Yield Evaluation and Primary Energy Assessment of the *Jatropha curcas* Oil Extraction Process for Use as a Biofuel in Engines

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Authors’ contributions

This work was carried out in collaboration among all authors. Author FTM designed the study, performed the statistical and primary energy analysis, wrote the protocol and wrote the first draft of the manuscript. Authors JATM, CLT and HEMG analyses of the study and managed the literature searches. All authors read and approved the final manuscript.

ABSTRACT

The aim of this work is to evaluate the performance of the extraction and mechanical filtering of *Jatropha curcas* oil and to evaluate the primary energy of the raw material resulting from the process, this is a qualitative-quantitative study of transversal order based on measurements and analysis of the process in situ: The following factors were evaluated as factors: weight of oil per seed processed, weight of pressed cake, and measurements in the filtering process, from which a balance of matter of the process used was constructed, and the energy valuation of the oil and pressed cake, energy was used as the response variable, measured in Tons of Oil Equivalent (TEP), Barrels of Oil Equivalent (BEP), and tons of Carbon Dioxide Equivalent (Ton CO2eq). The seed used is Creole, the one existing in the area, the extraction was carried out in a KEK-P0101 press, and a KEK-F0090 filter. The collected seeds were dried and then discarded, the average

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1. INTRODUCTION

The potential of biofuels as an alternative response to the growing global energy demand, increased consumption of fossil fuels and the depletion of oil reserves, is presented as a medium-term transitory path in the development of energy production technologies aimed at zero emissions and renewable character, with a high attraction for environmentalists, industrialists and scientists, who in many cases are attracted by the opportunity to generate knowledge, create new and modern industries, or mitigate environmental pollution and mitigate market alterations caused by anthropogenic climate alterations [1].

The production of biodiesel from vegetable oils constitutes a viable and ecological alternative to the current situation with fossil fuels due to their high prices, inevitable depletion, and level of pollution [2].

The use of biofuels is the most effective option that has been found, as they come from a renewable source, favor the development of agriculture, and contribute to reducing environmental deterioration. However, the sources of vegetable oils have generated another problem, as they include maize, soya, peanuts, to name but a few, whose use as biofuels affects food production, another of the serious problems facing humanity. This is why other sources have been sought, such as palm oil, Jatropha, cachaza (a by-product of sugar cane production), used frying oils, among others [3].

Jatropha is emerging on the market as the new proposal for obtaining biofuel. Jatropha Curcas is a plant belonging to the Euphorbeaceae family. Within the Jatropha genus, there are more than 170 species distributed in different parts of the world, especially in tropical areas. It has the advantages of being adaptable in areas not competent for food crops (due to resistance to low rainfall and low fertility soil conditions), having seeds with high oil content (30-40% by weight) and promoting job creation. However, there is little agro-industrial technological development [4].

The plant can reach 5 meters in height if pruning is not carried out. For this reason, it is known as a large shrub or small tree. The propagation method is varied: from sowing seed in soil, developing the crop in a greenhouse and then transplanting, or asexual reproduction (the latter is not recommended). Several authors recommend sowing in the warm months, during the rainy season, at 2 - 3 meters or 1.5 - 3 meters between plants and rows, generating a total of 1100 to 3300 plants per hectare. Seed germination takes 7 to 15 days, depending on the pre-treatment (wetting with water and acid solution) and agro-climatic conditions [5].

It is characterised as a crop suitable for planting in marginal soils, poor in nutrients, under arid and semi-arid conditions, with pH ranging between 6 and 8. This characteristic makes Jatropha Curcas a species used for soil reclamation, having a positive environmental impact from this point of view [7].

The fruit ripens 3-4 months after flowering, when the color changes from green to yellow. Harvesting is carried out manually, although there are new developments to make it mechanized. The time and extent of this stage varies according to seasonal conditions. In semi-arid regions, harvesting takes place during 2 months (daily or weekly), while in more humid areas, it can be harvested all year round [8]. Three seeds are counted per fruit. The fruit must be crushed to extract the seed, which represents 63.2% (36.8% corresponds to the fruit shell). The shell has a high fibre content compared to the
seed (85% vs. 3.5%), and a calorific value of 19.5 MJkg⁻¹, which allows it to be used as a direct fuel or in the form of briquettes [9].

The seed is dark in color, with a length of up to 2 cm. About 1375 units can be found in 1 kg of seed. The entire lipid content is found in the seed, the rest being crude protein and carbohydrates [4]. In Honduras, Jatropha or piñón is spread throughout most of the country; historically its cultivation was limited to the use of the plant as a living fence. There are villages and hamlets in municipalities in the south of Francisco Morazán where the seed is still used for the homemade manufacture of soaps, as well as for the treatment of some diseases, especially of the skin, wounds, rheumatism and as a purgative.

2. MATERIALS AND METHODS

The method used in this research is a qualitative-quantitative cross-sectional method based on measurements and analysis of the process in situ, evaluating samples of the quantity of oil per quantity of seed processed, quantity of pressed cake, and measurements in the filtering process. The seed collected from the field used in this transformation process is the creole seed existing in the area, the data were taken in situ in the vegetable oil bio extraction plant of DUMEN Investments, located in the city of Danlí El Paraiso Honduras. This plant carries out operations of transformation and commercialization of crude vegetable oil from the Jatropha curcas seed, which needs to process the large quantities of residual cake obtained during the process. The seeds will be harvested from approximately 100 acres of farmland located in the eastern region of Honduras.

2.1 Machines and Equipment used in the Process

The KEK-P0101 press has a pressure basket consisting of 22 sieve bars per section, there are two sections, one on the left and one on the right. The number of spacers between the individual bars depends directly on the type of seed to be pressed (Fig. 3).

The KEK-F0090 filter is a 21-plate filter that can carry 20 membranes (25x25 cm paper or cotton filters); the filters accumulate the solids from the dirty oil as it passes under pressure (about 5 bar), allowing a pure oil to be obtained. When the membranes become saturated with solids, the inlet pressure of the oil exceeds 5 bars and at this point the filter must be recalibrated, cleaning the membranes or making sure that the oil to be filtered is not too dirty (Fig. 4).

2.2 Description of the Jatropha oil Extraction Process Steps

Seed cleaning: Removal of weeds (sticks, sand, stone) to avoid damaging the press. This operation can be carried out manually or mechanically using a threshing machine. (Fig. 2)

Pressing: Extraction of seed oils can be carried out by two methods: physical extraction by pressing, or chemical extraction using a solvent. The selection of one or the other process on an industrial scale will depend on the size of the enterprise, with the chemical process being feasible when production exceeds 50 t of oil per day [7]. Extraction by pressing Jatropha seeds, depending on the type of machinery used, can take two forms: manual press or mechanical press. Sotolongo mentions that between 27-32% of the oil can be extracted by mechanical press [10] in this oil extraction process the temperature did not exceed 60 °C to avoid the release of phosphorus compounds. (Fig. 3).

Purification: The method of purification will depend on the amount of oil to be processed. For oil conditioning operations, the following methods can be used: filtration, decantation or even centrifugation [11].

Degumming and Neutralization: This stage of the process is carried out, in case refined oil is required. DIN 51605 states that the phosphorus content must be less than 12mgkg⁻¹. Phosphates, gums and other colloidal complex compounds can promote hydrolysis (increase of free fatty acids) of the vegetable oil during storage [12]. In this case the plant does not elaborate this process step.

In addition, these compounds can interfere with further refining steps such as trans esterification. The removal of these compounds is through a process called degumming. The process is initiated by heating the oil to 70-80 °C. Water is then added and agitated. The gums and phosphates will dissolve in the water and will be removed together with the water in a separation step [7].

Storage of the oil: Store in a cool, dry place, avoiding exposure to light and potential gaseous volatiles (such as gasoline). The tank in which
the oil is stored should preferably be hermetically sealed and filled to its maximum level. This prevents condensation and thus the presence of water in the oil [13].

Fig. 1. Cutting of fresh fruit and seeds (A), dried fruit and seeds (B) and green fruits (C) [6]

Table 1. SWOT analysis of Jatropha Curcas cultivation in Honduras

<table>
<thead>
<tr>
<th>STRENGTHS</th>
<th>WEAKNESSES</th>
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<tr>
<td>Jatropha Curcas plantations, as an energy crop and renewable source, have the potential to reduce emissions. Jatropha is a crop that grows well on marginal soils, can be used as living fences and is drought and disease resistant. By-products obtained from Jatropha Curcas seeds can be used in bio insecticides, hydraulic oil, organic fertilizer and biogas production, briquettes, etc. Existence of domestic market in transport and industry and trade. Native to Mesoamerica. The oil obtained needs less processing than the production of biodiesel. This crop grows wild in the national territory. There is a diversity of microclimates in Honduras. <strong>OPPORTUNITIES</strong> Favors the activation of the rural agricultural economy. Underutilized energy crop in Honduras. It contributes to the country’s energy sovereignty; this is a raw material that does not compete with human or animal food, and therefore promotes food security and sovereignty. There is existing cooperation to finance renewable energy projects. Other types of biofuels can be produced from Jatropha by-products. There is modified engine technology that works well. The price of renewable energy in Honduras is the highest in the Central American region.</td>
<td>The method to be used to extract the highest percentage of oil is by laboratory extraction, as it gives a higher extraction yield than that obtained by mechanical press. The people who make use of biofuel must have basic knowledge of the conditions under which vegetable oil can be used as fuel. It is a new product in Honduras, which generates some mistrust in the market. The toxicity of the by-products is limited to use for animal feed, unless otherwise treated. Absence of state policies on biofuels.</td>
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<tr>
<td>THREATS</td>
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<td>Because some properties of vegetable oil fuel have a higher flash point and higher viscosity than petro-diesel, conversion and modification in engines is indispensable. Climate change effects may affect crop productivity. Social opposition from the oil industry. High cost of engine modification. Lack of financial support for agricultural projects.</td>
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Oil filtering process: The KEK-F0090 filter is a 21-plate filter that can carry 20 membranes (25x25 cm paper or cotton filters); the filters accumulate solids from the dirty oil as it passes through under pressure (about 5 bar) allowing pure oil to be obtained. When the membranes become saturated with solids, the inlet pressure of the oil exceeds 5 bar and at this point the filter must be recalibrated, cleaning the membranes or making sure that the oil to be filtered is not too dirty. The capacity demonstrated by the plate filter was about 900 ml of clean oil in 21 minutes at each of the 10 filtered oil outlet valves. This is about 42.86 ml/min per valve, i.e. about 2571.43 ml/h (2.578 L/h) per valve, which makes a total of 25.71 L/h of clean oil obtained per hour. It is important to note that the internal capacity of the filter is about 20L, i.e. the filter will contain 20L of oil. From the above we say, it is not possible to filter a quantity less than 40L of dirty oil to obtain 20-25L of clean oil. (Fig. 4) The extraction of jatropha oil by means of the screw press requires constant monitoring due to the mechanical nature of the machine, at this point it becomes necessary to loosen the pressure flywheel to reduce the pressure exerted by the cone on the cake outlet.

2.3 Valuation of Equivalent Primary Energy resulting from the oil EXTRACTION Process

Given that the processing plant collects all the cake and has all the oil available, we calculate the energy available to it:

a. The energy contained in one ton of *Jatropha oil*: by means of the LHV (Lower Calorific Value) of the oil if we calculate based on one ton.

b. The calculation of the Lower Calorific Power (LCP) of the parchment was developed from the formulas proposed by [14], for the calculation of the lower calorific power of agricultural and forestry residues, and the calculation of biomass energy.

**Formula 1. Lower Calorific Value**

\[
PCI(x\%)(kJ/kg) = PCS(0\%)(kJ/kg) \times \left(\frac{100 - x}{100}\right) - 24.49 \times \left(x + 9 \frac{\% H}{100} \times (100 - x)\right)
\]

Where:
PCI = Lower Calorific Value
x = Biomass moisture.
PCI = Lower Calorific Value (kJkg⁻¹).
PCS = (kJkg⁻¹) Higher Calorific Power
%H = of hydrogen contained in biomass (*Cake Jatropha*).

**Formula 2. Obtaining biomass energy (15)**

\[
E_{\text{Biomass}} = PCI_{\text{Biomass}} \times \left(\frac{\text{kg Biomass}}{\text{dryingcycle/}}\right)
\]

Where:
E = Biomass Energy (kJ)
PCI = Lower calorific value of wood or parchment, (kJkg⁻¹)
kg Biomass per drying cycle
Also, evaluated estimating quantities of biomass energy (joule), Equivalent Tons of Oil (TOE), Equivalent Barrels of Oil (BEP) and Equivalent Tons of Dioxide of Carbon (Ton CO₂ eq)

3. RESULTS AND DISCUSSION

3.1 Material Balance Data

For the extraction process of crude oil from *Jatropha curcas* obtained from the measurements taken on the plant: The seeds were collected in the region of the plantations, dried to 6% humidity, and then discarded. The average weight of separated husk represents 40% of the total dry seed weight. An average of 13.60 kg of dehulled seed with 5.8% humidity was processed at different times. Based on this quantity, it was calculated to establish the percentages of the resulting products after the extraction process, obtaining on average the following results:

If we focus on the oil, which is the product of interest, we will see that 18.6% is rescued from the seed. The pressed cake represents 81.4 %. When the oil was put through the filter, no significant losses were obtained in terms of weight, as the same amount of oil that went in was the same as the amount that came out.

X. Aboubakar found that production techniques were used: extraction by the traditional method and extraction by the Bielenberg press. These extraction techniques have respectively a 22.02% yield (netyield) and a 26% yield (raw yield) [15-16]. They obtained 4.02% more oil than our method.

Furthermore, "15.2 % oil and 84.8 % pressed seed (cake) were obtained; these results were not used for the material and energy balance, as the press used has an efficiency of 70-80 % and the continuous press that will be installed has an efficiency of 90-95 %" [17]. Rovelo’s yields using the mechanical press model MPE-40 are relatively close, with a difference of 3.4% less than our study, and both works are from the same Eastern zone of Honduras, so the raw material was collected in the same geographical area of influence of this work.
Table 2. Material balance results

<table>
<thead>
<tr>
<th>Product</th>
<th>Average samples</th>
<th>Weight</th>
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</thead>
<tbody>
<tr>
<td>Pressed cake</td>
<td>5.78 Kg</td>
<td>42.50%</td>
</tr>
<tr>
<td>Cake in a basket</td>
<td>5.35 Kg</td>
<td>39.33%</td>
</tr>
<tr>
<td>Oil</td>
<td>2.47 Kg</td>
<td>18.6%</td>
</tr>
</tbody>
</table>

Table 3. Primary energy assessment of oil and cake

<table>
<thead>
<tr>
<th>TYPE OF OIL Equivalent</th>
<th>OIL</th>
<th>JATROPHA CAKE</th>
<th>TOTAL equivalent*Ton⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy MJTon⁻¹</td>
<td>39076.31</td>
<td>15969.30</td>
<td>55045.61</td>
</tr>
<tr>
<td>TEP</td>
<td>0.94</td>
<td>0.38</td>
<td>1.32</td>
</tr>
<tr>
<td>Ton CO₂ eq</td>
<td>2.90</td>
<td>1.18</td>
<td>4.08</td>
</tr>
<tr>
<td>BEP</td>
<td>20.87</td>
<td>8.53</td>
<td>29.41</td>
</tr>
</tbody>
</table>

According to the results in Table 1, show a final yield of 18.6% of Jatropha oil in the extraction by mechanical pressing using the press KEK-P0101, likewise we can denote that there is a 42.5% of pressed cake, as well as 33.33% of cake in the basket, making a total of 81.4% of cake, with a seed processed at an average of 5.8% moisture; According to [18] comments that by method of extraction of Jatropha oil an ultrasonic yield is obtained with 29.79% and in Soxhlet 26.03%. With extraction methods at laboratory level, which show a higher yield than the mechanical extraction used in this work with 18.6%, with the difference that the method used is industrial equipment, given that in the process used not all the oil contained in the Jatropha curcas seed is extracted, so a fraction of oil remains in the Jatropha cake after separating the oil.

Toral describes that "Having this plant and a group of new energy crops in marginal, eroded or potentially suitable but underutilized areas can be a strategic element to obtain biodiesel in a sustainable way, in combination with short-cycle crops and livestock, which would contribute to local agricultural development and, in parallel, would produce a beneficial effect on the economy of the countries, due to the development of various industries and technologies, generation of skilled labor and jobs, among others" [19]. This represents a crop with energy potential for the manufacture of oils for use as biofuels in the direct use of oil in engines, as well as the production of other products that could generate added value, especially in the dry tropical areas of Honduras. It also contributes to the country's energy sovereignty; this is a raw material that does not compete with human or animal food, and therefore promotes food security and sovereignty.

3.2 Primary Energy Resulting from the Process

Given that the processing plant collects all the cake and has the total availability of the oil, we calculate the energy available to it:

a. Energy contained in one ton of oil: The lower calorific value of Jatropha curcas is 9,335 kcal/kg according to [20] If we calculate for one ton of oil, we have an equivalent energy of 39076.39 MJ.

b. For the estimation of the available energy in the Jatropha cake we have the following data: Jatropha cake has a moisture content of 4.8%, for the yield of the cake we will take as a basis one ton of residue equal to 1000 kg, the percentage amount of Hydrogen that is contained in the Jatropha curcas seed is extracted, so a fraction of oil remains in the Jatropha cake after separating the oil.

Jatropha generates approximately one ton of seed cake per hectare (1000 kg) [20]. So, calculating the primary energy of the Jatropha cake using formula # 1 and # 2 we would have an equivalent energy of 15,969.3 MJTon⁻¹.

To obtain the equivalent energy from Table 2 we convert the PCI from kJ to MJ, and the kg to tons, and then apply the energy conversions in MJ. Primary energy comparisons, we use the conversion units of a TEP equaling 41680 MJ, and 7.2056 BEP, and 3.09 Ton CO₂eq [14].
According to Table 2 we determine that one ton of extracted oil has 39076.31 MJ Ton-1, which is equivalent to 0.94 TEP, 2.90 Ton CO2 eq, and 20.87 BEP. Similarly, one ton of Jatropha cake represents 15969.30 MJ, equivalent to 0.38 TEP, 1.18 Ton CO2 eq, and 8.53 BEP. The energy from the oil is destined for internal combustion engines or vehicles, but Jatropha press cake can also be processed and used as biomass for energy production or as fertilizer, thanks to its high content of nitrogen, phosphorus, and potassium. Another possible use is gasification: the calorific value (18 MJ kg-1) and the moisture content of 8% make Jatropha cake an interesting raw material for gasification [21].

### 3.3 Pure Vegetable Oil in Motors

Laurel cites that the processes required in the production of biodiesel compared to vegetable oil output material are more expensive to manufacture and therefore to sell on the market. Also, compared to vegetable oil and diesel fuel, biodiesel provides slightly less energy value, which translates into an increase in consumption of between 5 and 8% [22]. This is why the use of vegetable oil has many energy advantages over biodiesel, and in the Life Cycle Assessment (LCA) of the process it proves to be more sustainable, as the biodiesel process line is longer and generates by-products such as glycerin, considering that an engine using oil must be modified. Yuramaya write some use must be found for the large volumes of glycerin, which are by-products of transesterification [23].

On the other hand, biodiesel production is the cause of a huge shortage of food sources.

Therefore, two solutions are highlighted in the study to either increase the yield of existing biodiesel production. Processes or explore the new feedstocks for biodiesel [24]. Jatropha curcas in Honduras is a viable option for improving the energy matrix, since the country has unused land that has the conditions for the production and extension of this crop, and the plant grows wild in all regions of the country, and is a crop that is not used as a biofuel, since as an energy source it helps to reduce carbon dioxide, and as Toral et al. cite it is a plant native to Mexico and Central America [19].

### 3.4 Other uses of Jatropha Cake

The processing and utilization of production waste is considered a difficult task when exact methods are not known to make the best use of all existing resources in a processing plant. The constituents of the genus *Jatropha* include tannins, sapogenins, alkaloids, esters (oils), toxalbumins and cyanogenic compounds [25]. The toxicity of the plant is associated with different compounds of the aforementioned type, which are present in both leaves and fruits [3]. After extraction of the oil, which carries with it several of the toxic compounds, making it unsuitable for food use, the extraction cake still contains many of the toxic components that are present in the seeds of *Jatropha curcas* [3]. Pine nut cake has great potential to be used as a feed medium for both animal and human consumption after a detoxification process. Detoxification processes include thermal and chemical treatments. It has been determined that the nutrient content of pine nut cake after
detoxification treatments is not significantly reduced [26-28]. It is therefore necessary to look for other transformation alternatives to give it other uses, such as fertilizers, use of biomass, etc.

4. CONCLUSIONS

The use of non-edible vegetable oils such as Jatropha curcas oil is a viable option, as it does not require any extra transformation process, apart from filtering to be used by diesel engines, which greatly facilitates the process, making it more efficient compared to other options, such as biodiesel production. Of the raw material collected, the average weight of shell separated from the fruit was 40% in relation to the total weight of the dry seed, and in the processing line, average samples of 13.60 kg of seed with 5.8% humidity were pressed in each production cycle, obtaining an oil yield of 18.6% in relation to the weight of the dry seed, the rest being 81.4% of the weight of the pressed cake, and the oil obtained when it was passed through the filter, no significant losses were obtained in relation to the weight, as the same amount of oil in kilograms that entered was that which came out of the filter.

According to: Fig. 6 it was determined that the total primary energy between one ton of oil and one ton of Jatropha cake after oil extraction together contain 55045.81 MJTon-1, equivalent to 1.32 TEP, 4.08 Ton CO2 eq, and 29.41 BEP. The oil energy can be directly transformed into engines for different uses, likewise the Jatropha cake can be used in gasification, pyrolysis, or direct combustion processes by pre-treatment to improve efficiency, such as densification, size reduction, etc.

Because some properties of vegetable oil fuel have a higher flash point and higher viscosity than petro diesel, conversion and modification in engines is indispensable, in this case for the use of Jatropha oil a preheater was adapted to heat the oil before entering the compression chamber of the engine, an oil filter was also added, and an adjustment was made by increasing the pressure of the engine injectors, so the modified diesel engine car had an excellent performance with the combustion of the oil.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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