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Review

Obtainment, applications and future perspectives of palm kernel

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Of African origin and with an estimated world production of 6.85 million tons, palm kernel oil contributes about 3% of the total world production of oils and fats. With such production, the world waste generation was about 10,026 × 10^3 tons in 2017, which represents an important environment issue. The present work aimed to review the literature on the main methods of extraction, applications, and future perspectives of *Elaeis guineensis* Jacq., with emphasis on its seed: palm kernel. Regarding its main applications, biodiesel production was highlighted, since the biomass generated can be used as a substitute for fossil fuels in energy production.

Key words: *Elaeis guineensis* Jacq., palm kernel, extraction of vegetable oils, biodiesel.

INTRODUCTION

Palm kernel is an oleaginous seed found in *Elaeis guineenses* Jacq. fruits. Historically, the demand for its grains was much higher than that for oil, due to its high consumption. Progressively, the export of grains increased considerably along with the demand for palm kernel oil, beginning their exports around 1832. The export growth rate declined a few decades after the Second World War (Atinmo and Bakre, 2003; Corley and Tinker, 2016).

The palm kernel crop has important socioeconomic

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representation for the countries that produce it. They are grown both by smallholders on family farms and on large-scale plantations (Kusumaningtyas and Van Gelder, 2017). Currently, palm kernel is among the world's largest oilseeds, with estimated production of 18.59 million tons in 2017 (USDA, 2018). Its main world producers are Indonesia, Malaysia, Thailand, Nigeria and Colombia, but Colombia and Thailand are the countries with the highest production growth rate (Index Mundi, 2018).

The palm kernel oil can be extracted by several methods, such as: mechanical extraction, solvent extraction, microemulsion, and extraction with supercritical fluids (Norhaizan et al., 2013). This oil production presents social and environmental benefits, such as the generation in employment and income, and consequently improvement in the producer’s life quality, and trade development (Aziz et al., 2015). Regarding progress on culture and also new areas of palm kernel applications, several alternatives have been studied, from improvements in crop and new methods to obtain the oil, to the development of new products such as biofuels, cosmetics, and food products (Da Silva and Batalha, 2013; Cros et al., 2015; Bashir et al., 2015; Da Silva and Engelmann, 2017).

Palm kernel has higher productive potential compared to other oilseeds production costs (Zimmer, 2016), being considered as one of the crops responsible for supplying the vegetable oil world demand (Corley, 2009). It also presents production of approximately 10% of the total palm oil, being able to reach 0.4 to 0.6 MT of Palm Kernel Oil (PKO) per hectare (Sunilkumar et al., 2015).

With such expressive production, this crop generates challenges to balance the increase of yields with the deforestation reduction. Also, reduction of industrial residues from oil extraction processes are highly required, since 10,026 × 10^3 tons of Palm Kernel Cake (PKC) were generated in 2017 (Norhaizan et al., 2013; Index Mundi, 2018).

Regarding the destination given to PKC, due to its high energy value, is often used as an animal feed supplement (Hossain et al., 2011), and one way to guarantee the maintenance of these nutrients is to make the re-extraction of the residual oil present through supercritical fluid technology, since there is no use of organic solvents in it. This type of solvent would impair its use by the animals.

In this way, the utilization of biomass from the palm oil industry, which might still present in its composition up to 12% of residual oil, may represent an alternative for the production of fossil fuels, and can be used as a source of renewable energy, boosting regional economic development (Ab Rahman et al., 2012; Bezerra et al., 2018). Thus, the objective of this study was to present the main aspects of palm kernel oil obtainment, as well as the current scenario of applications, the management of extraction residues, and their technological advances.

METHODS OF OBTAINING PALM KERNEL OIL

Currently, there are several methods that have been used in the process of obtaining greases, such as solvent extraction, mechanical pressing, supercritical fluids, ultrasound, and others (Borges et al., 2016). In this research, the focus was on the most used method for extracting palm kernel oil: mechanical pressing. Extraction by supercritical fluids will be approached as an alternative to recover the remaining oil of palm kernel cake.

Mechanical pressing extraction

Pressing may be defined as a compression step in which a liquid is exuded from a porous matrix. In the industry, oilseed extraction is performed with continuous screw presses. This step does not require heat input or organic solvents, thus being the least expensive part of the process (Subroto et al., 2015). This type of oil extraction requires seed pre-treatment, which may include size reduction, cracking, drying, sieving, etc. This is necessary to efficiently extract the oil from the kernels. At first, they must be cleaned of materials that may contaminate the products and cause damage to the equipment. In order to remove metal residues, stones, sand, and other undesirable materials, magnetic separators and vibrating screens are commonly installed (Savoire et al., 2013; Rombaut et al., 2015; Firdaus et al., 2017). During expression, the raw palm kernel oil is separated for clarification and the residue is cooled and stored in a warehouse (Figure 1).

Malaysia produced 2.4 million tons of PKC out of 4.7 million tons of palm kernel, in world at 2012 (Ibrahim, 2013). As the organic solvent extraction cost is high, and the solvent recovery is difficult, the mechanical process is the most currently used. The content of PKC includes high contents of fiber, manganese, iron, and zinc (Akinyeye, 2011). The chemical and mineral compositions of PKC are shown in Table 1. With such composition, many studies have been carried out regarding the inclusion of PKC in animal feed (Thongprajukaew et al., 2015; Vibart et al., 2017; Alshelmani et al., 2017; Huang et al., 2018). According to Alimon (2004), PKC is one of the most flexible feed ingredients, since it can be used in all types of animal rations, consequently reducing conventional feedstuffs importation. However, quantities of anti-nutritional factors present may limit their feed value and usage. In this case, enzymes can be added in animal diets in order to supplement the enzymes already present in the digestive system (Zamani et al., 2017). Besides the use in animal feed, fibers and shells can still be used as feed in steam boilers, being useful as raw material in the coal industry (Zhang et al., 2018). On the other hand, refined oil has applications in products of the most varied sectors such as in the food, cosmetic, pharmaceutical, oleochemical, and chemical industries,

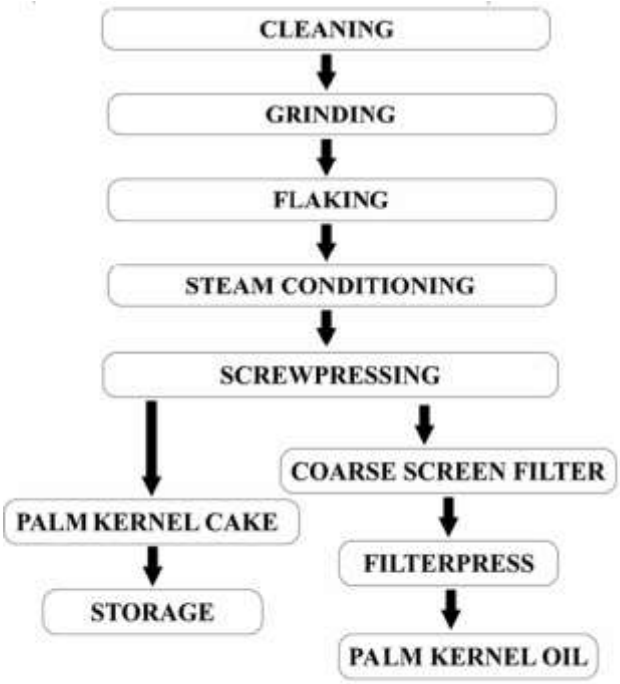

Figure 1. Mechanical extraction simplified flow chart of palm kernel oil.
Source: Sue (2004).

among others (Rezaeeet al., 2014; Septevani et al., 2015).

Embrandiri et al. (2012), Ibrahim (2013) and Subramaniam et al. (2013) specifically use the screw press technique to extract palm kernel oil. Ikechukwu et al., (2012) designed an expeller pilot plant to extract 200 kg of oil/day. The plant was tested with an initial input of 59.52 kg of palm kernel per hour, for 10 h. As a result, 200.05 kg of high-quality palm kernel oil was obtained. Regarding the crude PKO fatty acid composition, it presents about 82.6% of saturated fatty acids, with the lauric acid as the major component, followed by myristic and oleic acids (Table 2). Because of its saturation content, this oil is very resistant to oxidation (Ibrahim, 2013).

Supercritical fluids extraction (SFE)

Some researchers have reported the supercritical fluid extraction of palm kernel oil from palm kernel, obtaining yields up to 49.9% (Norulaini et al., 2004; Zaidul et al., 2007). In the work of Hossain et al. (2016), the optimum conditions of palm kernel oil extraction were pressure of 44.6 MPa, temperature of 60°C and extraction time of 50 min, whose yield was approximately 49.2%. A typical SFE apparatus is shown in Figure 2.

Zaidul et al. (2006) applied supercritical CO_2 to fractionate palm kernel oil and concentrate C16-C18: 2 fatty acids. Pressures ranging from 34.5 to 48.3 MPa at 80°C were the best operating conditions to optimize the yield up to 99.6%. Ab Rahman et al. (2012) reported the re-extraction of the screw press residues using supercritical carbon dioxide. In their research, different particle sizes were tested for the highest oil yield, obtaining yields up to 9.26%, at 70°C and 41.36 MPa, sample size of 150 μm, carbon dioxide flow rate of 2.0 ml/min, during 60 min. The increase in pressure and temperature, and the reduction in particle size favored the maximum extraction yield, as can be seen in Figure 3.

Krishnaiah et al., (2012) also obtained PKO from PKC, using supercritical carbon dioxide and ethanol as co-solvent. The fatty acid profile and the content of vitamin E and sterols were evaluated. The operating conditions were 19.8 MPa pressure, and 51°C temperature. Amounts of 45, 50, and 100 ml of ethanol were used in the expression runs. They found out that the highest quantity of ethanol provided the highest extraction yield. Also, lauric, myristic, and oleic acids, and two types of vitamin E (alpha-tocopherol and alpha-tocotrienol) were present in the oil samples. Table 3 shows the extraction yield of each run and Table 4 shows the quantitative analysis of fatty acids, vitamin E, and sterols.

Ab Rahman et al. (2011) evaluated the supercritical fluid extraction as a method that maintains the PKC nutritional components. They compared the nutritional composition of palm kernel fibre derived from three PKC

Table 1. PKC mineral content and chemical composition from mechanical pressing (%).

Parameter	Values
Calcium (%)	0.21 – 0.34
Phosphorus (%)	0.48 – 0.71
Magnesium (%)	0.16 – 0.33
Potassium (%)	0.76 – 0.93
Sulphur (%)	0.19 – 0.23
Copper (ppm)	20.5 – 28.9
Zinc (ppm)	40.5 – 50.0
Iron (ppm)	835 – 6130
Manganese (ppm)	132 – 340
Molybdenum (ppm)	0.70 – 0.79
Selenium (ppm)	0.23 – 0.30
Dry matter	88 – 94.5
Crude protein	14.5 – 19.6
Crude fibre	13.0 – 20.0
Esther extract	5.0 – 8.0
Ash	3.0 – 12.0
Nitrogen-free extract	46.7 – 58.8
Neutral detergent fibre	66.8 – 78.9
Metabolisable energy (MJ.kg^{-1})	
Ruminants	10.5 – 11.5
Poultry	6.5 – 7.5
Swine	10.0 – 10.5

Source: Adapted from Alimon (2004).

samples: supercritical PKC with test (SC-PKt), supercritical PKC without test (SC-PK), and PKC from palm oil mill. Carbon dioxide was used as solvent at 80°C temperature and 41.36 MPa pressure. Total dietary fibre, crude fibre, crude protein, ash, and moisture were determined and compared with PKC from palm oil mill. Table 5 shows the respective results. They concluded that supercritical fluid extraction is a great technique to improve the fiber production and oil separation, without affecting its nutrient composition. SC-PKt proved to be superior compared to SC-PK and PKC from palm oil mill. SC-PKt became higher in dietary fiber and protein, while moisture and ash contents reduced significantly. They highlighted the fact that such cake might be used for human consumption in the future.

USE OF PALM KERNEL FOR BIOFUEL PRODUCTION

The use of residues, such as palm kernel in biofuels production has been reported as an alternative for the use of biomass from palm agro-industry (Ayetor et al., 2015; Sukiran et al., 2017). Among these biofuels, biodiesel is an alternative to fossil fuels, because it has similar properties to those of diesel, it is a renewable source of energy, and when compared to diesel it is biodegradable, it presents lower toxicity, lower content of sulfurous, lower aromatic compounds, and lower emissions of particulates such as hydrocarbons, monoxide, and carbon dioxide (Prado et al., 2014; Farobie et al., 2016).

Conventional production of biodiesel

Many researchers have studied the biodiesel production with palm kernel oil (Ngamcharussrivichai et al., 2008; Benjapornkulaphong et al., 2009; Viele et al., 2013; Aladetuyi et al., 2014; Lucarini et al., 2017). Alamu et al. (2007) performed the PKO transesterification process with ethanol, using KOH as the alkali-catalyst. 100 g of PKO, different amounts of KOH, and 20 g of ethanol were used. Reaction time was equal to 100 min.

This type of production requires the following steps: a) transeterification process; b) settling, in which the reaction mixture stands in order to facilitate phase separation (biodiesel and glycerol) by gravity; and c) washing, in which water is added at 1:3 ratio (biodiesel:

Table 2. PKO fatty acid composition obtained from the pressing technique.

Fatty acid	Range (%)
Caproic acid (C_6:0)	0.2 – 0.4
Caprylic acid (C_8:0)	3.2 – 4.7
Capric acid (C_{10}:0)	2.9 – 3.5
Lauric acid (C_{12}:0)	45.4 – 49.8
Myristic acid (C_{14}:0)	15.4 – 17.2
Palmitic acid (C_{16}:0)	7.9 – 9.3
Stearic acid (C_{18}:0)	1.9 – 2.3
Oleic acid (C_{18}:1)	13.7 – 17.0
Linoleic acid (C_{18}:2)	2.1 – 2.9
Total saturated	82.6

Source: Adapted from Ibrahim (2013).

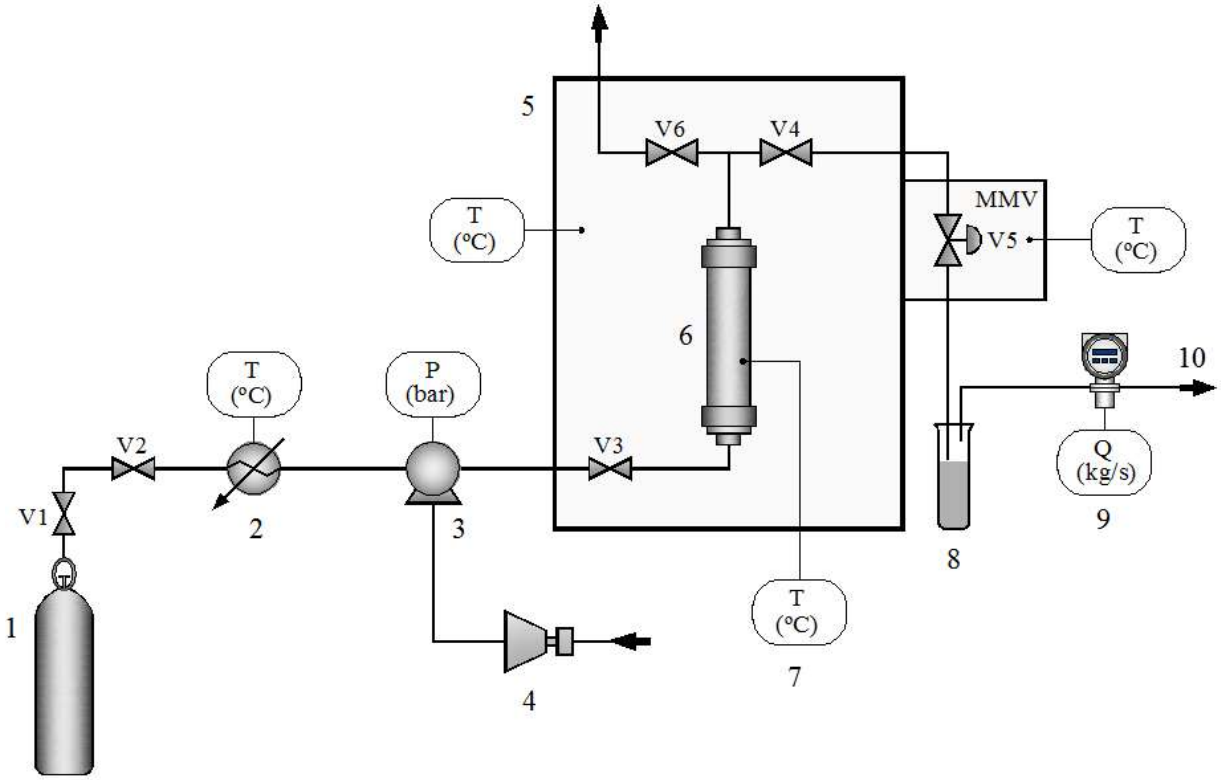

Figure 2. SFE apparatus. 1, CO_2 tank; 2, Cooling bath; 3, Pump; 4, Compressor; 5, Oven; 6, Extractor vessel; 7, Monitor; 8, Vial; 9, Flowmeter; 10, CO_2 Outlet; V1 – V6 Flow control valves.
Source: Bezerra et al., 2018.

water) in order to remove glycerol, soap, and fatty acids residues.

In their work, the PKO biodiesel highest yield was of 95.8% with 1.0% KOH concentration and 20.0% ethanol, at 60°C for 120 min. Unreacted alcohol, residual catalyst and emulsion removed during the washing stage count as process losses. Figure 4 shows the PKO biodiesel variation (%) with KOH concentration (%).

Jitputti et al., (2006) used ZrO_2, ZnO, $SO4^{2-}/SnO_2$, $SO4^{2-}/ZrO_2$, KNO_3/KL zeolite, and KNO_3/ZrO_2 as heterogeneous catalysts for PKO biodiesel production. They used 1:6 (oil: methanol) molar ratio. The temperature was equal to 200°C and the mixture stirred at 350 rpm. Then, filtration was used to separate the

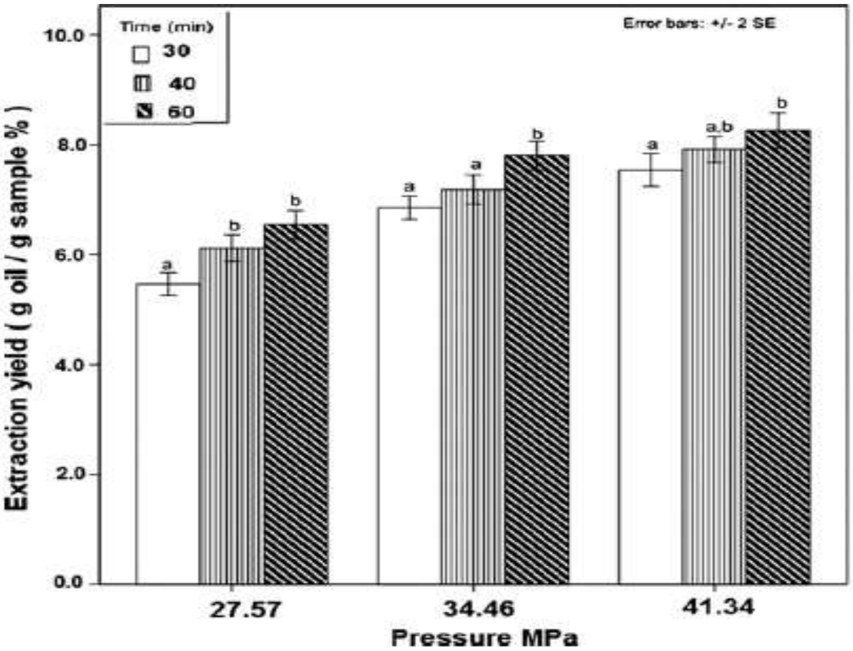

Figure 3. Effect of pressure on extraction yield at 70°C operating temperature, 1.5 mL/min flow rate, and ≤ 150 μm particle size.
Source: Ab Rahman et al. (2012).

Table 3. Amount of oil extracted in each run.

Sample	Pure CO_2	45 ml ethanol	50 ml ethanol	100 ml ethanol
Weight before (g)	62.736	62.758	61.770	61.662
Weight after (g)	62.998	63.350	63.601	65.330
Weight of oil content (g)	0.262	0.592	1.831	3.668

Table 4. Quantitative analysis of fatty acids, vitamin E, and sterols.

Sample	Fatty acid (%)			Vitamin E (ppm)		
	Lauric	Myristic	Oleic	α-tocopherol	α-tocotrienol	Sterol
Pure CO_2	59.3	21.1	19.5	230.0	300.0	650.0
45 mL ethanol	59.4	21.1	19.5	229.2	302.0	660.4
50 mL ethanol	59.5	21.2	19.3	228.0	300.6	677.2
100 mL ethanol	59.5	21.0	19.5	233.3	309.7	678.0

Source: Adapted from Krishnaiah et al. (2012).

Table 5. PKC composition with testa, without testa, and from palm mill.

Sample composition	Palm kernel with test	Palm kernel without test		Palm kernel cake	
	Before SFE PKt	After SFE SC-PKt	Before SFE SC-PK	After SFE SC-PK	Without SFE
Totally dietary fibre (%)	61.58	63.03	57.78	58.96	60.71
Crude fibre (%)	8.99	8.49	7.29	7.23	15.17
Moisture (%)	10.51	3.26	11.86	3.44	6.84
Crude protein (%)	15.61	14.40	15.01	14.06	13.56
Ash (%)	8.58	4.34	3.96	3.55	13.92

Source: Adapted from Ab Rahman et al. (2011).

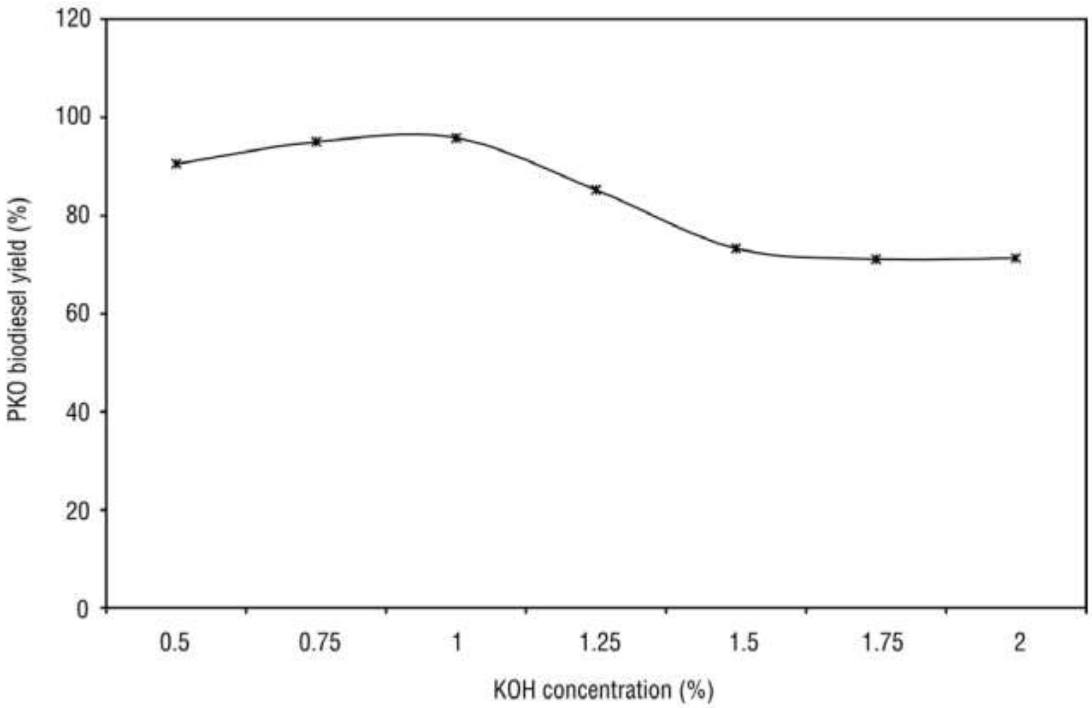

Figure 4. Variation of KOH concentration (%) with PKO biodiesel yield (%) through traditional experimentation technique.
Source: Alamu et al. (2007).

Table 6. Transesterification of crude palm kernel oil with solid catalysts.

Run	Catalyst	Methyl ester content (wt.%)	Methyl ester yield (wt.%)
1	-	32.3	30.4
2	ZrO_2	69.0	64.5
3	ZnO	98.9	86.1
4	SO_4^{2-}/SnO_2	95.4	90.3
5	SO_4^{2-}/ZrO_2	95.8	90.3
6	KNO_3/KL zeolite	77.8	71.4
7	KNO_3/ZrO_2	78.3	74.4

Source: Adapted from Jitputti et al. (2006).

catalyst from the product. Methyl esters were also separated from glycerol, which was removed. Then, the remaining phase (biodiesel) was washed (distilled water), and dried by the addition of sodium sulfate. Table 6 shows the PKO biodiesel yield according to the catalyst used. They concluded that the catalysts SO_4^{2-}/ZrO_2 and SO_4^{2-}/SnO_2 can increase the PKO methyl esters yield up to 90.3%. Also, one hour is enough time for the biodiesel to reach its highest yield. Alamu et al. (2008) also produced PKO biodiesel through the conventional method, obtaining yield of 95.8%. They used 100 g of PKO, 20.0 g of ethanol, and 1.0% of NaOH, at 60°C, for 90 min.

Biodiesel production by supercritical method

Other non-conventional transesterification methods have been recently applied. Among these, it is possible to emphasize the supercritical transesterification technology. The technique generally occurs in the absence of catalysts, under stringent conditions of temperature and pressure with the use of sophisticated equipment and with high energy requirements. The process is advantageous, since a product is obtained at a shorter reaction time, no waste of water, high purity, and with greater tolerance to impurities such as water and free fatty acids than with conventional techniques using

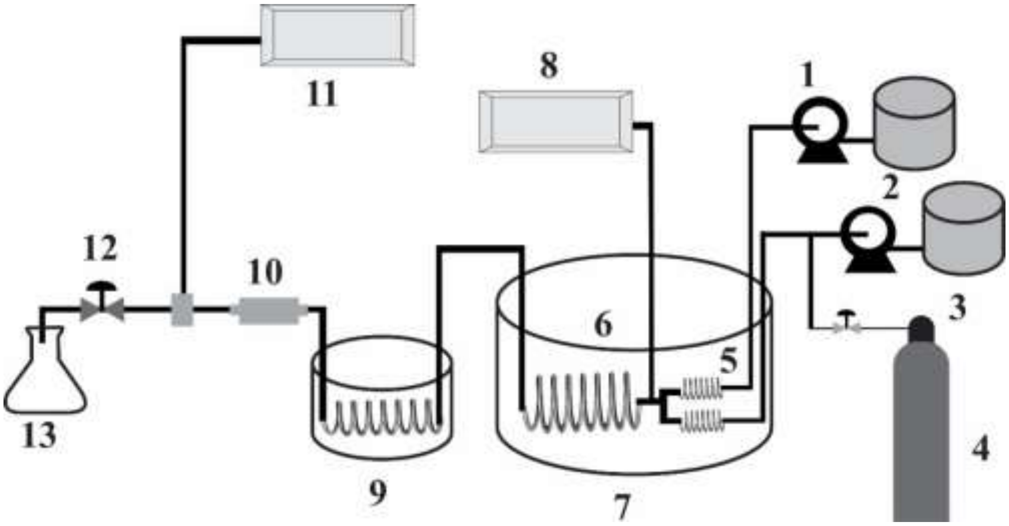

Figure 5. Schematic diagram of the continuous transesterification reactor system. 1, High-pressure pumps; 2, methanol reservoir; 3, vegetable oil reservoir; 4, nitrogen cylinder; 5, preheaters; 6, reactor; 7, salt bath; 8, temperature monitoring system; 9, cooling bath; 10, inline filter; 11, pressure monitoring system; 12, back pressure regulator; and 13, sample collector,
Source: Bunyakiat et al. (2006).

catalysts (Rodríguez-Guerrero and Rosa, 2013; Salam et al., 2016) (Figure 5).

The transesterification reaction, when performed under ambient conditions, favors the formation of two phases and the mass transfer controls the kinetics until there is esters formation. In the supercritical state, the alcohol forms a single phase with the oil, due to the dielectric constant reduction, causing the acceleration on the reaction speed, since there is no interference of the mass transfer between the interface to limit the reaction speed. Due to the elevation of temperature and pressure there is also the modification of other properties of alcohol such as viscosity, specific gravity, and polarity (Farobie et al., 2016; Román-Figueroa et al., 2016; Bezerra et al., 2018).

Especially using the supercritical method for PKO transesterification, Bunyakiat et al. (2006) achieved, in only 400 s, a methyl ester conversion of 96% at 1:42 (oil: methanol) molar ratio, 350°C and 19 MPa. They found out that by increasing the temperature from 270 to 300°C and 350°C, methyl ester conversions also increased. Regarding the molar ratio, when the methanol content increased, methyl ester conversion increased as well. This is favorable in as much as excess alcohol is desirable and also because it contributes to reduce the mixture critical temperature. Figures 6 and 7 show the effect of temperature and alcohol: oil molar ratio on the yield of methyl esters.

In the same way, Sawangkeaw et al. (2011) obtained 93.7% of alkyl esters conversion, with molar ratio, of 1:42, 325°C and 18.0 MPa. Performing a process optimization, they found out that to reach a methyl esters content of over 96.5%, the minimal molar ratio is 1:40. The supercritical method transesterification can be economically feasible despite the high operational cost (high energy requirements and equipment costs), through the technique improvement, for example with the addition of suitable cosolvents causing reduction of the mixture critical point, decreasing time, alcohol: oil molar ratio, reaction pressure, and temperature (Muppaneni et al., 2013; Micic et al., 2014; Kuss et al., 2015).

FINAL CONSIDERATIONS

The abundant and inexpensive availability of PKC that comes from the mechanical pressing process has attracted attention due to its potentiality to become an energy source and an effective ingredient in the feed formulation for animals, since it is rich in fibers, protein, and energy contents. However, in order to overcome some anti-nutritional factors present enzymes addition has presented promising results.

The palm kernel oil extraction main product, due to its characteristics and physic-chemical properties, is an excellent raw material for specific applications, such as cosmetics production, substitutes for cocoa butter, production of various foods, and biofuels, such as biodiesel. Also, the Malaysian Palm Oil Board (MPOB) has initiated research on the production of insecticides containing palm kernel oil, sustainable surfactants that can be used to formulate biodegradable cleaning products such as laundry detergents, oils, automotive lubricants and printing inks (Gan and Li, 2014). The supercritical extraction has proved to be an excellent method to recover the PKC remaining oil, since high oil yields can still be obtained. Regarding biofuels

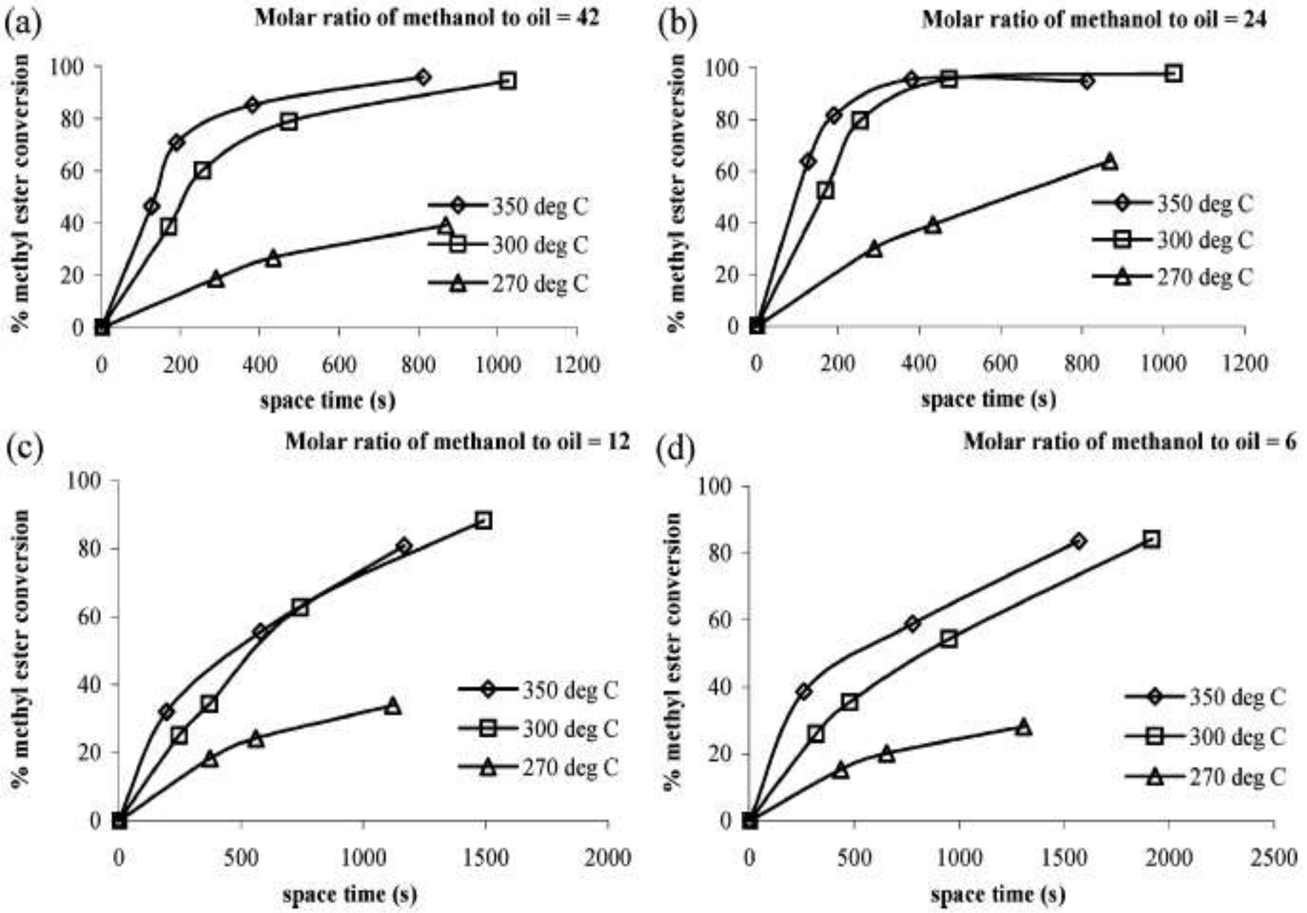

Figure 6. Effect of temperature on the % methyl ester conversion at various molar ratios of methanol: palm kernel oil, P = 19 MPa. (a) 42, (b) 24, (c) 12, (d) 6.
Source: Bunyakiat et al., (2006).

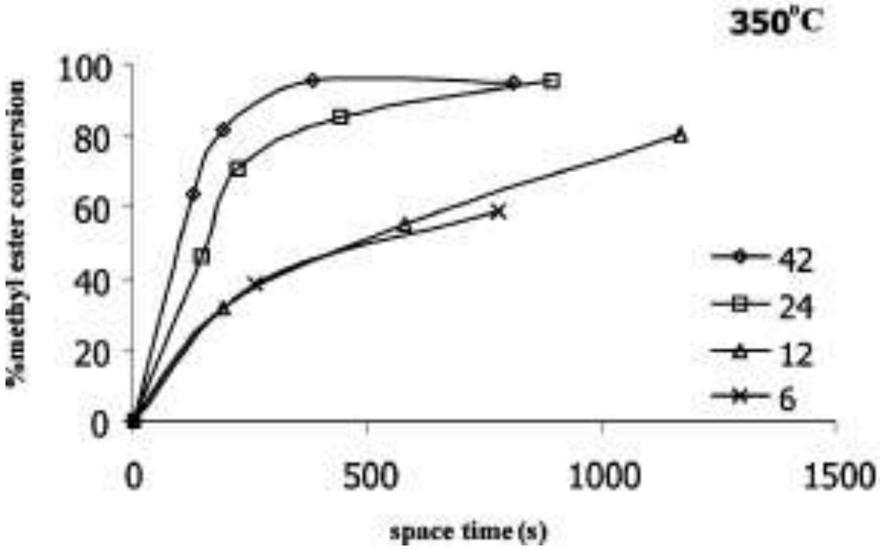

Figure 7. Effect of molar ratio of methanol: palm kernel oil on the % methyl ester conversion at 350°C, 19.0 MPa.
Source: Bunyakiat et al. (2006).

production, the supercritical transesterification was presented as an alternative to the conventional method. Studies showed that increasing temperature and molar ratio of methanol: oil also increase the yield of esters formed. Although supercritical technique provides short-time reactions and eliminates the need for catalysts, this method presents some drawbacks due to the high energy consumption, since conditions of high temperature and pressure are required.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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