of oil), a peroxide value of 10 and 8.06 (meq O_2/kg of oil), and a calorific value of 40.66 and 65.08 MJ/kg, respectively. Furthermore, the physicochemical analysis of the oils revealed that they are excellent choice for biodiesel production. In addition, the proximate analysis of the solid residues of *Bauhinia variegata* and *Pachira glabra* showed high level of protein, fiber, and total carbohydrates with respective values of 34.79 and 30.41 wt%, 10.44 and 15.16 wt%, and 47.50 and 52.92 wt%. Mineral analysis indicated a high concentration of minerals, particularly potassium, sodium, calcium, and phosphorus. The solid residues exhibit anti-nutritional properties, making it suitable for various applications such as bioconversion by black soldier fly larvae, bioelectricity, biogas production, and biofuels among others.

Keywords

Bauhinia variegata, Bioenergy, Oils, *Pachira glabra*, Seed Cake

1. Introduction

The depletion of fossil fuel and growing environmental concerns have stimulated the search for alternative fuels that can be derived from renewable sources [1]. To address this challenge, researchers have focused their efforts on production of biodiesel by using biomass, specifically non-edible seeds [2]. In this context, thanks to her equator-tropical climate, Cameroon, also

*Corresponding author: tebeulrich96@gmail.com (Ulrich Cabrel Kenmegne Tebe)

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known as Africa in miniature, has a diverse variety of oilseeds [3, 4]. This oilseed potential can not only create of large-scale oil processing industries but also provide employment opportunities to rural areas and diversify incomes for marginalized groups [5, 6]. The extraction of oil from these seeds results into two products: an oily part known as vegetable oil and a solid part called solid residue or cake [7]. The vegetable oils can be used to produce biodiesel, which can substitute conventional fuels and thus contribute to the reduction of greenhouse gases [1, 5]. On the other hand, oilcake is a solid material generated during the extraction of oil from seeds. It is considered as waste or by-product of little value [7]. Furthermore, the extraction of oil from oilseeds generates huge amounts of residues in the form of oilcake [5, 7-8]. For instance, out of 100 wt% of seeds used as biodiesel resources, only 35 wt% are converted into vegetable oil, while the remaining 65 wt% is oilcake, therefore, mismanagement of this waste could result in serious environmental issues in long term [5, 9]. It could contribute to greenhouse gas emissions [10] and cause unsanitary landfill conditions with several adverse consequences [11]. However, these residues contain bioactive compounds (carbohydrates, lipids, organic acids, proteins, vitamins, minerals, and antioxidants among others) that can be utilized in the agri-food, pharmaceutical, cosmetics, textile, and energy sectors [8]. By doing so, one adds more value to these solid residues while reducing the costs and risks associated with their disposal [12].

In literatures, many non-edible seeds, such as Neem, Jatropha, Karanja, Palm, and Castor [13] have been studied and found to be excellent choices for biodiesel production for engine applications. However, little is known about the seeds of *Bauhinia variegata L.* and *Pachira glabra pasq*, which are rarely or have not really been studied in Cameroon. These seeds are the raw materials used in this study.

Bauhinia variegata (BV) is an evergreen species of Leguminosae (Caesalpinioideae). It is commonly known in English as Orchid Tree, and Kachnar in Hindi [14, 15]. This tree has been identified in the western, southwestern, and northwestern regions of Cameroon, and has the potential to adapt to other parts of the country due to its ability to grow on all types of soil with low water requirement [16]. Also, BV is highly valued for ornamental purposes because of its beauty [16] and all parts of the plant are used for medicinal purpose [14, 15, 17, 18]. In addition, the seeds are good sources of protein, fat [17], vitamin A, and minerals [19], with a calorific value ranging from 20 - 21 MJ/kg [18-20]. However, the presence of anti-nutritional factors makes them harmful for animals and humans [21]. On the other hand, *Pachira glabra* (PG), also known as *Bombacopsis glabra*, is a tree that belongs to the Malvaceae family, and the Bombacaceae subfamily. This plant adapts well to various soil types and climates and is resistant to both drought and flooding [22]. In French-speaking countries, it is known as French peanut. In English-speaking countries, it goes by the name Malabar chestnut [22, 23]. PG is often cultivated in the recovery of degraded areas and as an ornamental plant in gardens and house yards because of its attractive flowers and its seeds [4, 24]. Moreover, their seeds contain 16-22 wt% protein, 40-50 wt% oil, fiber, minerals, vitamins, [22, 23], and have a calorific value of 22.57 MJ/kg [4]. However, the presence of anti-nutritional factors makes it difficult to optimally utilize these nutrients in humans [23].

Considering the potential of BV and PG seeds, this study aims to contribute to the development of current alternative energy resources that can replace conventional fuels and proposes ways to manage the waste products from extraction cakes. To this end, the oils from different seeds were produced via the Soxhlet extraction process with 99% pure n-hexane as solvent as described in section 2. The oils physicochemical properties were then analyzed according to the standard ISO (International Standard Organization). The cakes generated during the extraction process were analyzed for their proximate and mineral composition using AOAC (Association of Official Analytical Chemists) methods, as detailed in section 2. The results of these analyses and the potential of use the obtained products in industrial applications are presented in section 3.

2. Materials & Methods

2.1. Raw Materials and Sample Preparation

Approximately 1 kg of PG seeds were collected from the town of Djemgheu, while BV seeds (~ 1 kg) were obtained from the campus of the University of Buéa in Cameroon (Figure 1). To remove excess moisture from the seeds, they were dried at 105 ℃ for 12 hours until they reached a constant weight [25]. After drying, the seeds were finely ground using a SILVER CREST electric grinder (Model SC-1589). The resulting flour was then stored in dry paper bags to prevent any moisture absorption.

Figure 1. *BV seeds (A) and PG seeds (B).*

2.2. Oil Extraction from Seeds

For the extraction tests, 35 g of sample was used to extract oil using the n-hexane Soxhlet method. The method followed was described by ISO 659 standard method and reproduced by Suganya and Renganathan, [26] and Khan *et al.* [27]. The extraction was carried out at 60 ℃ for 6.5 and 10 hours for BV and PG respectively. The solvent volume in the flask was set at 200 ml. After the extraction time, the Whatman paper used to pack the sample was removed. To ensure complete distillation of the oil-solvent mixture, a final extraction cycle was performed to bring up the solvent still mixed with the oil in the extraction chamber. Finally, the flask containing the oil was placed in an oven at 100 ℃ for 12 hours to eliminate any residual solvent. The solid residues, along with the extracted oils, were packaged and stored for later analysis.

2.3. Chemical Composition of Oils

The oils obtained from BV and PG were analyzed using international standards ISO to determine their acid value and free fatty acid (FFA) content (ISO 660), iodine value (ISO, 3961), saponification value (ISO 3657), peroxide value (ISO 3960), kinematic viscosity at 40 ℃ (ISO 3104), and higher calorific value (ISO 1716).

2.4. Characterization of Solid Residues

2.4.1. Proximate Analysis of Solid Residues

The AOAC method was used to determine the proximate composition of oilcake. Moisture content was obtained using method no. 930.15. The Kjeldahl method was employed to determine the crude protein content by multiplying the total nitrogen content by the nitrogen factor 6.25 (method no. 988.05). Crude fiber was analyzed by acid digestion (method no. 958.06). To determine the ash content, the sample was heated at 500 ℃ for 8 hours as described in method no. 942.05. Lipids were extracted with n-hexane in a Soxhlet extractor. The carbohydrate content was calculated by difference according to Eq. 1, and the total energy value was estimated considering conversion factors of 4 kcal/g for proteins and carbohydrates, and 9 kcal/g for lipids [19, 28].

$$Carbohydrates\ (\%) = 100 - (Humidity + Ashes + Lipids + Proteins) \quad (1)$$

2.4.2. Mineral Analysis of Solid Residues

Flame spectrophotometry was used to analyze sodium and potassium content, while the photometric method was used to determine phosphorus concentration by AOAC [29]. Iron and zinc content were determined using UV-visible spectrophotometry following the method outlined by Thangiah *et al.* [30]. Calcium and magnesium contents were determined through EDTA (Ethylenediaminetetraacetate) complexometry, according the method described by Nielsen [31]. Finally, copper content was determined using the method described by Alikord *et al.* [32]. Mineral content was expressed in mg/100 g dry weight of oilcake.

2.5. Data Analysis

Each analysis was performed in three replicates (n = 3) and data were presented as mean values ± standard deviation.

3. Results & Discussion

3.1. Chemical Analysis of *Bauhinia variegata* and *Pachira glabra* Seed Oils

For BV and PG seeds, approximately 23.01 wt% and 47.08 wt% oil by mass were obtained, and the difference at 100% constituting the cake yield respectively. Table 1 presents the chemical properties of *Bauhinia variegata* seed oil (BVSO) and *Pachira glabra* seed oil (PGSO) extracted. The free fatty acid contents of BVSO and PGSO in this study are 2.31 wt% and 13.6 wt% respectively. For BVSO, this value is lower than what has been reported by Govindhan [20] (4.75 wt%) and Goga *et al.* [13] for Jatropha oil (2.7 wt%). On the other hand, these values are closed to that recommended by the Food Codex for cold-pressed virgin oils (2 wt%) [33]. However, it remains higher than those observed by Yatish *et al.* [18] (0.7 wt%) and Arain *et al.* [19] (0.6 wt%). For PGSO, it exceeds those reported by Ayodele & Badejo [23] (2.84 - 5.21 wt%) and Araújo *et al.* [24] (0.25 wt%). The FFA values obtained in this study may be due to seed storage conditions and time.

Table 1. Physicochemical properties of BVSO and PGSO.

No	Properties	*B. variegata*	*P. glabra*
1	Free Fatty Acid (wt%)	2.31 ±0.30	13.60 ±0.20
2	Kinematic viscosity at 40 ℃ (mm^2/s)	3.24 ±0.25	12.45 ±0.98
3	Iodine value (g of iodine /100 g)	17.26 ±0.18	12.37 ±0.27
4	Saponification value (mg KOH/g)	207.57 ±1.98	183.03 ±2.98
5	Peroxide value (meq O_2/kg)	10	8.06 ±2.02
6	Higher Heating value (MJ/kg)	40.66 ±0.06	65.08 ±0.13

No	Properties	*B. variegata*	*P. glabra*
7	Impurity content (%)	2.23±0.22	14.87±0.02
8	Oleic acid (%)	9.32±1.20	54.80±0.80

The respective kinematic viscosities of PGSO and BVSO are 12.45 and 3.24 mm^2/s. These values are significantly lower than those reported by Govindhan [20] and Yatish *et al.* [18] for BVSO (26.58 - 32.4 mm^2/s), by Yasin *et al.* [34] for *Anacardium occidentale* (13.78 mm^2/s) and coconut (27.64 mm^2/s) and by Araújo *et al.* [24] for PGSO (48.63 mm^2/s), rapeseed (37.0 mm^2/s) and soybean (32.6 mm^2/s). Furthermore, the kinematic viscosity of BVSO meets the requirements for the use of oil as biofuel according to ASTM D445 and EN ISO 3104, while PGSO does not [35]. However, both PGSO and BVSO cannot be used directly as biodiesel according to ASTM D 664 (acid value). Consequently, these oils must undergo post-treatment to improve their quality [34].

The iodine values for BVSO and PGSO are 17.26 and 12.37 g iodine/100 g, respectively. Sharma *et al.* [16] (84.5 g iodine/100 g), Govindhan [20] (83.7 g iodine/100 g), and Ayodele & Badejo [23] (8.28 g iodine/100 g) have reported iodine values that is higher than BVSO and slightly lower than PGSO. The values obtained in this study are lower than the values reported by Makinde *et al.* [36] for sesame (106 - 118 g/100 g) and Hoekman *et al.* [37] for rapeseed (116.1 g/100 g). According to the European Standard [35], the maximum iodine value of biodiesel should be 120 g I_2/100 g oil. The values obtained in this work indicate that both oils are excellent fuels for biodiesel production.

The saponification values of BVSO and PGSO are 207.57 and 183.03 mg KOH/g oil, respectively. These values are higher than those reported by Sharma *et al.* [16] (191.3 mg KOH/g oil) for BVSO and Ayodele & Badejo [23] (89.66 mg KOH/g oil) for PGSO, but close to those previously reported by Araújo *et al.* [24] (184.21 mg KOH/g oil) for PGSO and lower than the 248 - 265 mg KOH/g and 230 - 254 mg KOH/g reported for coconut and palm kernel oils [33]. In addition, the values obtained indicate the presence of a high proportion of low-molecular-weight triacylglycerols in BVSO and PGSO [19]. These values obtained comply with the quality requirements of the American standard for a use as biodiesel (ASTM D5558-95).

The peroxide values for BVSO and PGSO are 10 and 8.06 meq O_2/kg oil, respectively. These values are higher than 1.9 meq O_2/kg oil reported by Sharma *et al.* [16] for BVSO and lower than 28.56 meq O_2/kg oil reported by Ayodele & Badejo [23] for PGSO. The values obtained are also lower than 11.21 meq O_2/kg oil reported by Makinde *et al.* [36] for sesame seed oil. The peroxide values obtained comply with Codex Alimentarius [33], which sets a maximum value of 10 meq O_2/kg for refined oils and 15 meq O_2/kg for crude oils.

Finally, the higher heating values (HHV) for BVSO and PGSO were determined to be 40.66 and 65.08 MJ/kg, respectively. These values are higher than the values reported by Govindhan [20] and Yatish *et al.* [18] for BVSO, which ranged from 20.56 to 38.46 MJ/kg. They are also higher than the values reported for crude soybean and Jatropha oils, which were 39.6 MJ/kg and 40 MJ/kg, respectively [34]. Furthermore, the HHV values obtained in this study are comparatively high than other biofuels [34].

3.2. Proximate Analysis of *Bauhinia variegata* and *Pachira glabra* Oilcakes

Oil extraction from BV and PG non-edible seeds resulted approximately 76.99 wt% and 52.92 wt% oilcake, respectively. The proximate analysis of BV and PG seed cakes is shown in Table 2. The solid residues of BV and PG have low moisture content of 9.58 wt% and 8.98 wt%, respectively, which ensures longer storage stability without the need additional drying operations. The values are higher than the 6.7 wt% reported by Sharma *et al.* [16] for the BV sample and the 7.21 wt% reported by Yoca *et al.* [4] for the PG sample. The fat content of BV and PG oilcake are 2.89 wt% and 1.50 wt%, respectively. These values are close to those reported by Omowaye-Taiwo *et al.* [38] (1.56 - 2.57 wt%) for *Cucumeropsis mannii* seed meal. The protein contents of BV and PG solid residues are 34.79 wt% and 30.41 wt%, respectively. These values are lower than the 41.9 wt% reported for BV seed meal [16] but higher than the 24.23 wt% and 12.06 wt% reported for PG defatted seed meal [23] and *Pachira aquatica* seed [28], respectively. Thus, the solid residues of BV and PG can serve as an alternative protein source. BV and PG oilcake have total fiber contents of 10.44 wt% and 15.16 wt%, respectively, which are higher than the 6.9 wt% reported by Sharma *et al.* [16] for BV seed meal and the 9.20 to 10 wt% reported by Ayodele & Badejo [23] and Yoca *et al.* [4] for PG seeds. Therefore, BV and PG seeds are a rich source of total fiber. The carbohydrate contents of BV and PG seed cake are 47.50 wt% and 52.92 wt%, respectively. These values are higher than the 28.4 wt% reported for BV seed meal [16] and the 21.59 to 40.70 wt% reported by Yoca *et al.* [4] and Ayodele & Badejo [23] for PG seed meal. The solid residues of BV and PG can therefore be used as good sources of carbohydrates for human and animal nutrition.

BV and PG seed cakes have high ash contents of 5.25 wt% and 6.20 wt%. These values are higher than the 4.8 wt% reported for BV seed meal [16] and the 4.16 wt% reported by Rodrigues *et al.* [28] for *Pachira aquatica* seed meals.

Table 2. *Proximate composition of BV and PG seed cakes.*

Parameters	*B. variegata*	*P. glabra*
Dry matter (DM) (%)	90.43±0.12	91.02±0.13
Organic matter (%)	94.47±0.02	92.82±0.02
Moisture (% DM)	9.58±0.12	8.98±0.13
Ash (% DM)	5.25±0.35	6.20±0.28
Protein (% DM)	34.79±0.32	30.41±0.31
Fat (% DM)	2.89±0.01	1.50±0.06
Total fiber (% DM)	10.44±0.00	15.16±0.00
Total carbohydrates (% DM)	47.50±0.08	52.92±0.16
Total energy value (MJ/kg DM)	14.92±0.04	14.56±0.06

3.3. Mineral Analysis of *Bauhinia variegata* and *Pachira glabra* Oilcakes

This study reveals that BV and PG oilcakes contain a variety of nutritional essential minerals. For the solid residues BV, the most predominant is potassium (6288.85 mg/100 g dry weight (DW)), followed by sodium, calcium, and phosphorus (464.88, 368.50, and 314.80 mg/100 g DW, respectively) (Table 3). On the other hand, PG oilcake contains potassium (7925.13 mg/100 g DW) as the main mineral, followed by sodium, copper, and calcium (620.97, 456.45, and 417.50 mg/100 g DW, respectively) (Table 3). Interestingly, BV and PG oilcakes provide a better source of potassium than bananas, which are known to be a good source of this mineral. The oilcakes obtained in this study can help to meet the 31% of the Dietary Reference Intake for adult men and women, which is 4,700 mg/day [39]. It is worth noting that Ayodele & Badejo [23] found a lower mineral composition in PG seed meals with 20.35 - 32.6 mg/100 g DW potassium, 8.67 - 16.83 mg/100 g DW sodium, 17.21 - 23.84 mg/100 g DW phosphorus, 0.18 - 0.24 mg/100 g DW copper and 17.59 - 23.54 mg/100 g DW calcium compared to this study.

The concentration of copper in BV and PG seed cakes (110.85 and 456.45 mg/100 g DW) is higher than the recommended dietary allowance, which is between 0.9 and 2.0 mg/day. High levels of Ca, P, K, and Mg can also reduce blood pressure [23]. Furthermore, BV and PG oilcakes contain Zinc concentrations that exceed the recommended dietary intake of 15 mg, making them a good source of this essential trace element [28]. The Na/K ratio of solid residues is below 1.00, which is beneficial for diets aimed at regulating blood pressure. Additionally, the Ca/P ratio is higher than 1.00, indicating that oilcake could be used to prevent the reduction of bone mineral density in humans [23]. Therefore, BV and PG oilcakes are considered to be a good source of essential mineral elements.

Table 3. *Macro- and micro-mineral content of BV and PG seeds.*

Parameters	*B. variegata*	*P. glabra*
Micro-minerals (mg/100g)		
Fe	3.52±0.05	2.66±0.12
Zn	26.07±0.31	21.86±0.00
Cu	110.85±0.56	456.45±1.42
Macro-minerals (mg/100g)		
P	314.80±0.82	314.19±0.48
Ca	368.50±0.71	417.50±2.12
Mg	24.20±0.14	17.13±0.17
K	6288.85±1.62	7925.13±2.97
Na	464.88±0.02	620.97±0.37
Na/K	0.07	0.08
Ca/P	1.17	1.33

However, BV and PG oilcakes show high levels of Zn, which can lead to respiratory system damage, cause stress, and hinder normal growth and maturation [22]. Moreover, these seeds exhibit anti-nutritional factors that can negatively affect protein digestion (trypsin and chymotrypsin inhibitors), mineral absorption (lectins, phytates, and oxalates), starch digestion (amylase inhibitors and saponins), as well as the bioavailability of essential minerals [14, 21, 23, 28]. Therefore, the consumption of large quantities of these anti-nutrient-rich meals is toxic for both animals and humans. As a result, it is recommended to use the generated cakes for other purposes, as explained in section 3.4.

3.4. Energy Applications of Products

3.4.1. Energy Applications of the Oils Obtained

Non-edible oils are most commonly used in industry as a feedstock for biofuel production. BVSO and PGSO have physicochemical properties (iodine value, saponification value and peroxide value) that make them excellent fuels for direct use in engine applications, meeting ASTM D445 and EN ISO 3104 standards (see in section 3.1). However, even if the free fatty acid content and kinematic viscosity do not meet the requirements suggested for biodiesel feedstocks [34], their quality can be improved through post-treatment.

3.4.2. Energy Applications of *Bauhinia variegata* and *Pachira glabra* Oilcake

The most conventional practices of using oilcakes are animal or human feed and dumping in landfills [9]. However, using BV and PG seedcake directly as food or feed is not practical due to the presence of anti-nutrient factors, which affect the taste, protein digestibility, and absorption of essential nutrients [8, 40]. To use BV and PG oilcake as food, it needs to go through a combination of heat treatment and solvent extraction processes to remove the harmful compounds, which is economically feasible for commercial use [5]. On the other hand, oilcakes contain organic compounds that can be converted to generate energy for various applications, such as bioconversion into black soldier fly larvae (BSFL), bioelectricity, biogas, and biofuels.

Bioconversion into BSFL

Bioconversion using BSFL is an effective and promising alternative for valorizing BV and PG oilcake, due to its triple application. This bioconversion can produce protein-rich larval biomass at a lower cost, which can replace fish and soybean meal [41], but it also provides better compost that is rich in nitrogen, phosphorus, and potassium, which is highly beneficial for organic farming [42]. It can be used to synthesize biodiesel [43, 44]. The study conducted by Leonel *et al.* [45] used *Jatropha curcas* oilcake which is typically not used in animal feed due to its toxicity [46]. However, they fed it to black soldier fly larvae and achieved a high larval survival rate of 92.12% and bioconversion rate of 37.1%. The Jatropha oilcake used in their study had a lower organic matter content (92.86%) compared to BV (94.47%) and similar to PV (92.82%). It also had a crude protein content (22.29%) that was lower than BV (34.79%) and PG (30.41%), and an ash content (7.14%) that was not far from that of BV (5.25%) and PG (6.20%). BV and PG oilcake, although toxic to monogastric animals, can be a suitable feed for bioconversion by black soldier fly larvae, which could then be pressed to obtain larval oil for biodiesel production.

Bioelectricity

The valorization of BV and PG oilcake to generate bioelectricity could be a valuable option in rural areas that lack access to electrical infrastructure. Both BV and PG oilcake have a gross calorific value of 14.92 and 14.56 MJ/kg, respectively. A study by Raheman & Padhee [47] used Jatropha oilcake, which has a calorific value of around 18.2 MJ/kg [5], to produce briquettes for bioelectricity. This study showed an electricity output of 4.5 kW with consumption ranging from 4-5 kg/hour of Jatropha oilcake briquettes. Given that the calorific value of BV and PG oilcake is similar to that of Jatropha, it could be a viable alternative raw material to produce bioelectricity briquettes.

Biogas production

Another way to add value to BV and PG oilcake is by using them as a substrate for biogas production. The self-decomposition of oilcake in the open air, generates mainly methane, other gases of low proportions, and volatile organic compounds (VOCs) through the action of various micro-organisms [47]. The proportions of carbohydrates and proteins present in BV and PG oilcakes indicate that they can support anaerobic digestion, resulting a high calorific value in biogas, and a reduction in gaseous emissions like CH_4, VOCs, H_2S [5]. Pongamia oilcake has a gross calorific value of around 14.3 MJ/kg [5], similar to that of BV and PG oilcake, and was used in a study by Chandra *et al.* [48]. They observed a gas yield of around 0.703 m^3/day/kg in Pongamia cake over 30 days of retention time, with an average biogas methane content of 62.5%. Furthermore, biogas production via anaerobic digestion from BV and PG oilcake is great alternative to put oilcake to good use for energy production, and the effluent can be used for organic farming.

Thermochemical conversion

Due to their high organic matter content, thermochemical conversion is an effective way to use BV and PG oilcake. This process involves converting biomass into intermediate products such as liquids, solids, or gases through densification, pyrolysis, and gasification processes [8].

Densification involves compressing the residues to obtain high-density and calorific value solid products. Given their attractive gross energy value, as with the Jatropha oilcake used in the work of Primandari *et al.* [49], the production of BV and PG oilcake briquettes can replace the use of firewood or charcoal, which would generate income and reduce deforestation rates [50].

Pyrolysis, on the other hand, it is a process that uses heat to convert BV and PG oilcake in an inert atmosphere into three distinct products: biochar, bio-oil, and gas [5]. Like the studies by Figueiredo *et al.* [51], pyrolytic oil could be extracted from BV and PG oilcake with satisfactory yields and calorific values as bio-oil. These products could be used as biofuels in boilers, gas turbines, and stationary engines.

Gasification is a process that converts 60-90% of the energy contained in biomass into combustible gases. Studies on the conversion of Jatropha hulls (4% ash content with a calorific value of 16 MJ/kg) into synthesis gas have been carried out. These values are similar to those of BV and PG oilcake, indicating the potential of these oilcakes for energy exploitation by gasification. The potential synthesis gas produced could be used to generate electricity [5].

4. Conclusion

The results of the present study indicate that BV and PG seeds have oil yields comparable to several non-edible seeds. The oils from these seeds possess excellent physicochemical properties, making them a promising alternative for biodiesel production. Also, BV and PG seedcakes are rich in nutrients such as fiber, protein, and energy. They offer several advantages as biomass and can be used in bioconversion into BSFL, bioelectricity, biogas and biofuel. Future research may enable to assess the effectiveness of using BV and PG oilcake to produce bioenergy, and to evaluate its impact on pollution and environmental conservation.

Abbreviations

AOAC	Association of Official Analytical Chemists
BSFL	Black Soldier Fly Larvae

BV	*Bauhinia Variegata*
BVSO	*Bauhinia Variegata* Seed Oil
DW	Dry Weight
EDTA	Ethylenediaminetetraacetate
FFA	Free Fatty Acid
HHV	Higher Heating Values
ISO	International Standard Organization
PG	*Pachira Glabra*
PGSO	*Pachira Glabra* Seed Oil
VOCs	Volatile Organic Compounds

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Author Contributions

Ulrich Cabrel Kenmegne Tebe: Conceptualization, Formal Analysis, Funding acquisition, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing

Julius Kewir Tangka: Conceptualization, Investigation, Supervision, Writing – review & editing

Brice Martial Kamdem: Funding acquisition, Methodology, Validation, Writing – review & editing

Kunmi Joshua Abioye: Formal Analysis, Validation, Writing – review & editing

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Data Availability Statement

All data generated or analyzed during this study can be available upon request. If needed, you may contact the corresponding author for a soft copy of the data.

Conflicts of Interest

The authors declare no conflicts of interest.

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