

Variations in oil content and biodiesel yield of *Jatropha curcas* from different agro-ecological zones of Ghana

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Abstract: *Jatropha curcas* is a perennial, deciduous, shrub, which produces seeds rich in oil that is easily convertible into biodiesel. The major constraint in achieving higher biodiesel yield of *J. curcas* is insufficient information about its climatic variability. The objective of the current work therefore was to evaluate the oil content and biodiesel yield of *J. curcas* from different climatic conditions in Ghana. *Jatropha* seeds were collected from six different agro-ecological zones of Ghana. Oil from each sample was obtained by employing soxhlet extraction using n-hexane. Base-catalyzed transesterification reaction was used to transform the oil into biodiesel. The free fatty acid content and moisture content of the *jatropha* oil and its biodiesel were determined according to the Association of Official Analytical Chemist method. The seed moisture content ranged from 6.00 to 8.40%, free fatty acid ranged from 2.79 to 4.96% and the oil content ranged from 44.20 to 49.70%. The biodiesel yield ranged from 82 to 90%. The least value was recorded in the Evergreen forest zone whilst the highest value was recorded in the Transition Savanah zone. Climatic condition based on rainfall, seed moisture content and free fatty acid characters studied presented highly negative correlation with biodiesel yield. It can therefore be concluded that in selecting seeds for either biodiesel production or for plantation establishment, selection should be geared towards minimal values for these parameters studied which automatically raise the biodiesel yield in *J. curcas* seeds. The results of this study could provide the development of active bioenergy enterprise that aim at biodiesel production from *J. curcas* plant in Ghana.

Keywords: Transesterification Reaction, Climatecondition, Seed, Moisture Content, Free Fatty Acid

1. Introduction

Energy is an important factor for economic growth and high standard of living. The world will need 50% more energy in 2030 than today, according to the International Energy Agency (IEA) report [1] and Shahid and Jamal [2]. Climate change is believed to be the most crucial global environmental problem in current times. It is estimated that if the average global temperature increases by more than 2°C, up to one million species could become extinct and hundreds of millions of people could lose their lives [3]. It is expected that about 4.1 billion metric tons of carbon dioxide will be released to the atmosphere from 2007 to 2020 from fossil fuel usage. Globally, transportation sector accounted for about 23% and 22% of total world CO₂

emissions in 2007 and 2008 respectively [4].

Energy from biomass offers cleaner option to fossil fuel. Biodiesel production from edible oils have been reported by several workers [5,6,7] and, its competition with food consumption has been a global concern. About 6.6 Tg (34%) of edible oil was estimated for worldwide biodiesel production from 2004 to 2007 [8] and biodiesel is projected to account for more than a third of the expected growth in edible oil use from 2005 to 2017 [8]. Consequently, employing nonedible oils in biodiesel production would eliminate the competition with food consumption [9] and it will also allow for compliance with ecological and ethical requirements for biofuel.

There are a number of nonedible, plant-based oil seeds available in many countries worldwide [10] and these serve

as sources of potential biodiesel production. One of such oil seed plant is *Jatropha curcas*, a perennial, deciduous, stem-succulent shrub [11], which produces seeds rich in oil and easily convertible into biodiesel. The species shows considerable performance variability [12,13,14] and with its ability to reclaim degraded and/or dry lands with potentially positive impact on biodiversity and soil resources [15]. It has attracted much attention as a feedstock for biodiesel production.

The fatty acid methyl ester of *Jatropha curcas* has been determined to be one of the 26 fatty acid methyl esters of oil that are most suitable for biodiesel production [16]. However, the major constraint in achieving higher biodiesel yield of *J. curcas* is insufficient information about its climatic variability. The objective of the current work therefore was to evaluate the biodiesel yield of *J. curcas* from different climatic conditions in Ghana.

2. Materials and Methods

2.1. Materials

Jatropha seeds were collected from six different agro-ecological zones of Ghana. Seeds were cleaned and dried in a laboratory oven at 105°C till constant weight was obtained. All chemicals used were of analytical grade and purchased from commercial suppliers.

2.2. Oil Extraction

Dried seeds were crushed in a rotary mill. For each sample, 250g was weighed and transferred into an extraction thimble whereupon soxhlet extraction proceeded using n-hexane as solvent. N-hexane was chosen as the extraction solvent because it is considered the best solvent for the extraction [17,18]. The extraction temperature and time were respectively 70°C and 6 hours. The oil was concentrated in a rotary evaporator and any residual n-hexane left was driven off by drying in an aerated oven at 70°C till constant weight was obtained. Each extraction was done in triplicate.

Oil content was calculated as follows based on average mass:

$$X = \frac{Mo}{Ms} (100\%) \quad (1)$$

where X = percent oil content

Mo = mass of oil extracted

Ms = mass of powdered seed used for extraction

2.3. Biodiesel Synthesis

Each oil sample from the different agro-ecological zones was synthesized into biodiesel by a transesterification reaction in a 1-litre batch reactor which was fitted with a reflux condenser, a thermometer and a stirrer in different ports. The reactor was immersed in a constant temperature water-bath maintained at 60°C.

For each sample, 300g oil was heated to 105°C for 30

minutes to drive off moisture. 3g NaOH catalyst was dissolved in 100g of methanol. The oil was transferred to the reactor and allowed to equilibrate to the water-bath temperature of 60°C. The NaOH-methanol mixture was immersed in the water bath and allowed to equilibrate to the water-bath temperature after which it was also transferred into the reactor and agitation immediately started. The reaction was allowed to proceed for two hours. The mixture was removed and left for five hours in a separatory funnel to allow gravity separation of phases into glycerol and biodiesel.

Tannic acid was added to the biodiesel to neutralize any remaining catalyst and washed with 25 % vol. of hot distilled water to remove impurities such as glycerine, soap and excess methanol. The mixture was allowed to settle. By using a separatory funnel, the pure biodiesel was separated from hydrated methanol. The biodiesel was heated at 105°C for 30 minutes to dry off any residual water. For each sample, the biodiesel processing was done in triplicate.

Biodiesel yield was calculated based on average mass as follows:

$$Y = \frac{Mb}{Mu} (100\%) \quad (2)$$

where Y = percent biodiesel yield

Mb = mass of dried biodiesel

Mu = mass of oil used

2.4. Characterization of Oil and Biodiesel

The primary parameters relevant to biodiesel yield by transesterification of vegetable oils using alcohol and a base catalyst are the free fatty acids (FFA) content and moisture content [19]. Osawa *et al.* [20] reported that, the FFA determination is also a measurement that is linked to the nature and quality of the feedstock as well as the purity of the oil. In this study, the FFA content and moisture content of the *jatropha* oil and its biodiesel were determined according to the Association of Official Analytical Chemist method [21].

3. Statistical Analysis

The samples data were analyzed using SPSS 20 software package. Each parameter was determined three times for each sample. Data shown in the tables are the means. Analysis of variance (ANOVA) and a Least Significant Difference test were used to determine significant differences ($p \leq 0.05$) among the samples from the different types of ecological zones. Pearson correlations, were also performed on the virgin oil parameters, biodiesel parameters and growing site conditions of *jatropha* seeds.

4. Results and Discussions

The seed moisture content ranged from 6.00 to 8.40%, free fatty acid ranged from 2.79 to 4.96% and the oil content ranged from 44.20 to 49.70% (Table 1).

The Least Significant Difference (LSD) revealed that for each of the seed parameters (moisture content, free fatty acid content and oil content), some of the means were significantly different whilst others were not (Table 2). This was the case for variations within a particular agro-ecological zone as well as variations across different agro-ecological zones. The highest moisture content was recorded for seeds from Kojokrom (8.40%) in the Wet Evergreen Forest (WEF) agro-ecological zone which was not significantly different from seeds from Wasa Amenfi in the same agro-ecological zone, but significantly different from seeds from Bibiani which is also in the same agro-

ecological zone. The mean moisture content of seeds from Kojokrom was significantly different from all other agro-ecological zones (Table 1). The minimum moisture content was recorded for seeds from Bawku (6.00%) in the Sudan Savannah (SS) agro-ecological zone which was not significantly different from seeds from Garu and Tempene in the same agro-ecological zone, but significantly different from seeds from all other agro-ecological zones (Table 1). In general, the mean moisture content of seeds from the Savannah agro-ecological zones (Transition, Coastal, Guinea and Sudan) were significantly different from those of the Wet Evergreen Forest and Deciduous Forest.

Table 1. Differences in mean *Jatropha* seed parameters based on agro-ecological zones.

Agro-ecological Zone	Locality	Moisture Content (%) ± SD	Free Fatty Acid (%) ± SD	Oil Content (%) ± SD	Annual Rainfall (mm)*
Evergreen Forest	Kojokrom	8.17 ± 0.25 ^a	4.85 ± 0.10 ^a	45.07 ± 0.51 ^{a,b}	2,200
	Bibiani	7.80 ± 0.2 ^b	4.79 ± 0.05 ^a	44.73 ± 0.46 ^a	
	Wasa Amenfi	7.90 ± 0.3 ^{a,b}	4.81 ± 0.15 ^a	44.77 ± 0.51 ^a	
Deciduous Forest	Nkawkaw	7.03 ± 0.15 ^c	4.17 ± 0.15 ^b	45.77 ± 0.68 ^b	1,500
	Kwahu-Tafo	7.10 ± 0.2 ^c	3.91 ± 0.26 ^{b,c}	46.37 ± 1.2 ^{c,d}	
	Sepaase	7.17 ± 0.21 ^c	3.72 ± 0.15 ^{c,e}	46.43 ± 0.40 ^{c,d}	
Transition Savannah	Yeji	6.53 ± 0.21 ^d	3.10 ± 0.31 ^d	45.93 ± 0.40 ^c	1,300
	Nkoranza	6.50 ± 0.10 ^d	3.81 ± .08 ^{c,e}	48.96 ± 1.02 ^f	
	Kintampo	6.53 ± 0.35 ^d	3.58 ± 0.46 ^{c,e}	48.50 ± 0.95 ^{c,f}	
Coastal Savannah	Winneba	7.60 ± 0.20 ^b	4.18 ± 0.24 ^b	45.13 ± 0.40 ^{a,b,c}	800
	Dodowa	6.80 ± 0.20 ^{c,d}	3.71 ± 0.01 ^{c,e}	45.33 ± 0.57 ^{a,b,c}	
	Cape Coast	6.67 ± 0.15 ^d	3.63 ± 0.06 ^{c,e}	45.20 ± 0.30 ^{a,b,c}	
Guinea Savannah	Tamale	6.47 ± 0.21 ^d	3.60 ± 0.03 ^{c,e}	48.17 ± 1.21 ^{e,f}	1,100
	Wa	6.63 ± 0.15 ^d	3.63 ± 0.03 ^{c,e}	47.30 ± 0.50 ^{d,e}	
	Kurugu	6.50 ± 0.17 ^d	3.61 ± 0.04 ^{c,e}	46.13 ± 0.85 ^{b,c,d}	
Sudan Savannah	Bawku	6.13 ± 0.12 ^e	3.51 ± 0.19 ^c	45.33 ± 0.91 ^{a,b,c}	1,000
	Garu	6.20 ± 0.10 ^{d,e}	3.63 ± 0.03 ^{c,e}	45.33 ± 0.57 ^{a,b,c}	
	Tempene	6.20 ± 0.10 ^{d,e}	3.84 ± 0.42 ^{b,c,e}	45.80 ± 0.96 ^{a,b,c}	

Values bearing the same letter in a column have mean difference not significant at the 0.05% level by LSD. SD: Standard deviation

*Source: SRID [39]

The maximum free fatty acid content was recorded for seeds from Kojokrom (4.95%) in WEF agro-ecological zone which was not significantly different from seeds from Bibiani and Wasa Amenfi in the same agro-ecological zone, but significantly different from seeds from all other agro-ecological zones (Table 1). The minimum free fatty acid content was recorded for seeds from Yeji (2.79%) in the Transition Savannah (TS) agro-ecological zone which was significantly different from seeds from Nkoranza and Kintampo in the same agro-ecological zone, and also significantly different from seeds from all other agro-ecological zones (Table 1). In general, the mean moisture content of seeds from the Savannah agro-ecological zones (Transition, Coastal, Guinea and Sudan) were significantly different from those of the Wet Evergreen Forest and Deciduous Forest.

The water and free fatty acid (FFA) contents are critical factors for transesterification reaction. Transesterification reaction by a base catalyst requires water free and low acid value (< 1%) raw materials [22] for biodiesel production. If the oil samples have high FFA content (more than 1%) then the reaction requires more alkali catalyst to neutralize the FFA. Presence of water gives greater negative effect than

that of FFAs because Water can cause soap formation and frothing which can cause increase in viscosity. In addition formation of gels and foams hinders the separation of glycerol from biodiesel [22,23]. Water and FFA also leads to the reduction of methyl ester [24]. Thus, an important consideration in feedstock selection for biodiesel production is the content of free fatty acid (FFA) in the oil [25,26]. When oil with high FFA content is used to produce biodiesel, it results in low yield and soap formation [27]. Therefore, oil with low FFA content is often preferred for direct utilization in the transesterification process during biodiesel production. Also, the moisture content which depends on the quality of feedstock has significant effect on the transesterification of glycerides with alcohol as catalyst during the biodiesel production process [28].

Localities within the agro-ecological zones varied significantly in oil content (Table 2). Within localities, seeds collected from the TS had the highest oil content from Nkoranza (49.7 %) which was significantly different from oil content of seeds from all other agro-ecological zones except the GS for Tamale locality. The oil content from Nkoranza happened to be the highest recorded in this study. The Yeji locality had the minimum mean oil content

(45.93 %) in this agro-ecological zone which was higher than the mean highest value recorded for the Evergreen Forest (45.07 % in Kojokrom locality) (Table 2). For the other zones, the maximum oil content recorded were from the localities Sepaase (46.43 %), Dodowa (45.33 %), Tamale (48.17) and Tempene (45.33) in their respective agro-ecological zones. In the entire study, the minimum mean oil content was recorded for seeds from Bibiani (44.73 %) which was not significantly different from the other localities within its agro-ecological zone and the Sudan Savannah agro-ecological zone, but significantly different from Transition Savannah and Guinea Savannah (Table 1). In general, agro-ecological zones with high rainfall recorded low oil content (Figure 1). Oil content of seeds from Transition Savannah and Guinea Savannah were not significantly different but significantly different from Sudan Savannah which was not significantly different from seeds from Deciduous, Evergreen and Coastal Savannah zones (Figure 1).

Variation in oil content of oil seeds have been reported and have variously been attributed to genetic and/or climatic conditions [29-35]. In general, the oil content of *J. curcas* from drier areas were higher than those from wetter areas in this study. This is in agreement with work done by Jones and Miller [32] and Kumar *et al.* [36] who observed that drier climate improves the oil content in *J. curcas* seeds. The oil content were higher than those reported for India which ranged from 35-40% [37, 38]. The differences may be due to differences in environmental conditions, genetic make-up of the seeds and the oil extraction methods.

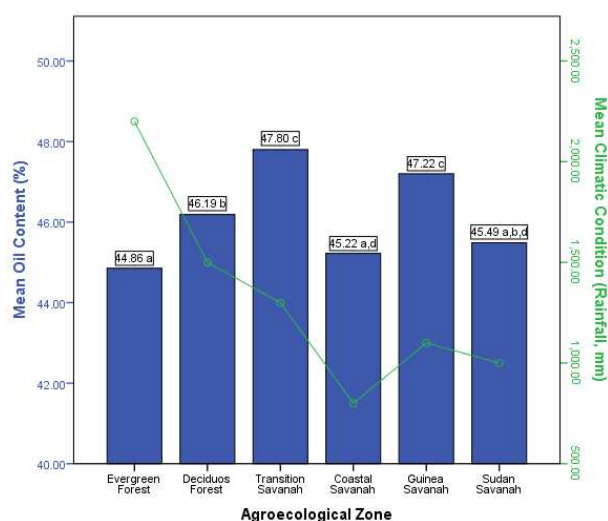


Figure 1. Effect of rainfall on oil content of seeds from different agro-ecological zones.

Values bearing the same letter are not significantly different at the 0.05% by LSD.

The biodiesel yield ranged from 82 to 90% (Fig. 2). The least value was recorded in the Evergreen forest zone whilst the highest value was recorded in the Transition Savannah zone. There were significant differences in the biodiesel yield from *Jatropha* seeds collected from the Evergreen

Forest zone compared to seeds from all other ecological zones. Similarly, there were significant differences in the biodiesel yield from seeds collected from Transition Savana zone compared to seeds from all other ecological zones. However, there were no significant differences in the yields from both Coastal Savana and Guinea Savana zones compared with Deciduous and Sudan Savana zones.

In the transesterification synthesis of biodiesel, the higher the FFA content of the oil the more alkali required to neutralize the FFA. This leads to soap formation and the separation of products becomes difficult resulting in low yields of biodiesel [40]. This could explain the low biodiesel yield of seeds in the Evergreen Forest zone which have relatively high FFAs. Free fatty acids have been found to increase due to the presence of moisture and oxygen [41, 42]. Also, increase in the FFA content of the seeds could be attributed to improper handling and storage of the seeds before the oil extraction process as reported by Kartika [43].

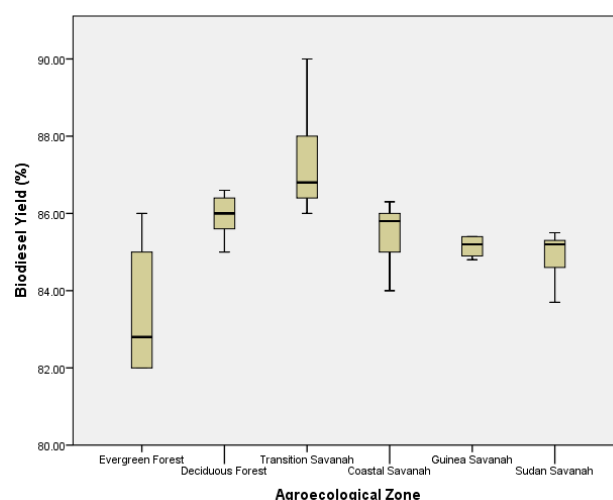


Figure 2. Biodiesel yield from different agro-ecological zones.

Table 2. Relationship between oil and biodiesel parameters and climatic conditions.

Pearson Correlations			
Interactions	Coefficient (r)	Interactions	Coefficient (r)
CCR-Seed MC	0.72*	BY-OC	0.35*
CCR-BY	-0.38*	BY-FFA	-0.72*
CCR-OC	-0.19	OC-Seed MC	-0.42*
CCR-FFA	0.73*	OC-FFA	-0.35*
BY-Seed MC	-0.45*		

* Correlation is significant at the 0.01 level (2-tailed).

CCR - climatic condition based on rainfall; MC - moisture content; BY - biodiesel yield; OC - oil content; FFA - free fatty acid.

In Pearson correlation, the general rule of thumb about the degree of relationship is that r values greater than 0.50 indicate a strong correlation, r values around 0.30 indicate a moderate correlation and r values less than 0.20 indicate a weak correlation. From Table 2 it can therefore be deduced that there is a strong positive relationship between rainfall climate condition at plantation site and *Jatropha* seed moisture content ($r = 0.72$) on one hand and free fatty acid on the other hand ($r = 0.73$). Thus, a higher amount of rainfall is related to a higher

amount of moisture content and free fatty acid. However, there is a moderate negative relationship between rainfall climate condition at plantation site and biodiesel yield ($r = -0.38$), as well as a weak negative relationship with oil content ($r = -0.19$). Thus, increased rainfall is related to a lower biodiesel yield and lower oil content. Similarly, there was a strong negative relationship between free fatty acid content and biodiesel yield ($r = -0.72$) as well as a moderate negative relationship with oil content ($r = -0.35$). Hence increased free fatty acid content is related to lower biodiesel yield and lower oil content.

5. Conclusion

This study showed that the biodiesel yield ranged from 82 to 90% in the different agro-ecological zones of Ghana. The maximum yield obtained was from seeds in the Transition Savannah zone whilst the minimum value was recorded for seeds in the Evergreen forest zone. In general, the oil content of *J. curcas* from drier areas were higher than those from wetter areas in this study. Although *jatropha* can withstand harsh climatic condition with very low rainfall, the oil content as well as the biodiesel yield is better in the Transition Savana with around 1,300 mm rainfall.

In the study, climatic condition based on rainfall, seed moisture content and free fatty acid characters studied presented highly negative correlation with biodiesel yield. It can therefore be concluded that in selecting seeds for either biodiesel production or for plantation establishment, selection should be geared towards minimal values for these parameters studied which automatically raise the biodiesel yield in *J. curcas* seeds. Similarly, seed oil content presented moderate negative correlation with climatic condition based on rainfall, seed moisture content and free fatty acid characters studied. Thus, in selecting seeds for plantation establishment, consideration should be given to minimal values for these parameters studied which automatically increase the oil content in *J. curcas* seeds.

The results of this study could provide the development of active bioenergy enterprise that aim at biodiesel production from *Jatropha curcas* plant in Ghana.

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