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Potential non-edible oil feedstock for biodiesel production in Africa: A survey

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ABSTRACT

Africa is a continent full of untapped natural resources ranging from biodiversity to vast water bodies but faced with food and energy crises. Prices of fuel are also escalating. With researchers and experts scrambling for the solution, biodiesel from vegetable oil will receive more attention. But the edible feedstock as the obvious cheapest choice will not be sustainable enough for the increasing energy and food demand; hence, there is a need for guaranteed feedstock. This study was therefore undertaken to explore feedstock that would not be suitable for food but useful for biodiesel in Africa. Among the highlight areas of the study include current energy situation in Africa, technologies of biodiesel production, current state of biodiesel in Africa, driving forces for increase in biodiesel production, current existing problems of biodiesel commercialization, potential benefits of biodiesel processes, need for non-edible oil plants, potential non-edible biodiesel feedstock, biology, distribution and chemistry of the selected non-edible oil plants. The study also throws light on the implication of biodiesel on the environment and the outlook. From the study, the use of non-edible oils can be guaranteed as sustainable feedstock for biodiesel since most of the non-edible plants can be grown on wastelands to reclaim them, not compete with food crops for limited lands, are relatively cheap, available and offer similar or even higher yields of biodiesel and fuel properties as the edibles. Developing biodiesel industry in Africa can help curb the high rate of unemployment through job creation as well as increase in income level of the rural populace. Weaning African economies from oil import dependencies could also be an economic achievement. It can be deduced from the study that there are promising non-edible oil resources in the system for biodiesel industrialization in Africa.

Contents

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1. Introduction

Energy is very critical in socio-economic development. It is a domestic necessity whose factor, especially cost of production, directly influences price of other goods and services [1,2]. Energy affects all aspects of development – ranging from social, economic and environment. The impact of energy also affects livelihoods, agriculture, health, access to water, population, education, etc. Access to energy is an important factor in industrial development as it provides vital services that enhance the quality of life [1,3]. However, petroleum products, which are the main source of energy (especially transport), are facing acute peaking problems due to the ever-increasing demand in the face of dwindling production. Coupled with these is the rate and devastating effects of climate change and its consequences – global warming resulting from excessive consumption of petroleum products, which greatly affects food security and threatens man's existence.

Nevertheless, ensuring adequate, affordable and reliable high-quality energy services with minimum adverse effect on the environment has been not only vital for Africa, but also crucial for the continent in which most of its countries are even struggling to meet their present energy demands [4–6].

Currently energy resources in African countries are unevenly distributed [4,7]. For example, the supply of 12% global oil is only concentrated in Nigeria, Algeria, Egypt and Libya. Only these few (four) countries with 9.5% oil reserves are said to be self-reliant in energy or exporters. The majority (more than forty-two countries) are net energy importers. They import petroleum fuel at a cost that places heavy economic burden on the country. These no doubt serve as evidence for urgent need of substantial investment in domestic energy for social-economic development [8,9]. Expanding the domestic energy facilities would increase the efficiency of how the continent uses its energy resources, thus enabling African countries to increase their reliability of supply and reduce the dependence on petroleum imports. This will also help improve energy security besides expanding access to energy services [1,10].

With current research on energy focusing on modern energy as promising, beneficial and guarantee to countries, biodiesel from vegetable oils and animal fats are the most obvious promising choices [11,12]. Growth projections of biodiesel, however, are placing more enormous emphasis on vegetable oils, especially the edible ones. Feasibility studies indicate that using all the edible oil resources will still not be sustainable [3,13]. An instance is the World Bank and Muller et al. [14,15] 2008 reports (Figs. 1 and 2). The reports clearly indicate that by 2030, biodiesel will represent about 60–80% transport fuel in Africa. And since the edible oil resources would not be sustainable, attention has been drawn to non-edible oil resources, which can serve as guarantee resources for sustainable biodiesel in order to augment energy and yet maintain food security. The non-edible plants have the advantage of being used for afforestation to reclaim wastelands, may not compete with food crops for limited lands and also are cheaper when compared with the edible ones.

Currently, the main non-edible resource for biodiesel in Africa is jatropha. But jatropha cannot single-handedly sustain biodiesel for Africa's energy security [3]. This study was therefore undertaken with the aim of exploring the potential non-edible oil resources for biodiesel in Africa. The study highlights areas such as current energy situation in Africa, technologies of biodiesel production, current state of biodiesel in Africa, driving forces for

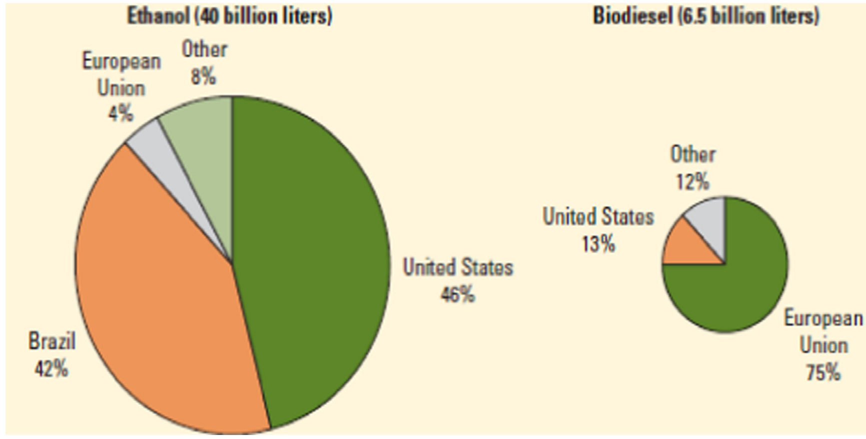

Fig. 1. Origin and production volumes of ethanol and biodiesel [14].

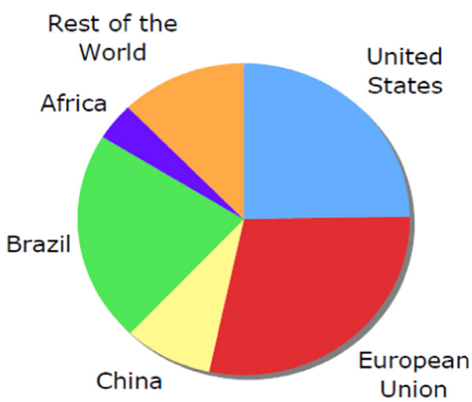

Fig. 2. Expected share of global biofuel consumption in 2030 for main consumer markets [15].

Table 1
African countries which import and export energy [18].

Major energy exporters[a]	Net energy exporters	Importers[b]
Algeria	Angola	Benin
Congo	Cameroon	Eritrea
Egypt	Congo	Ethiopia
Gabon	Cote d' Ivoire	Ghana
Libya	D. R. Congo	Kenya
Nigeria	Gabon	Morocco
South Africa	Sudan	Mozambique
	–	Namibia
–	–	Senegal
–	–	Tanzania
–	–	Togo
–	–	Zambia
–	–	Zimbabwe

[a] Major energy exports are in excess of 0.5 quads.
[b] Most of the African countries' imports are very small (less than 0.3 quads).

increased biodiesel production in Africa, current existing problems of biodiesel commercialization in Africa, potential benefits of biodiesel processes, vision for biodiesel in Africa, need for non-edible oil plants, potential non-edible biodiesel resources and biology, distribution and chemistry of the selected non-edible oil resources for biodiesel. The implications of biodiesel on environment and the African continent and the outlook were not left out.

2. Current energy situation in Africa

Africa is one of the fastest growing continents in the world. It has a landmass of over 30.3 million km^2 – an area equivalent to the United States of America, Europe, Australia, Brazil and Japan combined. As of 2004, Africa housed over 885 million people [16] in 53 countries of diverse socio-cultural entities. The continent is endowed with resources including fossil and renewable. According to World's energy report [17], about 9.5%, 5.6%, and 8% of the world's proven global economic recoverable reserves of oil, coal and natural gas, respectively, are in Africa.

The distribution of energy resources in Africa indicates that every sub-region of the continent except East Africa is a net exporter of energy, at the same time importing petroleum products at a cost that is burdening and crippling the economy [4]. For example, North Africa is by far the largest exporter of oil and gas to Europe and other markets. In West Africa, Nigeria until recently joined by Ghana was the leading exporter of oil. Southern Africa's net energy export (oil) is from Angola, who also suppliers 99% of Africa's coal output. Cameroon, Congo and Gabon are champions of Central Africa's oil-exporters to other regions. As at 1997, five major countries –South Africa, Egypt, Algeria, Nigeria and Libya – had contributed to 84% of all energy produced in Africa (Table 1) [18].

In spite of all these, Africa remains the lowest consumer of energy (Figs.1 and 2). An African consumes only 1/11, 1/6, and 1/2 of energy consumed by a North American, a European, and a Latin American, respectively [16].

Africa is, however, an unexploiter of biofuels, especially biodiesel, despite the fact that the majority of its nations rely so much on biomass as the main energy resource [4]. Fig. 3 typically shows the share of renewables in the total primary energy supply (Africa's renewables share was 50.1% in 2003) [19]. The high poverty level among African countries is revealed in the consumption model of modern energy as per its capita consumption (modern energy) is very low [1]. The heavy usage of traditional fuels – primarily biomass (Fig. 4) [20] rather than modern energy – can also be attributed to underdeveloped energy resources, poor modern energy infrastructure, and widespread and severe poverty, which make it impossible for the people to pay for conventional energy resources [21]. And this really indicates the need for energy diversification in which biodiesel can play a vital role. Table 2, however, indicates the energy potential of different non-edible resources in selected African countries for modern energy and the fact that biodiesel is an emergent one in Africa [22]. Biodiesel will offer African countries some prospect of self-reliance in energy at both the national and local levels which will enhance economic, ecological, and social development [4].

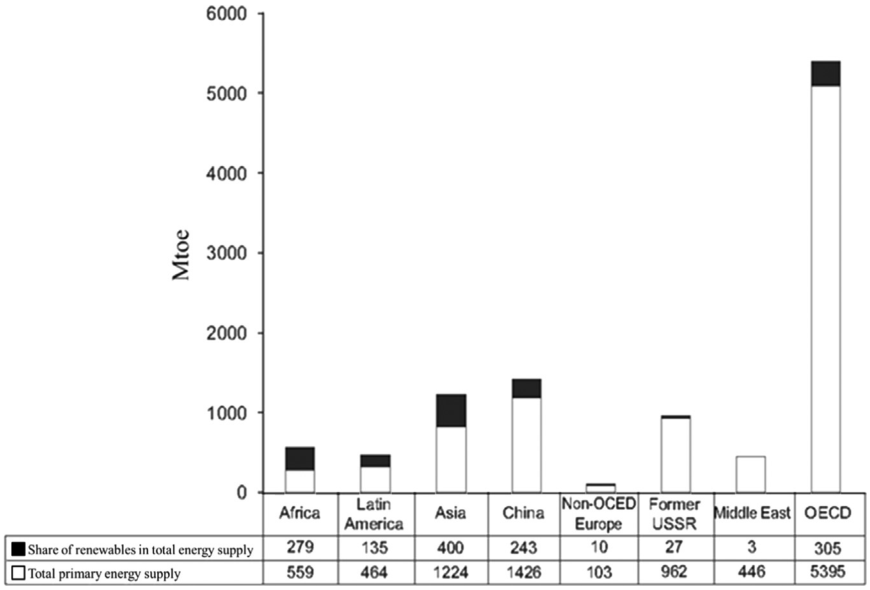

Fig. 3. Renewables share of total energy supply [19].

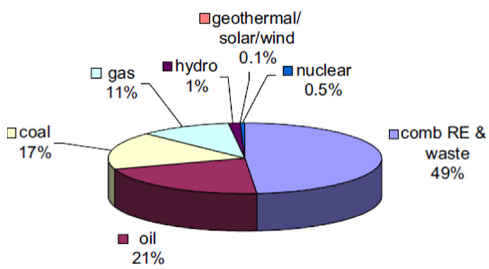

Fig. 4. Share of total primary energy supply in Africa [20].

3. Biodiesel

Biodiesel, mono-alkyl esters of long chain fatty acids, is produced from renewable biological resources such as vegetable oils and animal fats. The process of biodiesel production is modern and technological [23,24]. Biodiesel is renewable, environmentally friendly, non-toxic, biodegradable, has high engine performance, high flash point and can be blended with diesel since the characteristics are similar [25–28].

3.1. *Technologies for modifying or producing biodiesel from vegetable oil*

A number of methods are available for producing biodiesel [29–32]. Crude oils are modified to biodiesel in order to reduce their viscosities to make the oil suitable for diesel engines. The four main methods for producing biodiesel are blending, micro-emulsions, thermal cracking and transesterification.

3.1.1. *Blending*

Vegetable oils are not suitable for direct use in diesel engines and can be blended to enhance the viscosity. Blending is the process of reducing the concentration of a solution which is mostly done by mixing with more solvent. Crude oils can be mixed directly or diluted with diesel fuel. Having blended, the resulting solution is well mixed so that all parts of the solution are identical. A blending of 20–40% of vegetable oil with diesel fuel for diesel engine has yielded good results [33,34].

Table 2
Energy potential of different non-edible resources in selected African countries [22].

Country	Raw material	Biodiesel		Bioethanol	
		Megalitres (ML)	Mega Joules (MJ)	Megalitres (ML)	Mega Joules (MJ)
Benin	Jatropha	30	1.3×10^8	20	8.4×10^7
Burkina Faso	Sugarcane	–	–	20	8.4×10^7
Ivory Coast	Molasses	–	–	20	8.4×10^7
Ghana	Jatropha	50	2.1×10^8	–	–
Guinea Bissau	Cashew	–	–	10	4.2×10^7
Mali	Molasses	–	–	20	8.4×10^7
Malawi	Molasses			146	6.1×10^8
Kenya	Jatropha/ Molasses	40	1.7×10^8	413	1.7×10^9
Ethiopia	Jatropha/ Molasses	–	–	80	3.3×10^8
Niger	Jatropha	10	4.2×10^7	–	–
Nigeria	Jatropha/ Molasses	–	–	70	2.9×10^8
Sudan	Molasses	–	–	408	1.7×10^9
Swaziland	Molasses	–	–	480	2.0×10^9
Senegal	Molasses	–	–	15	6.3×10^7
Tanzania	Jatropha/ molasses	–	–	254	1.1×10^9
Togo	Jatropha	10	4.2×10^7	–	–
Uganda	Molasses	–	–	119	5.0×10^8

3.1.2. *Micro-emulsification*

Another approach of modifying vegetable oils is micro-emulsification. Micro-emulsions are clear, stable isotropic fluids with three components (oil phase, an aqueous phase and a surfactant). The aqueous phase contains salts or other ingredients while the oil phase contains a complex mixture of different hydrocarbons and olefins. This ternary phase of micro-emulsions can improve the spray characteristics by explosive vaporization of low boiling constituents in the micelles. Micro-emulsions with methanol, butanol, hexanol and octanol are said to meet the maximum viscosity limit for diesel engines [35]. Micro-emulsion can be prepared with or without diesel fuels. This process is seen as a dependable approach for reducing the viscosity of vegetable oils [35–38].

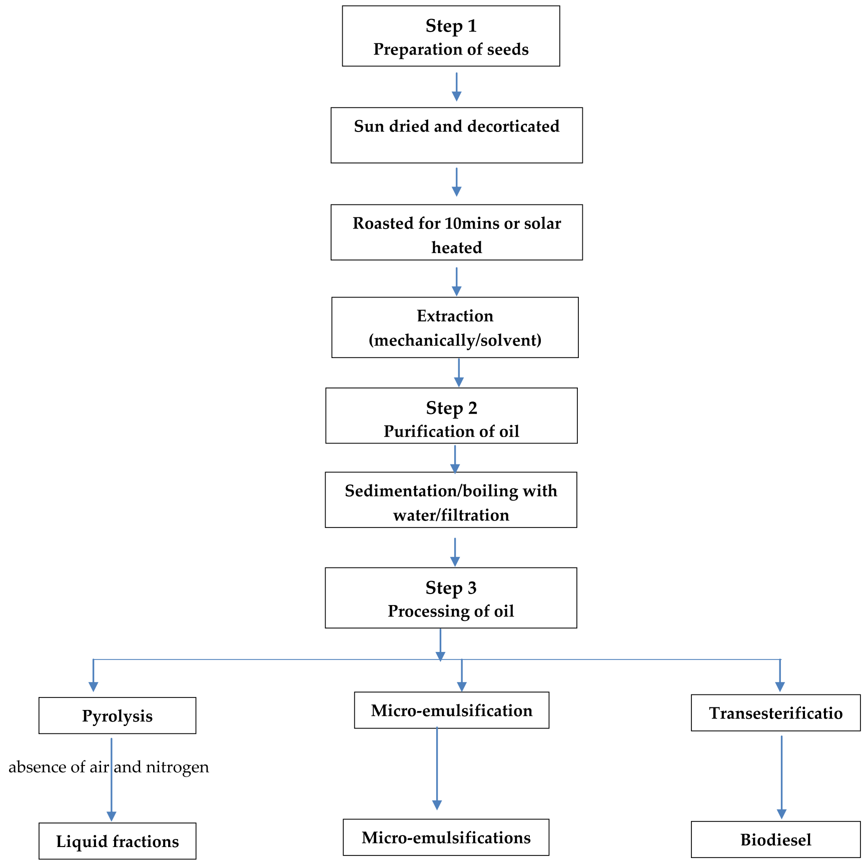

Fig. 5. Flow chart of converting vegetable seeds to biodiesel [50].

3.1.3. *Pyrolysis*

Pyrolysis, as one of the methods for reducing crude oil's viscosity, is the process of converting one substance into another by means of heat or catalyst in the absence of air or oxygen. The pyrolyzed materials have lower viscosity, pour point, and flash point but high cetane number than conventional diesel. The pyrolyzed materials, however, have equivalent calorific value as diesel. The materials also end up having an acceptable amount of sulfur, copper corrosion and water content, but unsuitable carbon residue, pour point and ash content [25,27,35–37,39,40]. Depending on the operating conditions, pyrolysis can be divided into three types, which include conventional pyrolysis, fast pyrolysis, and flash pyrolysis [41,42].

3.1.4. *Transesterification*

Transesterification is a chemical reaction that involves triglyceride and alcohol in the presence of a catalyst to form esters with glycerol as the backbone [43]. Transesterification involves three consecutive reversible reactions. These include the conversion of triglyceride to diglyceride, followed by diglyceride to monoglyceride and glycerol as the backbone. Catalyst is usually used to enhance the reaction rate so that the reaction can be completed in a relatively shorter reaction time [44,45]. The catalysts used can be grouped into alkalis, acids or enzymes [46,47]. Among them, alkali catalysts are usually preferred because of their higher reactivity and the milder process conditions (low-temperature requirement) [48]. A successful transesterification reaction produces esters and crude glycerol. Even though esters are the end products of transesterification reactions, glycerin recovery is also important due to its numerous applications in daily products [49].

Fig. 5 shows the flow chart of converting vegetable seeds through to oil and to biodiesel [50].

4. Current state of biodiesel in Africa

Biodiesel in Africa is an emergent one with plans for large-scale investment projects far advanced for the commencement of its commercial productions in various countries, including Ghana, Zambia, Liberia, Tanzania, Ethiopia, Nigeria, Senegal, Kenya, and South Africa [51–53]. Small-scale biodiesel production using *Jatropha curcas* is presently scattered in the continent. In Ghana for example, Anuanom Industrial Bio-Products and Biodiesel 1 Ltd have two biodiesel production plants in place with an annual capacity of 70,000 metric tonnes of jatropha oil per plant (combined annual capacity of 140,000 metric tonnes). The company (Anuanom) had a partnership with a German-Austrian private company for a 12-million-dollar factory for biodiesel production capacity of about 360,000 t/a. This was expected to be the first commercial biodiesel production plant in Africa. However, probably due to lack of funds the construction was stalled.

Notwithstanding this, the Bulk Oil Storage and Transportation (BOST) Company Limited (in Ghana) had recently agreed to offer Anuanom assistance to acquire equipment for the establishment of a biodiesel plant in the country. This was on condition that raw materials will be available to sustain the production. Other African countries have measures in place to push the biodiesel agenda in various strategic proposals. Typically, Energy Commission of Ghana has proposed that by 2015 a national biodiesel target of 20% should be met. Plans are in place to waive off duties and levies in support of this process [54]. Countries including Mali as well as Eastern and Southern African countries have targets in place with programmes initiated to enable smooth take-off and sustenance of the industry [55]. Zimbabwe's National Biodiesel Feedstock's Production Program (ZNBFPP) is aimed at substituting at least 10% of its daily consumption of imported fossil fuel through biodiesel in the next five years (2013–2018). South Africa has already started selling petroleum fuels blended with 10% biodiesel at its petrol and filling stations since 2007 [56]. In Zambia, a US$ 8 million biodiesel plant is in place, by kind courtesy of Marli Investment where jatropha oil will be the source of feedstock. Also located in Kabwe, about 140 km north of the capital, Lusaka, is a biodiesel plant which was expected to produce 60 million liters of fuel per year. This plant has already been in operation since August 2007 [56]. Angola already has over 80 million hectares of agricultural land reserved purposely for the cultivation of biodiesel crops and could, with effective strategies and coordination, become an African 'biofuels superpower' [57]. Other investments in Africa include D1 oils in Swaziland, Madagascar, South Africa and Zambia, International Biofuels Crops in Liberia, Nigerian National Petroleum Corporation and the Dutch biodiesel equipment manufacturer in Senegal (BioKing).

5. Driving forces for increased biodiesel production in Africa

Increasing interest in biodiesel in many African countries can be attributed to factors such as high prices of crude oil, fluctuations in their prices, local and global environmental impacts of petroleum fuels such as climate change, movement of developed countries (UK, Germany, Japan, etc.) from voluntary legislation to obligatory legislation and imposition of market share of biodiesel into the transport sector [1]. Others factors such as job opportunities, new research and technological advances, economic development, and the need to increased access to energy services to meet the Millennium Development Goals [58,59] also contribute. Africa can be seen as the single largest potential for the global production of bioenergy crops [58].

6. Current existing problems of biodiesel commercialization in Africa

Despite the prospects that can attract increase in biodiesel in Africa, some factors, practices, perceptions and policies may also hinder or delay biodiesel commercialization in the continent. A few of them are discussed next.

6.1. Food against fuel factor

Large-scale or mechanized production of energy crops is a concern for many developing countries [60]. This is much an issue when fertile lands are occupied with energy crops instead of food crops. The line between energy and agriculture in some African countries is very blurred and poses a problem when people are pushed to investment in energy crops [1]. This was a case in Kenya when Energy Africa Ltd. started introducing jatropha to the poor farmers' fields [61]. Rapidly declining crop production has left millions facing starvation, especially rural populations [62]. Studies have shown that increased demand for biodiesel is responsible for about 30% of the weighed grain price increase from 2000 to 2007 [63].

6.2. Land use and tenure system

Land is central to biodiesel development. In order to gain maximum benefits from biodiesel, large tracks of lands are required for production of energy crops. However, in Africa most lands are family property and do not belong to an individual. Others are also community lands and are only rented to investors for a short while. In cases where the land is taken away from the socially and economically vulnerable communities or families, it negatively affects them (poorest Africans). In Tanzania for instance, most of the land belongs to about 11,000 villages where smallholder production is the mainstay of rural livelihood [1]. Any attempt to secure such lands for commercial energy crops will not only prove difficult but also worsen the poor farmers' plight. Other African nations with community and customary oriented lands include Ethiopia and Mozambique [64].

6.3. Financial problems

The high initial cost of biodiesel production with respect to acquisition of resources and infrastructure as well as inadequate financial arrangements for biodiesel technology could be an important barrier to biodiesel commercialization in most African countries. Existing capital markets do not favor small-scale investments as required for some biomass energy. This even though might not be peculiar only to African countries [65], developing countries face the worse. Some factors contributing to this include lack of available credit facility with low interest rate.

6.4. Technical issues

Biodiesel production process presents distinct barriers related to technical issues [66]. The supply of feedstock is crucial to the success of biodiesel process. As such securing resources to produce biodiesel for transport in Africa could be problematic. By way of example, to supply 30% volume of the petrol used in South Africa would require the order of 5 million tons of soya bean. This is a reasonably large amount as it is only half the maximum available capacity [4]. Another factor could be the perception by the poor African that only the developed world can afford biodiesel. This is because only industrialized countries such as Brazil, Russia, Germany, USA, China, etc. currently have the technological base, the capital and infrastructure to push large-scale biodiesel production.

6.5. Information hurdles

Due to lack of awareness and limited information on biodiesel, the benefits (both economical and environmental) could also be a barrier to the market penetration of biodiesel in most African countries. The public do not have much education on the development, application, dissemination and diffusion of biodiesel's resources and technologies in the national energy market. The fact that stakeholders and the consumers are not sensitized to the potentials of biodiesel is another issue. This could even probably affect the view of investors as risky [1]. Poor telecommunication infrastructure and high cost of services could also be a source of barrier to biodiesel commercialization in Africa.

6.6. Lack of expertise

The limited availability of experts and skilled manpower for biodiesel development could hinder the development and market penetration of the industry. This is largely due to the exodus of highly trained manpower from developing countries, most especially Africa to industrialized nations. For example, Africa as a whole counts only 20,000 scientists (3.6% of the world total) and its share in the world's scientific output has fallen from 0.5% to 0.3% as it continues to suffer the brain drain of scientists, engineers and technologists [67]. The increase in number of this exodus could be attributed to the deterioration in political, economic, and social conditions in the continent and these reduce the availability

Table 3
Current land allocations for biodiesel in some African countries [72].

Country	Investor	Area and crop
DRC	China	2.8 million ha.
Zambia	China	2 million ha. – jatropha
Ethiopia	Flora EcoPower (Germany)	13,000 ha.
Ethiopia	Sun Biofuels (UK)	Jatropha
Mozambique	Sun Biofuels (UK)	100,000 ha.
Mozambique	Sekab (Sweden)	
Tanzania	Sun Biofuels (UK)	5500 ha. Jatropha
Tanzania	CAMS Group (UK)	45,000 ha. sweet sorghum
Tanzania	Prokon (Germany)	494,000 ha.
Tanzania	Sekab	9000 ha. Sugar
Tanzania	Sekab	22,000 ha.
Ghana	Biofuel Africa (Norway)	38,000 ha.

of skilled manpower (human resources) which African countries need for self-reliant and sustainable development [1].

6.7. Policy, institutional and legal hurdles

Commercialization of biodiesel requires adequate institutional support and corroboration. Lack of coordination among institutions involved in biodiesel development and commercialization such as government, ministries of energy/science and technology, research and financial institutions hinders efforts for the speedy adoption of biodiesel process. For instance, Ghana established the National Energy Board (NEB) in 1983 with one of its mandate being to develop and demonstrate renewable energy in the country. The NEB ceased to operate in 1991 and the activities were later taken on by the Energy Sector Development program (ESDP) established in 1996. The ESDP closed down in 2002 and now DANIDA is gradually assisting the activities of National Renewable Energy Board. These are happening due to the lack of appropriate institutional and legal policies. African countries are characterized by a weak legal system, with problems ranging from lack of appropriate legislation, little respect for the judicial system to weak legal enforcement.

7. Potential benefits of biodiesel processes

7.1. Poverty alleviation

Land for opportunities for agriculture and biodiesel resources are found in rural areas. These areas include the poorest Africans where many small-scale and subsistence farmers reside. Biodiesel activities are seen to contribute to poverty alleviation through provision of income per capita by cultivating and selling of crops (energy) produce [59]. By way of example, countries such as South Africa and Mozambique are committed to promoting biodiesel mainly in response to national poverty alleviation agenda. Whether biodiesel development enables the achievement of this goal is an issue that needs comprehensive investigation.

7.2. Address climate change and environmental problems

Biodiesel process has been stimulated by the opportunity to reduce greenhouse gas emissions. This is because biodiesel emits less greenhouse gases than fossil fuels [68]. Mining activities destroy the natural ecosystems and release greenhouse gases into the atmosphere when fossil fuel is being burned. The process also deprives the planet of natural sponges to absorb carbon emissions. Most African countries have made commitments to reduce greenhouse gases through their signatories to the United Nations Framework's Convention on Climate Change [1].

Table 4
Hectare requirement under import substitution scenario for biodiesel [73].

Country	Biodiesel demand in millions of bars in 2020	Required area for 100%	
		Oil palm in 1000 ha	Jatropha in 1000 ha
Angola	177	73	118
Benin	26	11	17
Botswana	49	20	33
Burkina Faso	16	7	11
Burundi	5	2	3
Cameroon	74	30	49
Cape Verde	11	5	7
Central African Rep.	5	2	3
Chad	5	2	3
Comoros	3	1	2
Congo (Brazaville)	27	11	18
Congo (Kinshasha)	47	19	31
Cote d'voire	95	39	64
Djibouti	18	8	12
Equitorial Guinea	6	2	4
Eritrea	21	9	14
Ethiopia	134	55	89
Gabon	46	19	31
Gambia	9	4	6
Ghana	167	69	111
Guinea	15	6	10
Guinea Bissau	6	3	4
Kenya	180	74	120
Lesotho	4	2	2
Liberia	9	4	6
Madagascar	78	32	52
Malawi	26	11	17
Mali	16	7	11
Mauritainia	8	3	5
Mauritius	60	24	40
Mozambique	77	32	51
Namibia	60	33	53
Niger	28	11	19
Nigeria	403	166	269
Reunion	47	19	31
Rwanda	18	7	12
Saint Helena	0	0	0
Sao Tome and Peripe	4	2	3
Senegal	109	45	72
Seychelles	35	15	24
Sierra Leone	23	10	16
Somalia	14	6	9
South Africa	1243	511	629
Sudan	304	125	203
Swaziland	13	5	9
Tanzania	116	48	77
Togo	39	16	26
Uganda	40	16	27
Zambia	51	21	34
Zimbabwe	59	24	40
Africa	4.044	1.663	2.696

7.3. Increase job creation with improved standard of living

Women in developing countries are responsible for securing energy and water for their households and also doing the majority of farm work. There is therefore the potential that biodiesel commercialization can assist in liberating women from these toilsome burdens [69], thereby empowering them and making fuel more accessible and affordable and at the same time freeing them for other activities. Biodiesel commercialization can also rapidly increase developing countries' agricultural productivity. The environmental and socio-economic transformations prompted by the growing global demand for biodiesel will have positive impacts on men and women in developing countries.

8. Vision for biodiesel in Africa

Most African countries suffer from the huge burden of petroleum importation. Biodiesel as an emergent technology in Africa has been envisaged in the following ways [51]:

(i) The process will lessen foreign exchange drain on the national coffers.
(ii) Help provide power for places without access to the national/regional grid.
(iii) To enhance job creation right from farm level to the marketing/exportation of products.
(iv) To attract funding of projects through international funding agencies. Such schemes could aid in exploring access to climate change projects and markets.
(v) To put to use the vast unutilized land resources in Africa to enhance food and energy security.
(vi) For Africa to become raw material exporter to other regions instead of importer.

Table 5
Estimated yields of the non-edible oil plants [49,75,80,81,83,85,91,92,96–104].

Common name	Scientific name	Plant type	Oil yield (kg/ha)
Jatropha	*Jatropha curcus*	Tree/shrub	1900–2500
Jojoba	*Simmondsia chinensis*	Tree/shrub	1818
Mahua	*Madhuca indica*	Tree	
Moringa	*Moringa oleifera*	Tree	4680
Petroleum nut	*Pittosporum resiniferum*	Epiphytic/pseudoepiphytic	–
Tung oil	*Vernicia fordii*	Tree	940
Camelina	*Camelina sativa (L.)*	Shrub	800–1200
Castor oil	*Ricinus communis*	Tree/shrub	450–2300
Derris indica	*Pongamia pinnata*	Tree	225–2250
Baobab	*Adansonia digitata L*	Tree	–
Citrullus	*Citrullus colocynthis*	Shrub	45–50
Croton oil	*Crotonis Oleum*	Shrub	–
Milk bush	*Thevetia peruviana*	Tree/Shrub	930–1060
Algae	*Agae*	Planktons	840–4160
Parkia	*Allanblackia floribunda*	Tree	–
Rubber tree	*Hevea brasiliensis*	Tree	4280
Tobacco	*Nicotiana tabacum*	Shrub	950–1150
Neem	*Azadirachta indica*	Tree	2670

9. The need for non-edible oil resources for biodiesel feedstock in Africa

With the prospects of biodiesel looming in Africa, coupled with a considerable amount of research conducted on alternative feedstock for biodiesel, there exist large prospects for feedstock. Some edible and non-edible oil plants for biodiesel with its engine and emission tests have already been tested. Oil resources such as jatropha, castor, karanj, rubber seed and neem are not suitable for human consumption due to the presence of toxic compounds in them. The anti-nutritional compounds in the non-edible oils, for example pongam in pinnata seeds, are usually used as fish poison [70].

Considering the food security situation coupled with the competitive nature of edible oils for food, it is obvious that the use of edible oils for biodiesel production will not be sustainable. The consequences of converting edible oils to biodiesel (food shortage) in Africa will be felt at the world stage with worldwide increase in food and commodity prices. The pressure to increase production of edible oil has also put limitations on the edible oils for biodiesel. Growing non-edible oil plants on commercial scale can relatively be cheaper than edible ones. The non-edibles can

Table 6
Geographical distribution and fatty acid composition of some selected non-edible oil plants [77,88,90,102–109].

Common name	Geographical distribution	Oil yield (seed)%	Fatty acid composition (%)
Jatropha	Angola, Zambia, Ethiopia etc.	20–60	14:0(1.4), 16:0(15.6), 18:0(9.6), 18:1(40.8), 18:2(32.1), 20:0(0.4)
Jojoba	Botwana, Ghana	45–55	16:1 (0.2), 16:0(1.08), 18:1(7.22), 18:2(0.04),20:0(0.23), 20:1(37.55), 22:0 (0.29)22:1(11.15), 24:0 (1.07)
Mahua	Ethiopia, Tanzania, India	34–50	14:0(1.0), 16:0(17.8), 18:0(14.0), 18:1(46.3), 18:2(17.9), 20:0(3.0)
Moringa	Ghana, Kenya	33–41	16: 0 (7.6), 16: 1 (1.4), 18: 0 (5.5), 18: 1 cis (66.6), 18: 2 cis (8.1), 18: 3 n3 (0.2), 20: 1 (1.7), 20: 0 (5.8)
Petroleum nut	South Africa	–	
Tung oil	Zimbabwe, Uganda, Sudan	–	16:0(2.3), 18:0(2.4), 18:1(5.6), 18:2(6.3), 18:3(0.1), 18:3(82.2), 20:0(0.2), 20:1(0.9), 24:0(0.1)
Camelina	Zambia, Ghana	–	14:0 (0.05), 16:0 (5.16), 16:1 (0.04), 18:0 (2.68), 18:1 (15.21), 18:2 (17.90), C18:3 (34.64), 20:0 (1.44), 20:1 (15.14), 20:2 (2.17),C20:4 (1.47), 22:0 (0.3), 22:1 (2.57), 22:6 (0.62), 24:0 (0.14)
Castor oil	Nigeria, South Africa	45–50	16:0 (1.09), 18:0(0.94), 18:1(3.70),18:2(4.44), 18:1 –OH (methyl ricinoleate) (89.93)
Derris indica	Ethiopia, Tanzania	30–40	16:0 (10.6), 18:0(6.8), 18:1(49.4),18:2(19.0),20:0(4.1), 20:1(2.4), 22:0(5.3), 24:0(2.4)
Baobab	Malawi, Zimbabwe, Mozambique, Mali, Benin	–	14:0 (4.6), 15:0 (2.5)16:0 (37.3), 16:1 (0.2), 17:0 (0.2), 17:1 (0.3)18:0 (4.2), 18 CE (6.2)18:1 n-9 (19.7), 18:1 n-7 (1.6), C18:2 n-6 (13.5), 19:CE (6.5), 18:3 n-3 (0.1), 19:CA (1.8),20:0(0.7)20:1 n-9(0.1),22:0 (0.1)
Citrullus	Morocco and the Cape Verde, Egypt	17–19	
Croton oil	Ghana, Gambia, Egypt	32	14:0 (0.1), 16:0 (6.5), 16:1 (0.1), 17:0 (0.1), 18:0 (3.8), 18:1(11.6), 18:2(72.7), 18:3(3.5), 18:3(0.4), 20:1 (0.9), 20:2(0.2)
Milk bush	Southern, and central Africa	60–65	16:0 (15.6), 18:0(10.5), 18:1(60.9),18:2(5.2),18:3(7.4), 20:0(0.3), 22:0(0.1)
Algae	Gambia, Mali, Ghana	60–62	16:0 (18.42), 16:1 (2.31), 16:2(3.26),18:0 (3.43), 18:1 (49.64), 18:2 (11.30), C18:3 (8.26)
Parkia	Sierra Leone, Cameroon and Gabon, Congo Brazzaville and Uganda, Ghana	64.4	–
Rubber tree	South Africa, Ghana	40–60	16:0 (10.2), 18:0(8.7), 18:1(24.6),18:2(39.6),18:3(16.3)
Tobacco	Ghana, Nigeria, Liberia	35–49	6:0 (0.69), 14:0 (0.09), 16:0 (10.96), 16:1 (0.2), 18:0 (3.34), 18:1 (14.54), 18:2 (69.49), 18:3 (0.69)
Neem	Ghana, Togo, Mozambique	20–30	16:0(14.9), 18:0(14.4), 18:1(61.9), 18:2(7.5), 20:0(1.3)

18:CE: Malvalic acid, 19:CE: Sterculic acid, 19:CA dihydrosterculic acid.

Table 7
Physico-chemical properties of biodiesel from the non-edible oil seeds [93–97].

Common name	Kinematic viscosity (40º mm^2/s)	Density (kg/m^3)	Cetane number	Flash point (°C)	Cloud point (°C)	Oxidation stability (110 °C)
Jatropha	4.80	880	55.84	135	2.7	2.3
Jojoba (15 °C)	5.2	920	55	186	16	
Mahua	3.98	850	56.61	208	5	7.1
Moringa	4.91	877.5	62.12	206	10	
Petroleum nut	–	–	–	–	–	–
Tung oil (15 °C)	7.84	903	39			0.3
Camelina	4.3 (4.15)	888 (884)	42.76	152 (151)	0 (3)	1.3 (2.5)
Castor oil	15.25	899	52.31	–	−13.4	1.1
Derris indica (15 °C)	4.85	890	58	180	–	6
Baobab	–	–	–	–	–	–
Citrullus	–	–	–	–	–	–
Croton oil	4.6	889.9	46.6	189	−4	–
Milk bush	4.33	875	61.5	+75	+12	–
Algae	9.8	–	71.67	149	−16	–
Parkia	–	–	–	–	–	–
Rubber tree	3.12	–	–	128	5	–
Tobacco	4.23	888	51.6	165.4		
Neem	5.21	884	57.83	–	–	0.8

Standard EN14214: Kinematic viscosity (40° mm^2/s) −3.5–5.0, Density (kg/m^3) – 860–900, Cetane number – > 51, Cloud point – 0.3 max, Flash point - °C > 101, Oxidation stability at 110 °C- > 3.

also be grown in large scale on non-cropped marginal and waste-lands which increases the desire and appreciation for "marginal lands" [71]. With Africa's vision to promote biodiesel, investments are already under way for its commercialization. Tables 3 and 4 show land allocations currently available for biodiesel and hectare requirement under import substitution scenario in Africa, respectively [72,73].

10. Potential non-edible oil resources for biodiesel in Africa

According to Subramanian et al. [74], there are over 300 tree species which can produce oil seeds. A report by Azam et al. [75] indicate that different oil-bearing plants are unutilized and have the potential to be used as raw materials for biodiesel. Their study revealed that 37 out of the total [76] species of plants found could be suitable for biodiesel. Currently, the main non-edible oil plant/s for biodiesel production in Africa is *J. curcas*. However, studies indicate that other non-edible oil plants such as karanj, castor, rubber, jojoba, mahua, yellow oleander, etc. with suitable properties for biodiesel are scattered in many parts of the continent. Tables 5 and 6 indicate the potential yield and fatty acid composition of oils of selected non-edible plants, respectively [49,75,77–92], while the physico-chemical properties of biodiesel from the non-edible oil plants are shown in Table 7 [93–97]. Fig. 6 also shows the photographs of the seeds from the different non-edible plants for identification. The biology, distribution and chemistry of the selected non-edible oil plants for biodiesel production are discussed below.

10.1. Biology, distribution and chemistry of selected non-edible oil plants for biodiesel production

10.1.1. Jatropha

Jatropha (*J. curcas*) belongs to the Euphorbiaceae family [98]. It is still uncertain where the place of origin is, but it is believed to be Mexico and Central America. It has been introduced to Africa and Asia and is now cultivated worldwide. This highly drought-resistant plant is adapted to arid and semi-arid conditions. The current distribution shows that its introduction has been most successful in the drier regions of the tropics, especially places with annual rainfall of 300–1000 mm. It grows well at lower altitudes (0–500 m) with average annual temperatures above 20°C. It can also grow at higher altitudes and tolerates slight frost. Jatropha thrives on well-drained soils with good aeration and is easily adapted to marginal soils with low nutrient content. Jatropha produces seeds with oil content of more than 37%. The oil can be combusted as fuel without being refined. It burns with clear smoke-free flame and has been tested as fuel for diesel engine. The oil also contains insecticide. The kernel of jatropha also includes oil which is about 60% and good for biodiesel [99].

The potentials of using jatropha as feedstock for biodiesel have received much attention and acknowledgment [35,100]. According to Silitonga et al. [101], biodiesel production from *J. curcas* offers many social, economical and environmental benefits with the potentials of solving the problem of energy crisis in many countries.

10.1.2. Jojoba

Jojoba, scientifically known as *Simmondsia chinensis*, belongs to the family Simmondsiaceae. It is a perennial, diecious, evergreen shrub or small tree. It has an extensive deep root system and requires little care if maximum seed production is not desired. Jojoba is native to the Sonoran desert. Most natural populations of jojoba are common in Riverside (California), Globe (Arizona), Guaymas (Sonora, Mexico), and Cabo San Lucas (Baja California, Mexico). Jojoba is currently being cultivated in Israel, Africa and India as a renewable source of unique high-quality oil. In Africa, the plant is cultivated around the Volta Region of Ghana. Much of the interest in jojoba is the plant's ability to survive in a harsh desert environment. The plant grows from sea level to about 1500 m altitude. For optimum production, the crop needs irrigation, care, and a good cultivar. Jojoba has attracted much attention in recent years due to its unique oil which is used in cosmetic, medical, pharmaceutical, manufacturing, and automotive industries. Jojoba seed contains an average of 50% pure oil with good physical and chemical properties [102,103]. Its composition is a little affected by temperatures of about 570 °F (300 °C).

After a relative success in separating FAME of jojoba oil by a single crystallization step, the physic-chemical properties of the FAME of the oil, including the density (863.5 kgm^{-3}), high calorific

Fig. 6. Seeds of the selected non-edible feedstock.

value (41.52 kJ g^{-1}) and cold filter plugging point (14 °C), were found to be in agreement with the European Union standard, even though the kinematic viscosity (9.0 mm^2 s^{-1}) was still above the maximum allowable limit (5.0 mm^2 s^{-1}) [102].

10.1.3. Mahua

Mahua (*Madhuca indica*) is one of the forest and arid lands borne non-edible tree-oil plants with a large production potential of about 60 million tons per annum [104,105]. Virtually being the lifeline of the tribal belt in central India, the tree is culturally most identified with Indian life in the plains. The tree is now widely cultivated in some parts of Central Africa. Besides being used as treatment of rheumatism and constipation, the seeds yield fat known as "Mahua Butter" which is used in adulteration of ghee, manufacturing chocolates and even soaps. The yield of alcohol in mahua is about 405 l from one ton of dried flower. The kernel of mahua fruits contains about 50% – depending on the size and age of the tree. The oil yield is between 34 and 37% by small expeller. Fresh oil is yellow in color, while commercial oil is generally greenish yellow with a disagreeable odor and taste.

Kapilan et al. [106] studied *Mahua indica* biodiesel and its blends with diesel as fuel in a direct cylinder injection and compression ignition engine. The outcome of the engine test indicates that *Mahua indica* biodiesel B5 and B20 blends could result in low CO, hydrocarbon and smoke emissions (as compared to diesel). The B5 and B20 blends, however, indicated higher efficiency (when compared to *Mahua indica* B100). Puhan et al. [107] also investigated emissions of diesel engine using methyl and ethyl esters of *Mahua indica* oil and indicated that the hydrocarbon and CO emissions were comparatively lower than those of diesel fuel [107].

10.1.4. Moringa

Moringa (*Moringa oleifera*), in the family moringaceae, is a single genus of oilseed with 14 known species. Of these, *M. oleifera*, which ranges in height from 5 to 10 m, is the most widely known [108,109]. *M. oleifera*, indigenous to sub-Himalayan regions of northwest India, Africa, Arabia, Southeast Asia, the Pacific, Caribbean Islands and South America, is now widespread [110]. It thrives best in a tropical insular climate. As one of the fast-growing drought-tolerant plant, *M. oleifera* can tolerate poor soils, wide rainfall range (25–300 cm^3 per year) and soil pH of 5.0–9.0 [110]. When fully matured, dried seeds are round or triangularly shaped with the kernel surrounded by a lightly wooded shell [111]. *M. oleifera* seeds contain between 33 and 41% w/w of oil. The plant is commercially known as "ben oil" or "behen oil" due to its content of behenic (docosanoic) acid. The oil also contains some amount of oleic acid. A recent study on 12 indigenous plants – derived from non-traditional oils in India – indicated that *M. oleifera* is a good potential for biodiesel production [30].

In a study of optimizing biodiesel production parameters from *M. oleifera* oil [66], a conversion efficiency of 82% was achieved. The properties of *M. oleifera* biodiesel were also within the recommended international biodiesel standards with the exception of the cold-temperature properties [112].

10.1.5. Pittosporum resiniferum

P. resiniferum, commonly known as "petroleum nut" or "abakel" in Tagalog, belongs to the Pittosporaceae family. It is an endemic species of concern from the Philippines and spreads to the southern part of Africa including South Africa. Its flowers are sweet and fragrant. *P. resiniferum* grows on trees but is not parasitic to them. It is usually grown in mossy forests at an altitude of 900–2400 m. *P. resiniferum* is noted for its large amount of resin in the fruit. The fruit of *P. resiniferum* is about 30 mm in length and 23 mm in width. The oil from the fruit is somehow interesting as it contains a generously large amount of normal heptane, which is significantly suitable for use in biodiesel [113]. It is currently grown in the Philippines as an alternative biodiesel plant, and has been recommended by the Philippine Department of Agrarian Reform and the Philippine Coconut Authority for biodiesel production [114].

10.1.6. Tung oil

The tung oil tree originates from southern China and was cultivated purposely for its oil [115]. "Tung" is etymologically derived from the Chinese *tongyou* [116], but currently cultivated in West Africa including Ghana. The oil is a drying one that is obtained by pressing the seed from the nut of tung plant (*Vernicia fordii*). As a drying oil, it hardens (dries) upon exposure to air. The resulting coating is transparent and plastic-like which is applied in wood finishing, oil paints and printing inks [117]. Tung oil has become a popular environmentally friendly biodiesel oil in Asia but is yet to gain prominence in Africa. The fatty acid (FA) composition of the oil varies with its origin. It usually contains more than 80 wt% of a-elaeostearic acid; long chain (C18) fatty acid with three conjugated double bonds (at carbons 9 cis, 11 trans, 13 trans). Biodiesel from tung oil exhibits excellent low-temperature operability due to its polyunsaturated structure [118]. The biodiesel is also unstable due to the presence of the high degree of unsaturated fatty acids [118].

The process of transesterification of tung oil using methanol catalyzed by KOH [30] indicates that the properties of tung biodiesel blends with 0# diesel (B20) or lower could be more stable than tung oil biodiesel (B100) [119].

10.1.7. Camelina

Camelina sativa (*L.*), also known as false flax or "gold of pleasure", is a broadleaf oilseed flowering plant of the Brassicaceae family. It grows optimally in temperate climates. Camelina originated from Germany in approximately 600 B.C. and later spread to Central Europe [120]. From the beginning of 20th century up to the 1930s, *C. sativa* was grown sporadically in France, Belgium, Africa, Holland, Balkans and Russia. *C. sativa* thrives well in less rainfall and less fertile lands than other traditional oilseed crops (rapeseed/canola, soybeans, and sunflowers) [120]. It also thrives in cool, arid climates and is nicely adapted to the northern regions of North America, Europe and Asia [121]. *C. sativa* yields somewhere between 336 and 2240 kg of seeds per hectare at maturity. The lipid content of individual seeds ranges between 35 and 45 wt%. The oil contains approximately 90% unsaturated fatty acids. The unusual fatty acids primarily include C18:1, C18:2, C18:3 and C20:1 [122,123].

A comparative study of *C. sativa* biodiesel emissions with those of the traditional biodiesel crops (soybeans and canola) indicates a better emission and performance as soybeans and canola [124]. A comprehensive characterization of *C. sativa* biodiesel using European and the American standards (EN 14214 and ASTM D6751) [83] also indicates *C. sativa* biodiesel contains approximately 90% unsaturated fatty acids. The high C18:3 content was, however, incompatible with EN 14214 specifications and negatively affects its properties [125].

10.1.8. Castor

Castor, *Ricinus communis*, belongs to the Euphorbiaceae family. India, China, Brazil, USSR, Argentina, Thailand, and the Philippines were the main countries known for castor production [126]. Presently castor has spread to different regions including tropical and sub-tropical countries. The castor plant may grow from 6 to 15 ft (2–5 m) in one season under favorable sunlight, heat and adequate moisture. In Africa, it is being cultivated at different altitudes (as high as 2500 m). In regions with frosts, its cultivation is restricted to 500 m. A well-distributed rainfall of 500–600 mm during the growing period will give reasonably good yields. Castor bean does not compete with food crops as it can be grown on marginal lands. Its seeds contain more oil and depending on the environmental conditions, the content of the oil varies (45–50% per seed).

Plentz-Meneghetti et al. [127] evaluated biodiesel synthesized from commercial castor oil through ethanolic and methanolic routes using different homogenous catalysts. The yields of the esters at even low temperatures and reaction times indicated the oil is a potential feedstock for biodiesel. Jeong and Park [128] and Dias JM, et al. [129] studied the optimization of biodiesel production using RSM with bleached castor oil and raw castor for biodiesel, respectively, and indicated the prospect of the oil for biodiesel.

10.1.9. Derris indica

Derris indica, also known as *Pongamia pinnata*, belongs to the Leguminosae family. Native to the Asian sub-continent, Derris indica has been introduced to humid tropical lowlands in the Philippines, Malaysia, Australia, Seychelles, United States and Indonesia [130]. It has also been naturalized in parts of eastern Africa and northern Australia. *Derris Indica* is a fast-growing evergreen tree that reaches 40 ft in height, forming a broad canopy with moderate shade. The tree grows wild on sandy and rocky soils. Although all parts of the plant are toxic and will induce nausea and vomiting if eaten, the fruits and seeds are useful in many traditional medicines. The seeds contain about 30–40% of oil, which is a good source of biodiesel [131]. The physico-chemical properties of the crude oil also established its suitability as a potential biodiesel crop [90].

A comparative study of the oil composition for biodiesel indicates the presence of high monounsaturated fatty acid (oleic acid 46%) in the oil more than polyunsaturated fatty acid (33%) [131].

10.1.10. Adansonia digitata

A. digitata L., commonly known as “baobab”, is in the Malvaceae family. It is regarded as the largest succulent plant in the world. *A. digitata* is an extremely large deciduous tree and is easily distinguishable by its huge trunk with a diameter of 10–12 m. It can grow to a height of 25 m. The large egg-shaped fruit capsule, covered by velvety hairs, contains numerous seeds and can reach 12 cm or more. Studies indicate that the mature plant can produce more than 30 kg of fruits [132,133]. The plant is found in many parts of Africa, including Mozambique, Malawi, Mali, Benin, Senegal, Zimbabwe, South Africa, Ivory Coast, Cameroon, Kenya, Uganda, Tanzania, Burkina Faso and Ghana. It is believed that the center of origin of the genus Adansonia is Madagascar. Seven out of the eight known species are all found on the island of Madagascar [133]. Baobab trees are restricted to hot, semi-arid regions, dry woodlands and places with low rainfall (less than 1500 annually). The seeds of the fruits produce oil which has industrial application. Baobab oil for example was included as a carrier/vehicle in a dermatological/cosmetic preparation containing an extract from baobab leaves [134].

Baobab oil is extremely stable with a highly variable shelf life, and estimated to last for 2–5 years. The high saponification value of the oil is comparable to some edible oils such as marula, groundnut and palm oils [135]. The iodine value of the oil placed it under non-drying oil [136]. In relatively small quantities of up to 20%, the oil may be incorporated into another carrier oil or base. The oil contains saturated (33%), monounsaturated (36%) and polyunsaturated (31%) fatty acids which is suitable for biodiesel [95].

10.1.11. Colocynth

Colocynth (*Citrullus colocynthis*), cultivated and naturalized in North Africa and India, occupies the vast area extending from the west coast of northern Africa (Senegambia, Morocco and the Cape Verde islands), eastward through the Sahara, Egypt, Arabia, Persia, and Beluchistan [137]. Colocynth has many varieties [138]. The plant usually lies on the ground for want of something to climb. However, it could climb over shrubs and herbs by means of axiliary branching tendrils. The seeds contain approximately 17–19% oil. India is, however, promoting the establishment of *C. colocynthis's* as a potential oilseed feedstock for biodiesel having considered it oil value.

The profile of non-conventional oil extracted from *C. colocynthis* seeds indicated that the main fatty acids of the oil include linoleic (66.73%), oleic (14.78%), palmitic (9.74%) and stearic (7.37%). The oil could thermally be stable even at a temperature of 286.57 °C. The study indicates that *C. colocynthis* seed oil is a potential oil plant for replacing conventional oils [139].

10.1.12. Croton

Croton (*Crotonis oleum*) is a tree belonging to the Euphorbiaceae family and native to India and the Malay Archipelago. It is currently grown in most African countries including Ghana. Croton seeds contain approximately 32% oil. The plant drops to the ground in seed pods when ripped, allowing for easy collection [88,140]. In traditional Chinese medicine, it is used as an ingredient in some liniments. Croton oil is the source of organic compound “phorbol” [140]. Presently, croton oil is the basis for rejuvenating chemical peels due to the caustic exfoliating effects on dermal components of skin. Croton oil is proven to be more effective for production of biodiesel than jatropha. One can obtain 0.35 l of biodiesel from a kilo of croton nuts [100].

A study to examine the feasibility of converting non-edible *Croton megalocarpus* oil to biodiesel indicated a yield of 95% without any pre-treatment. The reaction conditions of the study include 180 °C reaction temperature, 2 h of reaction time and 15:1 methanol to oil molar ratio at 3 wt% catalyst concentration [141].

10.1.13. Milk bush

Milk bush (*Thevetia peruviana*) is a shrub that is native to north-eastern, southern and central Africa. It grows in semi-arid tropical regions. Known by many other names including pencil cactus and firestick plant, milk bush can reach a height of between 12 and 20 ft (3.6 and 6 m). *T. peruviana* is classified as a tropical or tender perennial. It has hard wood and prefers full sun and soil with a pH of between 6.1 and 7.8. The plant can be grown indoors in a container or outdoors and is resistant to drought. It is used for several purposes including hedging, feed for cattle and medicine. The plant produces seeds rich in oil (60–65%) [142,143]. Milk-like latex produced from milk bush can be converted into fuel that is very similar to gasoline. As of 2010, there was an increasing interest in growing milk bush as a possible source of fuel. The sap can be converted into fuel similar to gasoline. The oil yield from the seeds per acre is comparable to that of other biodiesel sources.

Investigation using milk bush seed oil as biodiesel raw material indicated 96% yield [103]. The composition of the biodiesel was mainly methyl oleate (43.72%), methyl palmitate (23.28%), methyl linoleate (19.85%), methyl stearate (10.71%) and methyl arachidate (2.41%). The fuel properties of the milk bush conformed to standards of ASTM D6751, EN 14214, BS II and BS III [144].

10.1.14. Algae

Algae are naturally growing organisms and diverse in nature [145]. Algae reproduce themselves asexually by dividing themselves into two cells. Different algal strains have different properties. However, the main issue the choice of an algae strain which is easily available and can multiply easily at the prescribed location with maximum oil content [146]. Algal strains are normally selected based on many criteria of which oil content, productivity and harvesting ability are primary. The yield of oil from algae could be 200 times the yield from the best-performing plant/vegetable oils [147].

Studies have shown that algae can produce up to 60% of biomass in the form of oil. The oil can then be turned into biodiesel. The biomass (algae cake) can also be used for biogas and into methane to generate electricity. Study on the effect of storage temperature and time on lipid composition of Scenedesmus sp. (sp of algae) having used two-step catalytic conversion of the oil with high free fatty acid content indicates the good storage ability of algae biodiesel [40]. Also the conversion of algae to biodiesel by pre-esterification and transesterification showed complete conversion of the triglyceride (100%) under a methanol to oil molar ratio of 12:1, catalyst amount of 2% at 65 °C for 30 min. With the exception of the moisture content, the biodiesel conformed to Chinese National Standards [85,148].

10.1.15. Parkia

The tallow tree (*Allanblackia floribunda*) is a woody dicotyledonous and underutilized plant belonging to the *Guttiferae* family. It is an evergreen plant that thrives well in wet places, especially in the rainforest regions. The tree is widely distributed in most parts of Africa including Sierra Leone, Cameroon, Gabon, Congo Brazzaville and Uganda. In Ghana, it is found growing in the Western, Central, Ashanti and Eastern regions [149]. Traditionally, the oil is extracted from the seeds for preparing medicines and making soap. Properties of the oil including the high melting point make it superior to alternatives like palm oil [150]. The seeds of parkia contain 6.0% water, 2.2% ash, 3.6% crude protein, 3.1% crude fiber, 20.7% carbohydrate and 64.4% oil [151]. The oil content of the cake ranges from 4 to 6% or even up to 10%, depending on the oilseed and the processing equipment.

Studies by Ofori et al. [152] on the oil yield of parkia indicated 49% of oil from the seed of parkia. The oil has qualities suitable for the production of soaps, confectionaries and biodiesel, thus providing a basis for exploring it as a biodiesel feedstock [152].

10.1.16. Rubber tree

Rubber tree (*Hevea brasiliensis*) in the family Euphorbiaceae is the primary source of natural rubber. The tree's sap-like extract can be used in various applications [49,153]. Rubber is distributed in areas including Indonesia, Malaysia, Liberia, India, Sri Lanka, Sarawak, Thailand, Nigeria, Ghana, etc. The tree can grow up to 34 m in height and requires heavy rainfall. It produces seeds that weigh between 2 and 4 g per seed. Currently, the oil from the seeds does not have any major industrial applications. The oil content of the seeds could range from 40 to 50 wt% and is high in unsaturated fatty acids, primarily linoleic (39.6 wt%), oleic (24.6 wt%) and linolenic (16.3 wt%) [153]. Other fatty acids in rubber seed oil include palmitic (10.2 wt%) and stearic (8.7 wt%) [153].

In a typical study to investigate the interaction effect of process parameters on rubber seed oil biodiesel, it was found that the optimum biodiesel yield (96.4%) could be obtained at a methanol/oil ratio of 0.2% v/v using sodium hydroxide amount of 0.5% w/v. The biodiesel contained monoester volatile substance, which increases its suitability as a substitute for diesel in automobile engines [84,154].

10.1.17. Tobacco oil

Tobacco (*Nicotiana tabacum*) is a well-known plant. The leaves are commonly used to produce cigarette and cigar. The tobacco plant is said to have much potentials beyond its cigarette and cigar production. For a given plant, there are more seeds than leaves. Unlike tobacco leaves, tobacco seeds generally have not received commercial attention. However, the seeds have potential for commercial applications, including biodiesel. The amount of seeds that could be collected per area of hectare varies, depending on the place, the type of plant and weather conditions. The seeds per hectare area can reach 600 kg [114]. It is also known that the amount of seeds could increase beyond 1200 kg per hectare of area if the prevailing conditions are favorable [155].

Studies indicates that the amount of seeds could reach 2500 kg per hectare with estimate that the new generation of tobacco plants could give more than this amount. Tobacco seed contains a significant amount of oil (35–49% by weight) [155,156]. Even though the oil from the seeds does not contain nicotine [157], it is non-edible and can be used in different applications including biodiesel production [155].

Studies by Usta et al. [96] on the properties and quality of biodiesel from tobacco seed oil indicate that only the oxidation stability and iodine number of the biodiesel were not within the limits of the standard (European Biodiesel Standard –EN14214). However, antioxidants such as butylated hydroxytoluene, propyl gallate, pyrogallol, and butylated hydroxyanisole can be used to improve the oxidation stability [96].

10.1.18. Neem

Neem tree (*Azadirachta indica*) in the Meliaceae family can adapt itself to a wide range of temperatures (0–49 °C). Neem tree is found in various countries in Africa including Ghana, Togo, Nigeria, etc. It grows almost in all types of soils: clay, saline, alkaline, dry, stony, shallow soils. A mature tree can produce 30–50 kg of fruits every year and its life span is about 150–200 years. Annually, about 540,000 t of seeds can be obtained from a hectare, which can yield about 107,000 t of oils and 425,000 t of cake. The oil, being bitter in taste, has a great potential to make biodiesel to supplement other conventional sources. Crude neem oil generally contains high amounts of FFAs.

Kumar et al. [158] reported that crude neem oil with high FFA of 21.6 was pre-treated with an acid catalyst and the FFA was reduced to less than 1%. The biodiesel yield and properties from the optimum yield compared with those of diesel were found to be within the limits of prescribed American standards for biodiesel. In a related study, neem biodiesel produced by a two-step process of esterification and transesterification of high FFA oil (Feedstock FFA: 20%) indicated the density, viscosity and calorific values of the fuel and its blends being within the recommended standards [118]. The performance, emissions and combustion characteristics of the biodiesel indicated relatively better and higher fuel quality compared with mineral diesel.

11. Implication of biodiesel on environment and the African continent

The long-term impact of biodiesel production on the environment is very essential. Biodiesel is considered carbon neutral as the CO_2 released during consumption is trapped from the atmosphere for the growth of plants. Comparing pollutants emission of biodiesel to conventional diesel, biodiesel emits lesser pollutants [159,160]. According to Sarantopoulos et al. [161] evaluation of a small-scale biodiesel production technology: Case study of Mango'o village, in Cameroon, biodiesel instead of fossil fuel reduces the greenhouse gas emissions. This presupposes that the engine exhaust contains little or no SO_2, with less or reduced emissions of PAH, CO, HC and NOx. The growing of energy crops on marginal lands can also help reclaim wastelands to reduce competition of growing food crops on fertile lands. Growing of non-edible oil plants for biodiesel will also ensure infinite supply of renewable energy as the sun will continue to hit the earth to fuel all the activities for all year round [162,163]. Biodiesel will also strengthen the economy since more jobs can be created in the agriculture sector and the taxpayers' money would no more be used to import fossil fuel. Martin et al.'s [164] study on biofuel development initiatives in Tanzania attests to the fact that there is a great deal of optimism that biodiesel will reduce the burden of importing fossil fuels and improve livelihoods as well as alleviate poverty in Africa. It will also help strengthen international trade between Africa and the rest of the world.

However, biodiesel can contribute to green house gas emissions. A related study by Stephenson et al. [165] on global warming potential and fossil-energy requirements of biodiesel production scenarios in South Africa concluded that biodiesel activities contribute significantly to green house gas emission. Biodiesel activities could also contribute to forest depletion and biodiversity threat, instigation of land ownership and usage conflicts, food security, pollution, trade and its impact on national and global economies [18]. All the cultivation practices starting from land clearing and the consequent loss of forests and grasslands could aggravate the current threat of global warming and climate change. Using productive lands for energy crops can also result in increased competition for land for growing food crops and other industrial and urban purposes.

12. Outlook

It is no doubt that using the available fertile lands meant for growing edible plants to cultivate non-edible plants will worsen the current food versus fuel competition. On the other hand, growing non-edible oil plants on waste and abandoned lands means that these resources will profitably be used for biomass generation. Farm practices that depend on fertilizers, biocides and pesticides pose threats to the ecology due to pollution to fauna and flora. Therefore, organic farming is gaining ground. Using the farm lands to grow energy crops will be the favorable route. It is known that certain energy crops like jatropha thrive well on marginal and semi-arid lands which can be used for sustainable development of mining communities in most African countries. The introduction of biodiesel as another channel of marketing farm crops such as jatropha and neem can help curb the high rate of youth migration through job creation. Non-edible for biodiesel will also increased income level of rural populace through job creation by locating biorefineries in such localities which will consequently improve the local economy as a whole. There is also a possibility of high job diversification through integrated biodiesel practices which will offer competition for labor with other traditional employment avenues. This has the tendency to increase the income levels of employees as they would be offered more than a choice. In sub-Saharan Africa, women and children are mostly responsible for collecting traditional biomass for cooking. Replacement of these traditional fuels with biodiesel and other gel fuels has enormous potential for Africa by freeing time for the women and children to engage in other businesses and thereby promoting education. It is obvious that the strategic nature of fuels places many countries' and regional economies out of gear with distortions in crude oil prices. Hence weaning such economies from oil import dependency could be an economic achievement. This could be done through developing and patronizing biodiesel.

13. Conclusion

Energy is a key factor in industrial development and provides vital services that improve quality of life. However, its production, use, and by-products have resulted in major concerns on the environment (from the use of resource and pollution point of view). The inefficient, pollution, cost and environmental concerns of fossil energy represent a major challenge for sustainable development. The aim of Africa is to foster development and prosperity through gains in energy efficiency rather than increase consumption through transition towards environmentally friendly use of renewable resources. This transition will obviously see biodiesel as the solution. And with the energy potential of non-edible resources, especially jatropha (Table 2) in Africa, it is evident that the available edible resources will not be sustainable enough to meet the increasing energy and food security. Non-edible oil resources can therefore be guaranteed as sustainable feedstock for biodiesel in Africa for the fact that non-edible oil plants can be grown on wastelands to reclaim them, may not compete with food crops for limited lands, are relatively cheap, available and offers similar or even higher fuel yields and quality. Their development can be used to curb the high unemployment rate through job creation, increased income of the rural populace, diversification and therefore enhancing the quality of environment (reduction in pollution). Replacement of fossil fuels with biodiesel will also offer free time for women and children to engage in other businesses and promote education. Weaning African economies from oil import dependency could be an economic achievement. It can be deduced from the study that there are promising non-edible oil resources in the system for biodiesel industrialization in Africa.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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