Oil yield from *Euphorbia tirucalli* as an alternative bioenergy source in Tanzania

Hamisi Yunus Nchimbi

College of Natural and Mathematical Sciences, University of Dodoma (UDOM), P. O. Box 259, Dodoma, Tanzania

**ARTICLE INFO**

**Keywords:**

*E. tirucalli*

Liquid biofuel

Oil yields

Stem girth size

Phylloclades

Agro-ecological zones

**ABSTRACT**

Due to the worldwide increase in the demands for bioenergy sources to replace fossil fuels, *Euphorbia tirucalli* oil produced by stems and modified leaves (phylloclades) is a valuable liquid fuel as an alternative energy source for biofuel production. In this study, *E. tirucalli* oils were extracted from stem barks with varying stem girths (20cm–80cm) and fully grown apical phylloclades. Soxhlet apparatus was used in oil extraction according to Luque de Castro and García (2000). The percentage (%) oil yield was calculated by the weight of extracted oil to the total weight of the dried sample (20g). The study hypothesized that significantly higher oil yields would be obtained from larger stem girths than phylloclades of the same trees in different Agro-Ecological Zones (AEZs). Likewise, the difference in oil yields was higher in the Semi-arid AEZ than in the Southern highland and the Coast AEZs (p > 0.05). Results showed slightly higher oil yields from large stem girths [16.47% ± 0.34%/100g] max = 82.35% ± 0.34%/100g] than phylloclades [15.7% ± 0.49%/100g] max = 78.5% ± 0.34%/100g] in different AEZs. Oil yields from Semi-arid [82.35% ± 0.34%/100g] max and 78.5% ± 0.49%/100g] max were slightly higher than Southern highland [79.0% ± 0.34%/100g] max and 76.4% ± 0.49%/100g] max and the Coast [76.4% ± 0.34%/100g] max and 70.25% ± 0.49%/100g] AEZ. But the difference in oil yields was not significant (p > 0.05). Results exhibited increasing patterns in the percentage (%) oil yields from low (20cm) to larger (80cm) stem girths. High oil yields between stem girths (82.35%) and phylloclades (78.5%) suggest that *E. tirucalli* oil is suitable for liquid biofuel production as an energy source in Tanzania.

1. Introduction

Tanzania like other Sub-Sahara African countries are vulnerable to the global problem of the future crisis of inaccessible, unaffordable, and fluctuating costs of fossil fuels (Yamamoto et al., 2001; von Malitz and Stafford, 2011). Due to this problem, the country has to capitalize on the development of the biofuel sector, especially liquid biofuels. Liquid biofuels are renewable fuels derived either directly or indirectly from plant materials, which have emerged as alternative fuels having the potential to replace fossil fuels (OXFAM, 2008; Sulle and Nelson, 2009). The liquid biofuel sector is still underdeveloped, although it is an alternative to solve the liquid biofuel yield challenge in Tanzania (Sulle and Nelson, 2009). Liquid biofuels can be obtained from various sources including biomass from diverse oil-yielding plant species (Granda et al., 2007). However, the majority of oil-producing plants in Tanzania are based on traditional food crops such as maize, rapeseed, or sunflower, and a few non-food seed plant species, including *Jatropha curcas* (L. and P., 2011). *Phot* (2005) reported the possibility of using latex plants from various plant families such as Euphorbiaceae, Asclepiadaceae, Sapotaceae, Moraceae, etc. to produce oils that could be used as substitutes for fossil fuels. These oils have characteristics (low molecular weight of 20,000 and carbon chains of C15, C20, and C30) suitable for conversion into liquid biofuels and used as energy sources to drive moving and stationary engines (Torii et al., 1998; Sekar and Francis, 1998). *Euphorbia tirucalli*, L. (African Milk bush), is a tree in the family Euphorbiaceae which is abundantly naturalized in the Eastern African countries including Tanzania (Ohyama et al., 2009). *E. tirucalli* exudes a whitish milky sap (latex) which contains oils, when wounded (Loke et al., 2011). The oil fractions are sources of energy in the form of liquid biofuels that can be used to power engines and other machines (Taylor, 2015; Phot, 2005; Loke et al., 2011). The plant is cactus-like succulent tree that can reach 12m height and exceeds 75cm girth with spiny branches, whorled cylindrical and cracked green-brown stem bark (Van Damme, 2001). It contains brittle succulent branchlets of approximately 7 cm thick frequently produced in whorls that are modified to form phylloclades (Priya and Rao, 2015). The composition of *E. tirucalli* oils, just like other plants can be obtained as a mixture of volatile and natural organic substances called oils in non-seed parts such as stems and leaves.
(phyllochlades) (Alamu et al., 2007). These oils can be extracted through processes such as distillation, expression, or solvent extraction (Price-waterhouseCoopers et al., 2017). Oils from these parts have been extensively used in ancient Rome, Greece, Egypt, and the Middle East as perfumes, flavors, deodorants, antiseptics, and pharmaceuticals. As a result of advancements in processing technologies, they are currently used in liquid biofuel production (Alamu et al., 2007; PricewaterhouseCoopers et al., 2017).

Several factors including climate, seasonal variations, plant organs, and developmental stages have been reported to influence yields of oil in plants (Sangwan et al. 2001; Duarte et al., 2009). For example, Taveira et al. (2003), studied variations in oil yields in dry and wet seasons between stems and leaves of Aniba canellii. They reported higher oil yields in stems than in leaves in the same seasons. Another study from Manthias et al. (2012) reported oil yields only in stems of Aniba canellii than in leaves. Thus, the study hypothesized that oil yields were significantly higher in E. tirucalli stems than in phyllochlades and large stem girths had significantly higher yields than phyllochlades obtained from shoots of large stem girth trees in different AEZs respectively. Such higher yields might suggest the possibility of using whole or parts of E. tirucalli plants as sustainable sources of liquid biofuel production in Tanzania. Gershenson et al. (2000) reported that there are differences in oil yields between leaves and stems whereby higher yields were obtained from new stems than the older ones. According to Gershenson et al. (2000), small stems results in higher yields than large stems. Also, Bisht et al. (2019) studied variability in oil yields from Santalum album L. trees, and obtained different results; higher total oil yields of 3.6 % from larger girth size trees (82.4 cm) than yields of 1.6% from small girth size (47.1 cm) trees. These results showed that there was high variability in oil yields between large and small stem girths. Due to this information, the study further hypothesized that the difference in oil yields between large (old) and small (new) stem girths was significantly higher among AEZs such as Dodoma, Dar es Salaam and Mbeya. Also, Dodoma AEZ had significantly higher yields than Mbeya and Dar es Salaam AEZ. However, in some cases described above, there were no explanations for a particular percentage of oil yielding trends between the girth sizes (cm). Furthermore, it shows that yields of oil from plants vary widely, and each species has a specific response to factors influencing yields. In general, there is a shortage of important studies reported to date, which revealed suitability on yields of oil from E. tirucalli plant parts in Tanzania. Also, harvesting E. tirucalli parts instead of cutting the whole plant is an alternative and sustainable means of oil production. Besides, conducting oil yield studies using E. tirucalli is of particular importance as a means of assessing its difference from other plant species as an alternative energy source for sustainable means of oil production. Besides, conducting oil yield studies using whole or parts of E. tirucalli plants as sustainable sources of liquid biofuel production (Alamu et al., 2007; PricewaterhouseCoopers et al., 2017).

2. Materials and experimental methods

2.1. Description of study areas

Sample collection was carried out in three study areas viz., in semi-arid (Bahi-Dodoma), coast (Goba-Dar es Salaam) and, Southern highland (Iyela-Mbeya) AEZs (URT-NAPA, 2007). The selection of these areas was based on the difference in their eco-environmental conditions described by URT-NAPA, (2007). Such differences possibly resulted in the disparity in oil yields from E. tirucalli plants parts (stem girth and phyllochlades). The climate of Dodoma AEZ, is semi – arid having latitudes 4°S and 7°S and longitudes 35°E – 37°E. Its altitude is 1000–1500 m and has a well - drained soils with little fertility. Dodoma has about 31 °C and 17 °C and 800mm – 500 mm average maximum and minimum annual temperature and precipitation respectively. The rainfall in Dodoma is unimodal and, erratic (URT, 2007; Mayaya et al., 2015). The climate of Dar es Salaam is tropical which is warm and humid. This zone is lying between latitudes 6.45°S and 7.25°S, and longitudes 39°E and 39.55°E having an altitude of below 3000meters. It has moderate to low sand soil fertility. The minimum temperature is roughly 26 °C, with 32 °C maximum temperature during the hot season. There are two rainfall modes in Dar es Salaam, with the average rainfall per year is around 750–1200mm (URT, 1997; 2007). The climate of Mbeya AEZ is tropical with latitudes 7°S and 9°S and Longitudes 32°E and 35°E. Mbeya is located at an altitude of 1200–1500m. There is unimodal and reliable rainfall distribution in Mbeya, which is approximately between 800-1400mm. The annual temperature is 21 °C. The zone has volcanic clay soil with medium fertility (URT, 1997; 2007; Janssen, 2005).

2.2. Collection of plant samples

E. tirucalli trees with 10cm difference in girth sizes from each other, were collected for oil extraction in three studied AEZs. A total of four stem girth samples were collected through peeling away the square (20cm wide by 20cm long) outer stem bark from four trees of equal girths covering (20cm–80cm) girths at breast height from selected tree girths. Mature apical phyllochlades were collected from E. tirucalli shoots from the same trees where stem bark sampling has been previously conducted. Then, samples were packed into labeled plastic bags and transported to the Chemical and Mining Engineering laboratory (CMEL) at the University of Dar es Salaam (UDSM) for oven drying at 70°C. The dried samples were ground into fine particles by using an electric blender, then their dry weight was determined. After obtaining sample dry weight, they were stored in a refrigerator (4 °C) for oil extraction and analyses.

2.2.1. Oil extractions and partitioning

Four corresponding dried samples (20g) from the ground plant samples were collected for oil extraction (Figure 1) in each designated study area. Then, the finely ground samples were extracted with 150mls analytical grade acetone for 8 h in a conventional Wheaton Soxhlet apparatus (500-mL flask, ASTM E 438 Type 1) available at CMEL, according to the methods described by Kalia and Saekia (2004); Luque de Castro and García (2000). Soxhlet technique was suitable for extraction and separation of a large number of solid samples (e.g. 10–30g), did not require filtration after the extraction, and was not matrix-dependent (Luque de Castro and García (2000). After vaporizing acetone at 38 °C from the rotary evaporator after 8 h, the remaining E. tirucalli extracts were collected in a flask. Then the extracts were separately partitioned using a separatory funnel in blends of hexane and water. The dissolved oils (in hexane) were distributed at the top of the funnel, and the polyphenols (polar components dissolved in water) persisted at the bottom. Hexane was evaporated with a rotary evaporator at 68 °C to obtain oil fractions. The remaining oil extracts were collected in a weighed flask which was then kept to cool for roughly 5 min before reweighing the flask again. By deducting the weight of the empty flask from the weight of the flask with oil, then the weight (g) of oil extracts was determined. The procedures were repeated for all samples to obtain mean oil yields (g).
2.2.2. Oil yields determination (%)

After obtaining average oil yields (g) from each stem girth size and phylloclade. Then the percentage (%) yields were calculated using Eq. (1);

\[
\text{The percentage yield} \% = \frac{\text{Weight of the Oil Extracts (g)}}{\text{Dry Weight of the Sample (20g)}} \times 100
\]

3. Data analyses

By using Statistical Package for Social Sciences (SPSS Purchased v.15), the 2- tailed paired sample t-test was used to determine any differences in oil yields between \textit{E. tirucalli} phylloclades and stem girths from three AEZs at the \( p < 0.05 \). Graphs were drawn using one-way multivariate analysis of variance (one-way MANOVA) profile plots in SPSS Statistics. Oil yields were reported in terms of percentage \%/C6 Standard Error \%/C6 which were analyzed by means of individual stem girth sizes.

4. Results

The percentage (%) oil yields (stem girths and phylloclades) of \textit{E. tirucalli} acquired from different AEZs in Tanzania are presented in Table 1. Results showed that there were differences in oil yields (%) between \textit{E. tirucalli} phylloclades and stem girths from low (20cm) to larger stem girth sizes (80cm). Such differences occurred within and among different AEZs as follows; in Dodoma semi-arid, stem girths produced 4.2% ± 0.01%//(20g) to 21% ± 0.01%//(100g) and 16.47% ± 0.34%//(20g) to 82.35% ± 0.34%//(100g), while phylloclades produced 4.9% ± 0.02%//(20g) to 15.7% ± 0.49%//(100g) and \( p < 0.05 \). In Mbeya Southern highland, stem girths produced 4.17% ± 0.01%//(20g) to 15.8% ± 0.34%//(100g) and 20.85% ± 0.01%//(100g) to 79% ± 0.34%//(100g) while phylloclades produced 4.85% ± 0.02%//(20g) to 15.27% ± 0.49%//(100g) and \( p < 0.05 \). Also, in the Dar es Salaam coastal zone, stem girths produced 4.17% ± 0.01%//(20g) to 15.28% ± 0.34%//(100g) and 20.85% ± 0.01%//(100g) to 76.4% ± 0.34%//(100g) while phylloclades produced 4.82% ± 0.02%//(20g) to 70.25% ± 0.49%//(100g) and \( p < 0.05 \). These results showed that, the maximum oil yields from \textit{E. tirucalli} which occurred in large stem girths (80cm) and phylloclades were slightly higher in Dodoma semi-arid [82.35% ± 0.34%//(100g)] and [78.5% ± 0.49%//(100g)] than in Mbeya Southern highland [79% ± 0.34%//(100g)] and [76.35% ± 0.49%//(100g)] and Dar es Salaam coast [76.4% ± 0.34%//(100g)] and [70.25% ± 0.49%//(100g)] AEZs respectively.

The results revealed that large stem girths (80cm; 16.47% ± 0.34%) from semi-arid AEZ had high oil yields and the lowest yields were obtained from low stem girths (20cm; 4.17% ± 0.01%) both in the southern highland and, the coast zones respectively (Figure 2). Also, the high oil yields in phylloclades were obtained from large stem girths (80cm; 15.7% ± 0.49%) in semi-arid while the lowest yields were obtained from low stem girths (20cm; 4.82% ± 0.02%) in the coastal zones, respectively (Figure 3). However, the t-test results (Table 2) demonstrated that such difference in \textit{E. tirucalli} oil yields between stem girths and phylloclades was not significant at the \( p > 0.05 \) level both within and between selected AEZs. This means that in spite of the differences in oil yields obtained
Table 1. Variations in E. tirucalli oil yields (Percentage (%) ± standard error) from stem girth and phylloclades among different agro-ecological zones.

| Ecological zone           | Stem Girth Size (Cm) | 20   | 30   | 40   | 50   | 60   | 70   | 80   |
|---------------------------|----------------------|------|------|------|------|------|------|------|
| **Dodoma semi-arid zone** | Average Oil Yields from the Stem girth (%) | 4.2 ± 0.01 | 8.47 ± 0.89 | 10.27 ± 0.83 | 12.72 ± 0.89 | 13.87 ± 0.94 | 15.7 ± 1.64 | 16.47 ± 0.34 |
|                           | Average Oil Yields from the Phylloclades (%) | 4.9 ± 0.02 | 6.68 ± 0.68 | 9.85 ± 0.77 | 10.9 ± 0.37 | 12.9 ± 0.42 | 12.8 ± 0.46 | 15.7 ± 0.49 |
| **Mbeya southern highland zone** | Average Oil Yields from the Stem girth (%) | 4.17 ± 0.01 | 9.8 ± 0.89 | 10.42 ± 0.83 | 12.05 ± 0.89 | 12.72 ± 0.94 | 13.93 ± 1.64 | 15.8 ± 0.34 |
|                           | Average Oil Yields from the Phylloclades (%) | 4.85 ± 0.02 | 7.25 ± 0.68 | 7.8 ± 0.77 | 10.37 ± 0.37 | 11.57 ± 0.42 | 12.67 ± 0.46 | 15.27 ± 0.49 |
| **Dar es Salaam coastal zone** | Average Oil Yields from the Stem girth (%) | 4.17 ± 0.01 | 6.7 ± 0.89 | 7.85 ± 0.83 | 9.77 ± 0.89 | 10.65 ± 0.94 | 12.15 ± 1.64 | 15.28 ± 0.34 |
|                           | Average Oil Yields from the Phylloclades (%) | 4.82 ± 0.02 | 8.35 ± 0.68 | 10.32 ± 0.77 | 11.65 ± 0.37 | 12.77 ± 0.42 | 14.12 ± 0.46 | 14.05 ± 0.49 |

among stem girths and phylloclades, but differences were essentially the same among considered AEZs.

The overall oil yields from E. tirucalli in all AEZs, ranged from stem girths i.e., 16.47% ± 0.34%/ (20g) to 82.35% ± 0.34%/(100g) maximum and phylloclades i.e., 15.7% ± 0.49%/ (20g) max ± 78.5% ± 0.49%/ (100g) maximum, respectively. These ranges are quite high enough to solve the yield problem of the unsustainable source of liquid biofuels for energy in Tanzania.

5. Discussion

The maximum oil yields from E. tirucalli were obtained in large stem girths (80cm) than small girth sizes (20cm) in semi-arid than in Southern highland and the coast AEZs respectively. The paired sample t-test (2-tailed) results showed no significant difference in oil yields between phylloclades and stem girths within and between selected AEZs at the p > 0.05 level. This showed that such differences were the same among different AEZs. Despite equal amounts of oil obtained from E. tirucalli in all AEZs, but such yields were higher enough to reduce the yield problem of the unsustainable source of liquid biofuels in Tanzania. Comparisons of the obtained results with other authors showed that the present results were higher compared to the reported oil yields of Inga laurina stem girth and leaf both in dry and rainy seasons, respectively (Furtado et al., 2014).

The results were also higher than reported leaf oil yields from Eucalyptus crebra oil (Najum et al., 2005). Furthermore, Sankarikutty and Narayanan (2003) reported the variations in essential oils from plants from 0.05% to 18.0% which agree to the maximum oil yields of 4.2% ± 0.01% to 16.47% ± 0.34% obtained from E. tirucalli in the present study. Also, higher oil yields from stem girths than phylloclades obtained in this study are in line with the findings reported by Manhíes et al. (2012) that the oil productivity of Aniba canelilla stems was higher than leaves both in pruned tree crowns and in re-sprouts. In addition, Gershenzon et al. (2000) reported that there are differences in oil yields between leaves and stems whereby higher yields were obtained from new stems (small) than the older ones (large). These results differed from the findings of the present study which stated that E. tirucalli oil yields were higher in larger stem girth sizes than smaller ones. However, higher oil yields in larger stem girth sizes than smaller ones that were obtained in the present study corresponded to the findings reported by Bisht et al. (2019) who studied variability in oil yields from Santalum album L. trees, and found higher total oil yields of 3.6% from larger stem girth - sized trees (82.4 cm) than yields of 1.6% from small stem girth size (47.1 cm) trees. However, their results did not present particular trends in oil yields among girth sizes (cm).

The obtained percentage oil yields from E. tirucalli trees were higher compared to the reported oil yields of Inga laurina stem girth (0.34% ±
0.04% in the dry season and 0.49% ± 0.17% in the rainy season) and leaf (3.71% ± 0.98% in the dry and 3.07% ± 1.10% in the rainy season), respectively (Furtado et al., 2014). Furthermore, it has been reported that the yields of essential oils from plants vary widely, and the broad range was about 0.05%–18.0% (Sankarikutty and Narayanan, 2003). This range relates to the maximum oil yields (4.2% ± 0.01% - 16.47% ± 0.34%) from E. tirucalli obtained in the present study. Also, the obtained higher oil yields from stem girths than phylloclades in this study are in line with the findings previously reported by Manhães et al. (2012). Furthermore, higher oil yields in larger than smaller stem girth sizes that were obtained in the present study corresponded to the findings reported by Bisht et al. (2019) who studied variability in oil yields from Santalum album L. trees, and found higher total oil yields of 3.6% in larger (82.4 cm) than 1.6% small stem girth sized trees (47.1 cm). However, their results did not present particular trends in oil yields among girth sizes (cm).

There are various factors such as climate, seasonal variations, plant organs, and developmental stages that have been reported to influence yields of oil in plants (Sangwan et al., 2001; Duarte et al., 2009). For example, Taveira et al. (2003) studied variations of oil yields in dry and wet ecological conditions between stems and leaves of Aniba canelilla. They reported that oil yields in stems were higher in dry than wet conditions of the same year, while oil yields in leaves did not change. These results relate to findings of the present study in that the stem girths in semi-arid (dry) produced higher oil yields than stem girths from southern highland (tropical and wet) and, the coast (tropical) AEZs respectively. But their results differ from the present study in that phylloclades (leaves) oil yields varied among different AEZs, while their results presented no yield variation in leaves. Another study from (Manhães et al., 2012) reported that only stems responded to seasonal variations in oil yields of Aniba canelilla while leaves showed no response. These results also conform to variations in stem girths oil yields but differed in variations of oil yields in phylloclades (leaves) of the present study. In the present study, the obtained higher E. tirucalli oil yields from old stems having larger girth sizes than new stems with small girth, sizes indicate that the final developmental stages of stems in E. tirucalli plants accumulated more oil than initial developmental stages. Since, phylloclades have been collected on similar stem girth sizes from which stem girth samples were collected and produced a relatively high amount of oils. This means that there is a positive direct relationship between stem girths and phylloclades in terms of oil yields whereby young and small growing stem girths with associated phylloclades can produce a low amount of oil while old and large stem girths with associated phylloclades can produce a high amount of oil. The obtained results were in agreement with the results of Mirzaie-Nodoushan et al. (2001) which reported that stem diameter was among the factors that had a positive direct effect on leaf essential oil yield in Mentha spp. Similar results were reported by Talle et al. (2012) for Lemon balm (Melissa officinalis, L.) where the essential oil of the plant was positively significantly correlated with, stem dry weight among other factors. The fact that E. tirucalli trees grow vigorously once established means that the plants can increase their biomass and rapidly accumulate oil containing latex once established (Loke et al., 2011; Photi, 2005). Thus, the increase in plant biomass is correlated with the increase in latex production together with its oil content (biofuel component) as plants grow and increase in stem girth sizes further continue. The accumulation of latex and its subsequent oil content in E. tirucalli stems as the stem girth size increases is probably a form of resource re-allocation in accordance with the general theory which states that when plants get older and larger, the upper leaves (phylloclades in the case of E. tirucalli) start to shade lower leaves consequently, larger plants have to allocate more resources away from the assimilating parts of leaves and roots and

![Figure 3. E. tirucalli oil yields variation from phylloclades, indicating higher yields in Dodoma semi-arid, than from Mbeya southern highland and Dar es Salaam coast, agro-ecological zones, respectively.](image)

**Table 2. Analysis (Paired sample t-test) on differences in E. tirucalli oil yields between stem girths and phylloclades within and between selected agro-ecological zones.**

| Agro-ecological zone       | Mean     | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | t  | df  | Sig.(2-tailed) |
|----------------------------|----------|----------------|-----------------|------------------------------------------|----|-----|----------------|
| Mean % of Oils from the Stem Girth | % of Oils from the Phylloclades | 0.224 | 3.68718 | 0.40230 | -0.5761 | 1.02417 | 0.56 | 83 | 0.579 |


invest more in support tissue, especially in stems (Poorett and Pothenmann, 1992).

Pertaining to the agro-ecological climate, *E. tirucalli* can survive under various climatic regimes mostly in semi-arid conditions due to its succulent habits (Brulffert, 1993; Loke et al., 2011). This permits its water storage and utilization during drought conditions (Brulffert, 1993). Furthermore, despite the fact that *E. tirucalli* exploits both C3 and CAM pathways, but the CAM pathway is an adaptation for *E. tirucalli* to manage carbon, water, upgrading yields and, as a survival strategy, for adverse conditions. Herrera (2009), Kluge et al. (2001) and Van Damme (2001), reported that the extent of succulence has been positively correlated to both colonization of increasingly arid habitats and an increased contribution of CAM activity to total carbon gain. Loke et al. (2011), (1993) argued that succulence is a survival strategy for plants in arid and semi-arid areas. According to the results of the present study, the climatic conditions in the Dodoma AEZ were more conducive for the growth and productivity of *E. tirucalli* trees than the conditions prevailing in Mbeya and Dar es Salaam AEZs. The Dodoma AEZ had a mild and semi-arid climate (Temperature range: 17 °C–31 °C; Rainfall: 500mm–800mm) (See section 2.1). Mild temperatures do not favor the rapid microbial breakdown of organic matter. Yet, the indicated semi-arid rainfall regime does not lead to rapid leaching of the nutrients from topsoil and, therefore, the fertility of the soil is not lost much. This is the possible explanation on why the Dodoma semi-arid AEZ had higher yields than either Mbeya or Dar es Salaam AEZ where the mean annual rainfall levels were higher (See section 2.1 and URT, 1997; 2007; Janssen, 2005). Therefore, all the above-presented results showed that the overall range of oil yields from stem girths and phylloclades of *E. tirucalli* in all AEZs are higher to resolve the yield's problem of unsustainable sources of energy in Tanzania. The obtained high oil yields from *E. tirucalli* have the potential for conversion into liquid biofuel in profitable quantities under the climatic and ecological conditions prevailing in different parts of Tanzania. Thus, it would be advantageous to grow the plant for fuel production on a large scale in Tanzania. Growing the plant over large tracts of land would have double benefits. On one hand, it would provide a carbon dioxide sink and, consequently, contribute towards reducing the effects of climate change caused by global warming that is associated with the accumulation of carbon dioxide in the atmosphere. On the other hand, the plants would provide energy. For it has been reported that the species has a high potential for the uptake of carbon dioxide (FARA, 2008). Also, the species is considered a low-input plant with high drought and salinity stress tolerances that can be grown on land that is not suitable for food and cash crop production. Furthermore, the use of oil extracts from *E. tirucalli* would further benefit the environment by reducing deforestation since the liquid biofuel produced would replace charcoal and firewood in rural domestic uses of lighting and cooking. In addition, growing *Euphorbia tirucalli* on a large scale would also bring about economic advantages to farmers who would engage in its cultivation; and to the Government of Tanzania, which might see a reduction in its balance of payments deficit due to the switch from the importation of fossil fuels to the use of liquid biofuel from *E. tirucalli* and alleviate the problem of too much dependence on fossil fuels. Besides, *E. tirucalli* is not food, fiber, or an economic crop. Thus, it is an appropriate plant species for alternative energy production as its use would not compete with other human uses as is the case for such species as maize and sugar cane.

6. Conclusion

This study concluded that *E. tirucalli* oil yields from large stem girths were slightly higher than phylloclades obtained from shoots of large stem girth trees within and among different AEZs. Oil yields from stem girths and phylloclades in Dodoma Semi-arid were slightly higher than Mbeya Southern highland and the Dar es Salaam Coast AEZs respectively. However, results revealed that differences in *E. tirucalli* oil yields from stem girths and phylloclades among AEZs were not statistically significant. Moreover, the obtained oil yields both from stem girths and phylloclades displayed patterns of increase between girth sizes and oil yields from trees with low stem girth sizes to large stem girth sizes. Finally, study findings showed that the obtained percentage range of oil yielded by the stem girths (82.35% max) and phylloclades (78.5% max) of *E. tirucalli* trees was high. This indicated that *E. tirucalli* plant species could be utilized as important sources of liquid biofuel to resolve the yield problem of unsustainable sources of energy in Tanzania.

Declarations

Author contribution statement

Hamisi, Y. Nchimbi: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

Acknowledgements

The author enthusiastically acknowledges the College of Engineering and Technology, UDSM for providing laboratory facilities to ensure that the research work was accomplished on time. Special thanks go to the UDOM for providing office space for research write ups.

References

Alamu, O.J., Wahedd, M.A., Jekayinsa, S.O., 2007. Biodiesel production from Nigerian palm kernel oil: effect of KOH concentration on yield. Energy Sustain. Dev. 11 (3), 77–82.

Bisht, S.S., Ravindra, M., Gayathri, D.N., 2019. Variability in yield and composition of oil from Indian Sandalwood (Santalum album L.) trees grown in homogeneous conditions. Trop. Plant Res. 6 (1), 31–36. Bisht et al., 2019.

Brulffert, J., 1993. Life strategies of succulents in deserts, with special reference to the nambú desert. 3. In: von Willert, Dieter J., Eller, Benno M., Marinus, J., Werger, A., Brackmann, Enno, Blendenfeld, Hans-Dieter (Eds.), Q. Rev. Biol., 68, p. 437, 437.

Duarte, A.R., Naves, R.R., Santos, S.C., Seraphin, J.C., Ferri, P.H., 2009. Seasonal influence on the essential oil variability of Eugenia dysenterica. J. Braz. Chem. Soc. 20 (2), 987–974.

Furtado, F.B., et al., 2014. Seasonal variation of the chemical composition and antimicrobial and cytotoxic activities of the essential oils from inga laurina (sw.) willd. Molecules 19 (4), 4560–4577.

Gerthsenzson, J., McConkey, M.E., Croteau, R.B., 2000. Regulation of monoterpene accumulation in leaves of peppermint. Plant Physiol. 122 (1), 205–213.

Granda, C.B., Zhu, L., Holtzapple, M.T., 2007. Sustainable liquid biofuels and their environmental impact. Environ. Prog. 26 (3), 233–250.

Herrera, A., 2009. Crassulacean acid metabolism and photosynthesis under water deficit stress: if not for carbon gain, what is facultative CAM good for? Ann. Bot. 103 (4), 645–653.

Janssen, R.R., 2005. Biofuels for Transportation in Tanzania 2 Partnership WIP. Renewable Energies. Deutsche Gesellschaft für Technische Zusammenarbeit (GIZ). Accessed: Oct. 24, 2020. [Online]. Available: http://wip-munich.dehttp://www.themabatch.co.ukhttp://www.tatedo.orghttp://www.integration.org.

Kalaria, D., Saikia, C.N., 2004. Chemical constituents and energy content of some latex bearing plants. Bioresour. Technol. 92 (3), 219–227.
