McHenry, M.P., Doepel, D., de Boer, K. and Zhou, E. (2015) Co-production of high-protein feed and bio-oil for poultry protein productivity and fuel switching in Mozambique: Avoiding transesterification and food insecurity. In: McHenry, M.P., Kulshreshtha, S.N. and Lac, S., (eds.) Agriculture Management for Climate Change. Nova Science Publishers, pp. 81-93.

Chapter 7

CO-PRODUCTION OF HIGH-PROTEIN FEED AND BIO-OIL FOR POULTRY PROTEIN PRODUCTIVITY AND FUEL SWITCHING IN MOZAMBIQUE: AVOIDING TRANSESTERIFICATION AND FOOD INSECURITY

Mark P. McHenry[1*], David Doepel[2], Karne de Boer[1], & Emerson Zhou[3].

[1]School of Engineering and Information Technology, Murdoch University, Western Australia [2]Africa Research Group, Murdoch University. [3]Beira Agricultural Growth Corridor (BAGC), Mozambique

ABSTRACT

This chapter explores the next steps of expanding village poultry productivity in Mozambique post control of communicable diseases by assessing co-production of edible oils and high protein poultry feeds. The production of oil was analysed from the perspective of a suitable non-fossil fuel without the need for transesterification to produce biodiesel. A range of feedstock issues were considered for co-producing vegetable oil as a fuel and high protein animal feed. Technical considerations of the direct use of straight vegetable oil (SVO) in diesel engines and oil conversion to biodiesel are discussed and identify more suitable options for additional mechanisation options for smallholder farmers. Potential synergies with private-public partnerships between smallholders, food production companies, and education institutions to assist introduction of new mechanisation options were investigated. The research findings indicate the lack of access to training and equipment, and also education and experience of refining bio-oil derivatives, and the parallel high demand for human and animal food/feed presented a high prospectivity of producing SVO for use in suitable engines. The chapter concludes with a strategy to maximise the potential benefits of SVO production and use within agricultural communities.

Keywords: Biodiesel, poultry, productivity, protein, vegetable oil, smallholders, partnership.

INTRODUCTION

A producers' capacity to purchase modern inputs is co-dependent on a households' land holdings, human capital, labour availability (Crawford et al., 2003), and it is less common for

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[*] Mark P. McHenry. Email: mpmchenry@gmail.com

subsistence farmers to purchase agricultural inputs to improve overall productivity. As a result, production drops to basic domestic subsistence rather than commercial production and sales (Counguara and Moder, 2011). The result is that the volume of production is well below the threshold to justify modern technology (for example, transport), and with a limited availability of appropriate inputs, such as fertilisers, out-dated production methods remain in use (Gwillam et al., 2009; Speielman et al., 2010). The associated yield and income gap between subsistence farming and commercial agricultural production exists primarily due to the relatively high costs of modern inputs and their associated complexity of use, and lower returns from increased production of commercially low-value crops (Godfray et al., 2010). Compounding the spiral into poverty is the misplaced emphasis on understanding agriculture as a stand-alone industry on the African development agenda, instead of within the context of larger economic drivers such as, flows of labour, capital investment, and product transfer between urban and rural areas (Woodhouse, 2009). Agriculture-specific input, credit, market support mechanisms, and subsidy programmes (commonly fertiliser and fossil fuel), are often very costly and are unsustained (Speielman et al., 2010). Therefore, it is necessary to gather a wider scope of rural development-related information, involving local appraisals, and undertake detailed analyses outside of traditional agricultural supply chains to avoid implementing inappropriate strategies and systems (Werblow and Williams, 1998). The introduction of new farming technology and knowledge without a thorough understanding of the social and economic context is problematic, and a greater level of stakeholder engagement is required at all levels (Woodhouse, 2009). As an example, while agriculture accounts for 70% of African countries' total employment and 65% of whom are women (Opara, 2011), women often remain excluded from consultation and decision-making. Furthermore, relatively superficial understandings of how to support locally appropriate agricultural development activities commonly introduces false dichotomies between public and private interests. For example, elements of the 'bioenergy vs food security' debate have been presented as in direct competition for inputs and land, rather than from a co-dependent rural development perspective (Lynd and Woods, 2011). Modern biofuel facilities generally take place near good infrastructure, service centres, areas with processing and storage facilities, and a skilled labour force (Schut et al., 2010). In general, the present poor transport infrastructure in many regional areas limit both the potentially positive and negative impacts of bioenergy developments on food insecurity, poverty, and lands, and is highly variable at the local level, which are also limited by crop species, land use, technologies employed, and supply chain specificity for the agricultural system (Lynd and Woods, 2011). The investigation of interrelationships between food security, and local smallholder commercial co-production of biofuel, edible oils, and high protein fodders was a major focus of this research.

BACKGROUND AND INTERVIEW (KYEEMA, MOZAMBIQUE)

The Kyeema Foundation office in Maputo, Mozambique focusses on poultry disease prevention and production development. The authors met with Dr. Rosa Costa, the Regional Manager of the Kyeema Foundation, through recommendations from Dr. Robyn Alders, a board member of the Kyeema Foundation living in Australia. Dr. Costa ran the research institute that administered the thermostable vaccine project to combat Newcastle Disease (ND) in sub-Saharan Africa, a devastating condition that can kill between 50-80% of chickens infected. The community-based ND control programs improve peoples livelihoods as they depend on chickens as a subsistence and cash income strategy. Dr. Costa stated that in the provinces the foundation has generated substantial descriptive information and recorded data regarding ND, village chickens, and the wider social and economic implications in these regions. In summary, around

97% of the families in the villages have chickens. Average villages would contain between 400 and 1,000 families per village. These families will be able to sell around 18 to 20 eggs each month. This is a major source of income in the region, particularly for the women in the village, who generally own and maintain the chickens. Dr. Costa clarified that with the success in ND inoculation programs, there is a growing population of village chickens, and that a major limitation in these provinces is the lack of a suitable and cost-effective high-protein feed. Dr. Costa noted that this is a major opportunity to improve the lives of people in these provinces. At present, they are looking at conventional feeds such as cowpea, and *Moringa oleifera* (drumstick tree) as high-protein multi-purpose fodder species that can also provide building materials and energy services such as firewood. Dr. Costa explained that high protein commercial feeds are largely unavailable in these regions, and in any case are too expensive for the villagers to purchase. Villagers sometimes have to travel large distances to source appropriate feeds, and must process them so they are suitable for the chickens to eat, requiring much time and energy. The village chickens are also vulnerable to being killed an eaten by various pests, which prevent them from venturing too far from the village. Therefore, in addition to being cheap and cost-effective, any new chicken feed must be high-quality and energy dense to reduce transport requirements back to the village, or be produced locally to reduce already high physical burdens on villagers owning chickens, commonly women.

The authors were intrigued with the parallels between the local requirement of high-protein and energy dense feeds for poultry farmers noted by Dr. Costa, and the growing interest of ‘straight vegetable oil’ (SVO) displacing biodiesel in the local extractive industries. In parallel, the large demand for edible vegetable oils in the region for human consumption can also be supplied by the same oilseeds that can be used to produce SVO for mining equipment. If larger-scale commercial production of oilseeds occurs in the region, then this might lower the currently high cost of edible oils, and benefits will flow onto the local food market, bolstered by investment focussed on a new local supply of SVO. However, if this scenario plays out, the larger-scale edible oil production will also increase the availability of oil byproducts, including high-protein, energy dense biomass (commonly known as meal), which is often suitable as animal/human feed/food. By using biomass feedstock that is edible (as opposed to oils derived from Jatropha for example), a commercial supply of suitable poultry/other animal/human feed/food may occur as a consequence of new SVO production investment, underpinned by commercial supply chains needing a diesel alternative to lower local fuel costs. The authors caution for how this theoretical supply chain development may play out in practice, particularly concerning land allocations. The complete supply chain requires further exploration to ensure negative externalities are minimal and positive externalities are leveraged. Yet, in terms of potential positive externalities, decreasing local fuel (and as a consequence animal feed costs) through increasing production of edible oils suitable for SVO in extractive industry machinery (and the food market) is likely to require investment in agricultural mechanisation and local oilseed productivity. If smallholder farmers can also play a role within this context, they are likely to capture benefits from partnering with suitable commercial players using the PPP model of guaranteed off-take supported by the keystone extractive industry investment in SVO, and through enabling organisations providing investment in agricultural mechanisation extension and capacity on a sustained commercial basis. This example demonstrates the unique perspective of how food and fuel security are related in subsistence farming communities, as in the case of both, it is the *net* energy produced locally that is important. As subsistence farming requires a large amount of human manual labour, the energy-intensive diet required to maintain this output may be more efficiently allocated to biofuel-enabled labour-saving devices or other alternative energy inputs to increase net food security. However, within each region subsistence production system adaptation towards mechanisation, the net impact on the local food availability and energy supply, prices, etc., require ongoing analysis.

POTENTIALS FOR SMALLHOLDER MECHANISATION FOR FUEL/FOOD

In agricultural regions with low food security, consideration of total net energy expenditures for producers is a fundamental area of research need. Without mechanisation, much of the energy input into agricultural production systems is manual labour. This labour is 'bioenergy' at it is most basic, and can be measured in terms of energy output akin to mechanical equipment. The basal metabolic rate of a human adult is generally under 100 Watts, and is the minimum amount of energy required to keep all body parts functioning. Activities when not at rest require additional energy. A person's peak Watts is the maximum amount of energy that can be produced physically at any one time. For example, riding a push bike a long distance at around 20 km/hr (a medium level activity) will use on average around 100 Watts of energy in addition to the basal metabolic rate consumption. In comparison, jogging or riding up a steep hill can require around 300 or more Watts above the minimum, depending on the fitness and strength of the individual. At the extreme, the amount of energy a trained professional sprinter can produce can be between 1,000 and 2,000 Watts, which can only be sustained for a few seconds at most.

As the majority of the sub-Saharan population have no access to convenient, safe, healthy, and affordable energy services (Karekezi, 2001; Schultz et al., 2008), smallholder mechanisation will require detailed on-site analyses to explore how these new technologies are, or are not, technically appropriate and cost-effective in specific socio-economic and agricultural production systems, and if the input energy supply chains are appropriate. In a similar manner to agricultural supply chains, there is growing interest in support for clean energy enterprise development where system manufacturing, dissemination, commissioning, application, and servicing occurs at the local level. This enables local businesses to develop on the back of a new clean energy technical solution (Karekezi, 2001). In practice, renewable energy system programmes and technologies often have a chequered history of generating unrealistic expectations with optimistic expected outcomes and high costs (Martinot et al., 2002; McHenry, 2009b; McHenry, 2012b), commonly associated with zero product testing prior to their introduction (Adkins et al., 2010). It is known that a renewable energy partnering approach from an 'investment perspective', rather than solely a 'development' or 'donor' focus, is more effective than simple donations of new capital (Hall et al., 2001; Irvine-Halliday et al., 2008; Adkins et al., 2010). Therefore, researchers, industry, and development agencies need to take a collaborative approach in such programmes and focus on private/business concerns regarding energy services and technologies in terms of system technical performance, robustness, commercial viability, and community acceptability (Glover et al., 2008; Irvine-Halliday et al., 2008). Importantly, donating technologies without any cost recovery extinguishes local small-scale markets, and inappropriate subsidies can undermine local entrepreneurship, private businesses, and employment (Martinot et al., 2002; Onyango, 2010). The local production of energy (for example from edible oil crops), provides energy for both people and mechanisation technologies, and these activities accelerate the existing production and user base of both fuels and agricultural production. SVO use in diesel engines is particularly relevant in communities that are based around subsistence agriculture, as the capacity to produce biofuels to international standards are likely unavailable, and the required technical training and education requirements prohibitively impractical for the near future. The authors believe that the use of simple technologies to co-produce vegetable oils for both human and mechanisation needs, with high protein feed production from the bybroduct wastes is a major opportunity in the region;

particularly as an integration and convergence of adaptation and mitigation potentials for climate change and economic development within the agricultural sector (Taylor et al., 2007; McHenry, 2009a; Kerekes and Luda, 2011; McHenry, 2011; McHenry, 2012a).

OPTIONS FOR PROTEIN AND BIOFUEL FEEDSTOCKS: EDIBLE OILS

Over the last 110 years vegetable oils and their derivatives have been used as liquid fuels in diesel engines. Vegetable oil use is more common in remote locations where fossil diesel is unavailable, or at times when it is prohibitively expensive. However, in more recent years the use of vegetable oil and more specifically the vegetable oil derivative, biodiesel, has become widespread due to concerns related to energy security and climate change. The first use of vegetable oil in a diesel engine can be traced to its inventor, Rudolf Diesel, who reported a trial of peanut oil in the diesel engine that was conducted by the French Otto company under the impetus of the French government. Diesel explained that the French government's interest in peanut oil was energy self-sufficiency in their African colonies. In-spite of this initial interest the abundance and low cost of petro-diesel has ensured that historically the diesel engine has almost exclusively been powered by fossil fuels. However, with the petro-diesel price increasing, one of Diesel's remarks was somewhat prophetical: *'[vegetable oils] make it certain that motor-power can still be produced from the heat of the sun which is always available for agricultural purposes, even when all our natural stores of solid and liquid fuels are exhausted'* (Diesel, 1912).

Before the 1980s, the use of vegetable oils and their derivatives in diesel engines only occurred when fossil fuel supplies were severely threatened or in remote locations where diesel was expensive or unavailable (Van Gerpen et al., 2007). Despite their limited use, many different types of oils and oil derivatives were trialled in diesel engines, generally providing satisfactory results (Knothe et al., 2005). The interest in vegetable oils as fuels rapidly accelerated in the late 1970's during the Organization of Petroleum Exporting Countries (OPEC) oil embargo. This culminated in a 1982 ASAE (now ASABE – American Society of Agricultural and Biological Engineers) organised conference entitled 'Vegetable oil Fuels' (Van Gerpen et al., 2007). The majority of papers at this conference covered the use of vegetable oils as fuels while a few examined the alkyl ester products of oil transesterification as diesel fuel substitutes (The reaction used to convert triglycerides (oil) into Fatty Acid Methyl Esters - Biodiesel). According to Van Gerpen (2007) the general consensus from this conference was that while unrefined vegetable oils showed promise *'they had a tendency to cause injector coking, polymerisation in the piston ring belt area causing stuck or broken piston rings, and a tendency to thicken lubricating oil causing sudden and catastrophic failure of the rod and/or crankshaft bearings.'* This is confirmed in various other studies, for example that of Srivastava *et al.,* (2000). In response to these problems it was seen that the greatest need was to find a method for reducing the viscosity of the oil and its tendency to polymerise. The most promising of these methods was the transesterification of vegetable oil to produce fatty acid methyl esters, which when refined are called biodiesel.

Initially, biodiesel was produced from virgin vegetable oils especially soybean (America), Rapeseed (Europe) and Palm (Asia), however, increasing vegetable oil prices has resulted in a shift to new crops, tallow, used cooking oil, trap grease and other low cost feedstock sources. Although many focus on the engine technology or the conversion process from oil to biodiesel, the major issues is almost always the cost-effective and practical supply of sufficient feedstock. History has repeatedly shown that a reliably available, appropriately priced source of vegetable oil is the foundation for any successful program where vegetable oil is used as fuel. Vegetable oils are currently sourced from a wide range of terrestrial crops that are typically grown on arable farmland. These sources of oil have traditionally been grown as a food source, however, with the growing market penetration of biodiesel, they are now in demand as a biofuel. Other sources of triglycerides include animal fats, which are generally produced as a by-product of the rendering process, and oils from microalgae, however, the latter is not yet considered commercially feasible. When considering a crop for suitability as a vegetable oil source for diesel engines, the most important consideration is yield: How many tonnes of oil can be produced per hectare of land. Although this is critical, others factor must also be considered: value of by-products and suitability with current agricultural systems; water use efficiency and drought tolerance; ease of harvesting; time for plants to reach maturity; and nutrient use efficiency.

Typical yields for vegetable oils yields are highly dependent on cultivar strength, available rainfall, climate, nutrient availability, and soils. As an indication consider palm oil, where some new palm plantations can produce oil yields of between 8000-10,000 L/ha, while older plantations will struggle to produce 3,000 L/ha. The high yield of the oil palm relative to other crops also demonstrates why this crop has been so popular in Asian nations. On the other hand, in the case of soybeans (another widely grown crop) the oil is the by-product from protein production for both human and animal feed. Rapeseed or canola, is different again, with a reasonable oil yield coupled with valuable protein in the meal making it an attractive crop in temperate climates. New crops like Pongamia and Jatropha have received significant attention because of the following positive attributes: high yields with potential up to 5,000 L/ha technically feasible; both plants are legumes and are thus can fix nitrogen to the soil; they have fatty acid profiles that are high in oleic acid which is ideal for biodiesel; both produce hulls that can be used for bioenergy and feed protein; both are perennials that enable vegetable intercropping, and; both plants can survive in harsh conditions and poor soil. The major disadvantage of these crops is that the meal or seedcake (left over after pressing) contains compounds that are toxic or taste bitter making it difficult to use the protein for animal feed. Furthermore, both crops have only recently received the interest of agricultural scientists, and as a result both cultivar properties and plantation management practices are relatively undeveloped. Although microalgae has the highest yield and can be grown on barren land using saltwater, it is currently uneconomic to produce oil from these organisms. The simple reason being that the cost of production of algal biomass is between US$4-10/kg which leads to an oil cost of between $12 and $30 per litre. Vegetable oil production steps can occur at the farm scale, at a farm cooperative level, or at a central processing site. The oil extraction efficiency and product quality increase with the increasing capital expenditure and economics of scale. Seed pressing can also be replaced or supplemented with solvent extraction to maximise oil yield, while pre-processing and post-processing operations after milling will depend strongly on the crop grown and the intended market for the oil and meal. Having produced the oil, the oil can either be directly used in diesel engines with some modification so that it can be used in standard diesel engines.

VEGETABLE OIL IN DIESEL ENGINES

Vegetable oils have been used to directly fuel diesel engines in numerous applications. Currently, the major users of vegetable oil in diesel engines are: straight coconut oil and coconut oil blends with diesel or kerosene in cars and power generation, especially in Vanuatu and other pacific islands (Carr, 2009); palm oil for utility scale power generation in Europe and Asia; rapeseed/canola oil for cars in Europe. Although it is true that almost all diesel engines will run on vegetable oil, the key question is how long they will continue to run due to the differences between vegetable oil and diesel (Carr, 2009). The major issues associated with using vegetable oil in standard diesel engines are: high viscosity causing incomplete combustion and subsequent coking of injector, valve, manifolds and piston rings; passing of the vegetable oil past the piston rings into the lubrication oil; overpressure in the injector pump causing failure; impurities in the vegetable oil causing filter/injector blockage; cleaning effect of the vegetable oil in tank causing filter blockage, and; solidification of the vegetable oil when temperatures fall. To solve these issues, the following methods have been used (The last two methods have met with the most success as they reliably solve the cause of the issues listed previously): mixing with a thinning agent to create an emulsion with lower viscosity and better combustion properties. Thinning agents can be kerosene, diesel and various other organic solvents; operate the engine with a ‘two tank system’ in which the engine is started and operated on diesel until it reaches operating temperature at which point the fuel supply is switched to vegetable oil that has been heated by the engine coolant (When the engine is shut off it is also run on diesel to prevent any issues on start-up), and; modification of the engine with new injectors, increased injection pressure, vegetable oil heaters and better filtration.

Engine types and Oil Properties

The third method has been adapted by many modern engine users, as current injection systems have little tolerance for the different properties of vegetable oil. Older engines using indirect injection technology and different combustion system designs are less affected, as they were designed in an era when fuel quality was much less predictable then it is today. These engines are still being produced in China and India, and can run on vegetable oil without any modification. Two examples of engines in this category are the Lister and the Changfa, which are essentially copies of antiquated engines designs that have proven their mettle throughout the last century. Their simple and antiquated design has proven very effective for use as vegetable oil fuelled engines (Carr, 2009). They are also well suited to agricultural duties such as pumping. Another consideration when using vegetable oil directly in diesel engines is the properties of the vegetable oil. These properties are almost solely determined by the fatty acid profile of the oil, with the key properties being chain length and level of saturation. Chain length refers to the amount of carbons in a fatty acid, while saturation refers to the quantity of double bonds, with unsaturated oil having one or more double bonds. (See Figure 1 for their general effects).

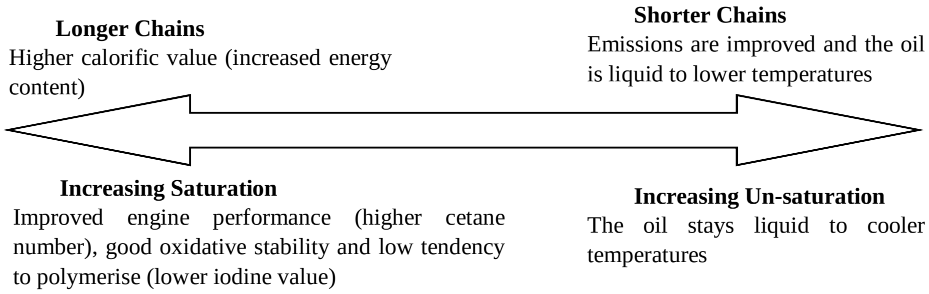

Figure 1. Effect of chain length and level of saturation on fuel properties (de Boer, 2010).

Figure 1 demonstrates that vegetable oils with high levels of unsaturation (e.g. soybean or poppy seed oil) are unsuitable for diesel engines as they polymerise and have low oxidative stability. Conversely, oils that are high in saturation and have low carbon chain lengths (e.g.: coconut oil) are ideal as they tend to not polymerise or oxidise and have reasonable cold flow properties because of the short chain length. Table 1 compares the fatty acids of rapeseed and palm oil, which are commonly used in diesel engines. Palm oil is an excellent engine fuel because of the high level of palmitic (saturated) fatty acid, with the only negative being the corresponding high melting point of the oil. Rapeseed, which is used extensively throughout Europe is very high in oleic acid (mono-unsaturated) and has a good balance of cold flow properties, combustion properties and a reasonably low tendency to polymerise. The fatty acid profile is a critical characteristic of any oil being considered for use in diesel engines and should play a major role in the choice of feedstock for diesel engines in agricultural systems.

Table 1. Fatty acid profiles of two vegetable oils.

Fatty Acid	**C:N**[a]	**Rapeseed Oil**[b] **%**	**Palm Oil**[c] **%**
Lauric	C12:0	0	0.4
Myristic	C14:0	0	1.1
Palmitic	C16:0	4	43.8
Palmitoleic	C16:1	0	0.1
Stearic	C18:0	1	4.4
Oleic	C18:1	60	39.90
Linoleic	C18:2	25	9.6
Linolenic	C18:3	9	0.2
Others		1	0.5

[a] Number of carbons in the fatty acid chain: Number of double bonds; [b] Low Erucic acid (Mittelbach and Remschmidt, 2006); [c] Darnoko and Cheryan, (2000).

Due to the difficulties associated with modifying multiple engines to use SVO, it has become the norm to convert the vegetable oil to biodiesel via chemical means. Biodiesel has a viscosity that is 1/10 that of vegetable oil and has very similar properties to petro-diesel. Most diesel engines can use straight biodiesel or a biodiesel/diesel mix with little or no modification. Vegetable oil can be converted to biodiesel where vegetable oils or animal fats (triglycerides) are converted into fatty acid methyl esters (FAME). Upon purification to fuel standards such as EN 14214 (Europe) and ASTM 6751 (America), the FAME are known as biodiesel. The transesterification reaction involves the stepwise removal of fatty acids from the glycerol backbone of the triglyceride; these fatty acids then react with methanol to produce FAME. The stoichiometry of this reaction is 3 molecules of methanol for every molecule of triglyceride to produce 3 molecules of FAME and 1 molecule of glycerol. Although the transesterification reaction is relatively straightforward, the production of biodiesel requires multiple processing steps (Figure 2). A large range of biodiesel production systems are commercially available, however, all of them use transesterification.

The major advantage of biodiesel is that it can be produced at any scale from small batches of 50 L to continuous production producing in excess of 280,000,000 L/yr. The major disadvantage with biodiesel is that the process requires chemical inputs (methanol and catalyst-potassium hydroxide or sodium methylate), requiring transportation to the production site. Furthermore, the process is relatively complex in comparison to typical agricultural operations, requiring multiple processing steps, and quality control on the feedstock and final product to ensure reliable production of high quality biodiesel. Some key metrics for biodiesel production including: the cost of converting vegetable oil to biodiesel is typically US20-25 c/L, in addition to the feedstock cost. (However, this depends on the delivered cost of methanol and catalyst, as well as the cost of labour and energy); the methanol volume required is typically 11% of the desired biodiesel volume; the catalyst is typically 0.8% by weight of the biodiesel produced, and; 1 L of biodiesel requires 1 L of oil (de Boer, 2010). Therefore, access to training and equipment and education and experience is necessary for biodiesel quality control and safe chemical handling procedures. In contrast, the high demand for human and animal food/feed is a fundamental consideration is exploring SVO production rather than conventional fossil-based biofuels. In specific areas and applications, the authors recommend further investigation of producing SVO for diesel engines as a agricultural food and food security development opportunity (Table 2).

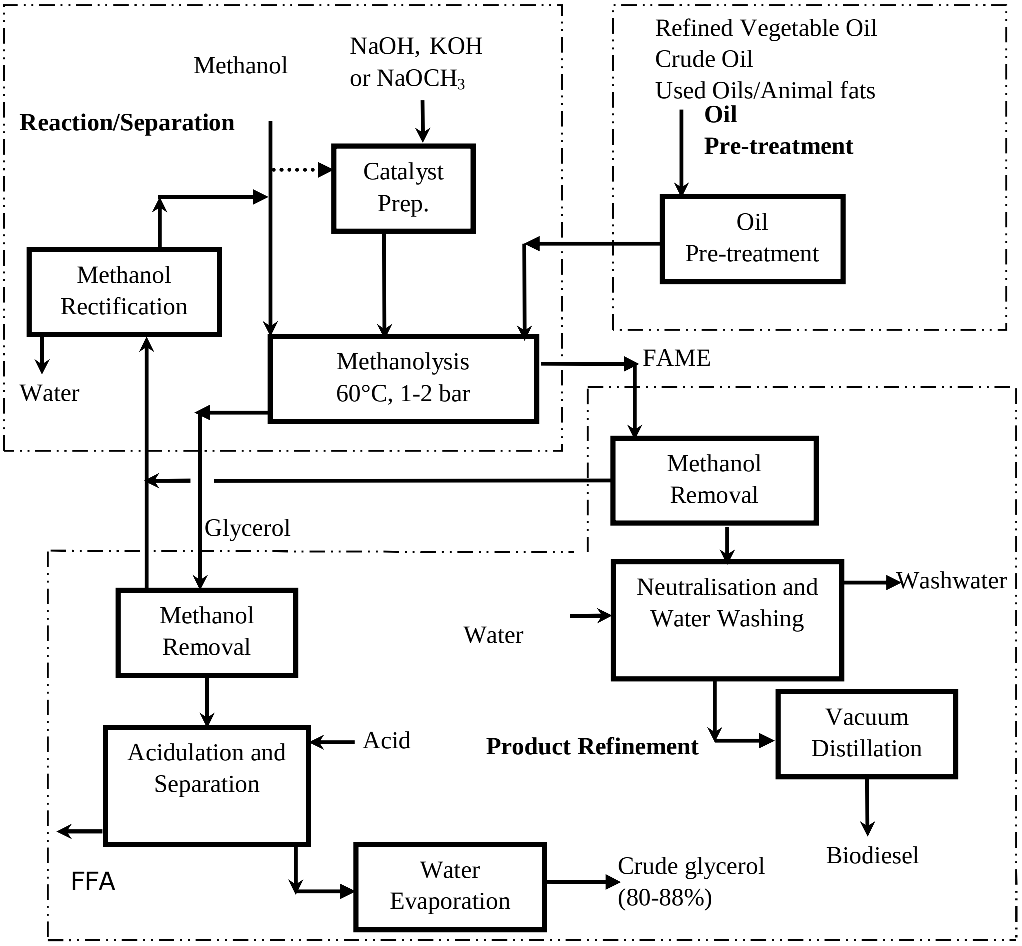

Figure 2. Biodiesel production (de Boer, 2010).

Table 2. Comparison of different approaches for using vegetable oil in diesel engines.

Advantages	**Disadvantages**
Direct use of Vegetable Oil in Diesel Engines	
Limited processing required	Potential damage to engines
No inputs required	Limited range of equipment with suitable engines
Concepts within subsistence capacity	Engines need to be modified
Conversion of Vegetable Oil to Biodiesel	
Biodiesel can be used in a large range of diesel engines without modification	Chemical and explosion hazards associated with processing
Reliability of engine is increased relative to direct vegetable oil use	Comprehensive quality assurance required
	Chemical inputs required
	Complicated production process
	Increased cost of fuel due to processing

CONCLUSIONS

The authors recommend a parallel focus on the production and use of SVO oil for suitable agricultural equipment, as this may provide an effective foundation for further economic development. Economic development generally increases total agricultural biomass production, and it has been demonstrated that it can both ‘feed’ and ‘fuel’ nations. As this development trajectory accelerates, the existing production and user base will reach suitable scale for the local development of fuels. With this in mind, the authors propose the following strategy to be considered to maximise the potential benefits of SVO production and use within subsistence agricultural communities: 1) Identify a suitable crop that produces oil with desirable qualities at reasonable yield in the agro-ecosystem, while at the same time providing co-products (meal) that can sustain livestock or other industries; 2) Exploration with farmers options to access mechanised equipment that can process feedstock into oil and other by-products; 3) Explore with farmers diesel powered agricultural equipment that can, or is amenable to modification to handle vegetable oil as a fuel, and; 4) Leverage the increased biomass production and experience with vegetable oil to lay a foundation for an industry that produces vegetable oil derivatives that are compatible with existing diesel engines.

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