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PRODUCTION, CHARACTERIZATION AND APPLICATION OF TERNARY PHASE DIAGRAMS FOR THE PURIFICATION OF BIODIESEL PRODUCED FROM TROPICAL ALMOND SEED OIL

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ABSTRACT

This study presents the application of ternary phase diagrams to tropical almond biodiesel components separation and purification at two temperatures. The seed oil was extracted mechanically and alkaline transesterified to produce biodiesel. The oil and biodiesel were characterized using standard methods. Tie lines and binodal solubility curve data were determined using modified cloud point titration procedures. Gas chromatographic method was employed in the analysis of the phase compositions. The mixture of biodiesel, methanol and glycerol were investigated at 20 °C, 30 °C and withdrawal times of 2 to 32 minutes at 2 minutes intervals. Distribution coefficient, K and solvent selectivity, S analysis were performed. Results obtained showed that S > 1 indicating the ability of methanol to promote phase separation and purification. K < 1 implying that there was lower quantities of methanol solubilized in the biodiesel phase. The ternary phase diagrams provided the means of predicting the components distribution.

Keywords: *Production, Characterization, Tropical Almond Biodiesel, Purification, Ternary Phase Diagram*

1 INTRODUCTION

Globally, fossil fuel energy application and utilization is gradually been replaced by sustainable alternative energy sources [1, 2] to power household equipment, vehicles and machineries [3, 4]. These alternate energy sources, which have been under investigation for many years, would eventually lead to reduction in pollution [5 – 8]. It is imperative that these globally concerted efforts at various alternatives be implemented across different continents of the world before the current supply chain is completely depleted. The use of biodiesel to meet the global energy demand has several advantages [9]. Biodiesel is a renewable energy fuel produced from vegetable oil and animal fats [10, 11]. Characterization of the oils and biodiesels provides a means of identification and quantification of the fatty acid composition of the oil and sources.

Tropical almond is botanically known as *Terminalia catappa.* It is a large tropical tree in the *leadwood* tree family known as *combretaceae*. It is popularly known as tropical almond, Indian almond, sea almond and false kamani. It is found in many parts of north central and southern Nigeria and often referred to as 'fruit' and 'ebeleboh' in local parlance [12, 13]. Sun-dried nuts contain about 60 % of bland, yellow, semi-drying oil [14].

Practically, biodiesel separation and purification involve unit operation processes of distillation, extraction and adsorption [15, 16]. However, to enhance the efficiency of the purification process, accurate phase equilibrium data for the biodiesel

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product interactions are required. This would require the determination of the tie lines and binodal solubility compositions of the specific biodiesel, alcohol and glycerol which are the fundamental information required for biodiesel purification.

In the determination of the phase compositions, tropical almond biodiesel (TAB) was produced from tropical almond seed oil (TASO) using hydraulic press machine. Separation and purification of the biodiesel produced was done using conventional processes. The characterization of the oil and biodiesel was undertaken to determine the physicochemical properties. Application of ternary phase diagrams was undertaken to determine the phase separation and purification of the tropical almond oil biodiesel mixture components consisting of the tropical almond biodiesel, alcohol and glycerol constituents at temperatures of 20 °C and 30 °C. This provided a basis for determining the component distribution in the phases thereby enhancing the viability of the process in terms of product purity.

2 MATERIALS AND METHODS

2.1. Materials

The materials used in this research included tropical almond seeds (TAS) sourced from Awo-Akpali and Ukpaba villages in Ankpa, Kogi State, Nigeria; tropical almond seed oil (TASO) which was extracted from tropical almond seeds (TAS) by means of hydraulic pressing machine and tropical almond biodiesel (TAB). The tropical almond biodiesel was produced by alkaline transesterification reaction of tropical almond seed oil with methanol. Tropical almond biodiesel (TAB) was produced in the laboratory from tropical almond seed oil (TASO), glycerol (99% -100% JDH, Acros Organics, USA), methanol (Merck, Germany, 99.5% purity). The equipment used included burette, mechanical agitator – stirrer, analytical balance, pipette, water-bath for temperature control, conical flasks, stop watch, beakers and gas chromatography mass spectrometry /flame ionization detector (GCMS/FID). All the chemicals used were of high analytical grade and no further purification was undertaken prior to its use.

2.2 Methods

2.2.1. Oil seed preparation

The tropical almond seeds (TAS) were obtained from matured tropical almond fruits. The fruits were initially washed and separated into the seeds and the pulp. The seed preparation process included cleaning, drying, size reduction, hull removal, drying and extruding. The seeds were separated from the hull by cracking with a hammer and thereafter dried to reduce the moisture content. This was done to minimize degradation on seed storage. Afterwards, the seeds were crushed and ground using motorized industrial grinding machine.

2.2.2. Extraction of tropical almond seed oil (TASO)

The ground tropical almond seeds were wrapped in filter cloths woven from horse-hair in small batches of 400 g each. They were manually loaded into perforated, horizontal boxes below the head block and above the ram of the hydraulic press. The boxes were pressed together using upward hydraulic pressure on the ram. The hydraulic press type used was a commercial Mikel-Mexicol hydraulic press with a thermal casing, maximum pressure capacity of 68.65 MPa, 150 mm piston diameter, 1000 Watt commercial strength at 127 V and data logger system which had capacity for cold press and hot press extraction method. The ability of the hydraulic press was due to the presence of a *k*-type thermocouple capable of temperature-controlled oil extraction processes. The thermocouple was maintained at a specific temperature during the extraction process in order to maintain the natural state of the extracted oil (active principles) with minimal effects on oil quality. The oil was pressed out through the filter cloths and spent cakes were manually removed from the hydraulic press. The residual oil in each spent cake for each batch operation was less than 5 %. On completion of the extraction process, the oil was allowed to stand undisturbed for 24 hours in a dark room so solid particles could settle to the bottom of the container. Thereafter, the oil was filtered using a fine cloth and heated to 40 °C to drive off traces of water and destroy any bacteria present. Additionally, to ensure high purity and quality of the oil, the resulting oil was severally centrifuged at 1200 rpm for 20 minutes using a centrifuge (Mark IV, Auto Bench, Baird and Tatlock Ltd, London, UK) to further remove any contaminants present. The packaging and storage was done in clean dry containers made of glass and plastic materials. The containers were sealed against moisture, air, and light to protect the oil from going rancid and kept in dark boxes to help increase the shelf-life.

2.2.3. Physicochemical characterization of the tropical almond seed oil (TASO)

The TASO obtained after extraction and clarification was subjected to physiochemical characterization and fatty acid profiling according to various standard methods (AOAC, AOCS, EN and ASTM) to determine the properties. Acid value was determined using ASTM D664 method with a limit of 0.8 mgKOH/g, kinematic viscosity at 40 °C was determined by ASTM D445 method with limits of 1.9-6.0 using a Rheomat viscometer (Mettler Toledo, USA), water content (%) was determined by ASTM D2709 method with a maximum limit of 0.050max, iodine value (g/100) was determined by ASTM D5554 and saponification value (mgKOH/g) was determined by ASTM D5558. Oil color was measured using a colorimeter (CR 300, Konica Minolta, Japan) according to ASTM D1500-12 standard. The fatty acid composition or profile of the TASO was determined by GC method in accordance with ASTM D6584, EN14214 and EN14105 using a Thermo Scientific Trace GC Ultra AS 3000 Auto-Sampler gas chromatography/mass spectrometer connected to a flame ionization detector (FID).

2.2.4 Production of tropical almond biodiesel (TAB)

The reaction mechanism employed in the production of the biodiesel was alkaline transesterification. The biodiesel was prepared in a batch glass reactor from the oil with a molar ratio of 6:1 for methanol and oil respectively. The basis for the molar ratio used was to achieve higher product (biodiesel) formation. Higher volume of methanol in biodiesel production is needed to force the equilibrium of the transesterification reaction in the right direction (product formation) according to Le Chatelier's Principle. Potassium hydroxide at a concentration of 5 %w/v (due to its high reactivity potential) was used as the catalyst at a temperature of 60 °C. The oil was first introduced into the reaction chamber and heated using a Gallenkamp thermostatic hotplate with magnetic stirrer to the desired reaction temperature (60 °C using a thermometer). Thereafter, the catalyst/methanol mixture was added to the heated oil to attain the reaction temperature. The reaction temperature was maintained at 60 °C with the stirrer speed set at 1200 rpm. Constant agitation was maintained throughout the reaction. At the completion of the reaction, the contents of the reaction chamber was drained into a separating funnel and the mixture allowed to separate into two layers with the biodiesel layer on top and the lower layer consisted of mixtures of glycerol and methanol. Thereafter, the lower layer was drained off. The biodiesel top layer was then washed with one litre of acidified water (0.01M H_2SO_4) to neutralize any catalyst remaining and further washed with one litre of distilled water to remove glycerol and soaps. Additionally, the biodiesel sample was centrifuged (Mark IV, Auto Bench, Baird and Tatlock Ltd, London, UK) at 5 °C for ten minutes at 1200 rpm to remove water and any remaining soaps.

2.2.5. Physicochemical characterization of biodiesel (TAB)

The properties of the biodiesel were determined in accordance with AOAC (2006) and ASTM (1984) standards. The acid value by AOAC Ca5a-40; saponification value by AOAC 920:160; iodine value by AOAC 920.158 and peroxide value by AOAC 965.33. The viscosity was determined by using Oswald viscometer apparatus; the density by using density bottle, moisture content by the Rotary Evaporator Oven (BTOV 1423); ash content by heating to drying in Veisfar muffle furnace and the refractive index by using Abbe refractometer (Model: WAY-25, Search tech. instruments). The fuel properties of the produced biodiesel were determined by ASTM and EN standards. The acid value was determined using ASTM D664 and BS EN 1404 methods, the water or moisture content was determined by ASTM D2709 and according to ISO 12937 (Karl-Fisher) methods, the oxidative stability index was by BS EN 14112 method, flash point was by ASTM D2500 method, pour point was determined using ASTM D97, kinematic viscosity at 40°C was by ASTM D445 method, iodine value was by ASTM D5554 and saponification value was determined by ASTM D5558 method.

2.2.6. Ternary phase composition/diagram

Phase composition/diagram of biodiesel + methanol + glycerol (binodal solubility curve composition and Tie lines determination).

The binodal solubility curve composition for the tropical almond biodiesel ternary system at the different temperatures and withdrawal time intervals was determined by the cloud-point method using titration procedure under isothermal conditions employed by several researchers [17 – 19] with some modifications introduced to achieve desired objectives.

3. RESULTS AND DISCUSSIONS

3.1. Production and characterization of tropical almond seed oil (TASO) and tropical almond biodiesel (TAB)

Table 1 presents the analysis conducted on the tropical almond oil in terms of its physico-chemical characterization. From the table, the values of the properties fall within the range of values for oils used in similar applications with reference to ASTM D9751, ASTM D6751 and EN14214 as well as the American Oil Chemists Society (AOCS). These properties are used to establish the identity of the particular oil and were chosen to measure specific characteristics of the oil. Some of the properties were mostly used to specify the characteristics of the oil. The others are empirical in nature though they also give useful guidance in identifying the oil. The smoke point, fire point, flash point, cloud point and pour point all showed that the oil had huge fuel potentials for industrial application. The fire, flash and smoke points of the oil have linear relationship with the content of the free fatty acid present in the oil because these parameters are indicative of the combustion potentials of the different oil [20, 21]. The physico-chemical characterization of the tropical almond oil is presented in Table 1

Figure 1(A – D) shows the fruits of tropical almond, the dried seeds, the crushed and ground seeds and the purified tropical almond seed oil (TASO) respectively obtained after mechanical extraction using hydraulic press machine

3.2. Application of ternary phase diagrams (Tie lines and binodal compositions)

An analysis of tie line composition for tropical oil biodiesel upper-rich and glycerol lower-rich phases' mixture after separation at the studied temperature and withdrawal time intervals are given here.

The tie line data for the tropical almond oil biodiesel ternary system at the investigated conditions is presented in Table 3. The tie line plot for tropical almond oil biodiesel/glycerol/methanol system at the investigated temperatures of 20 °C and 30 °C are shown in Figure 2.

Table 2 presents the results of the analysis of the tropical almond biodiesel sample in terms of the physico-chemical properties with a comparison of the determined parameters of the biodiesel with the different standards. From the table, the results compare favorably with the different standards. Figure 2 shows the ternary phase diagrams of the biodiesel-rich and glycerol-rich compositions at temperatures of 20 °C and 30 °C respectively. From the figure, it could be observed that the concentration of biodiesel was higher in the biodiesel-rich phase as expected than glycerol.

Table 1: Tropical almond seed oil (TASO) physico-chemical properties

Parameters	Results
Density (g/cm^3)	0.855
Moisture content (%g/gOil)	0.580
Refractive index	1.452
Saponification value (mg/KOH/gOil)	165.50
Iodine value (g/100g)	35.70
Perioxide value (mleq.oxy/Kg)	1.472
Acid value (mgKOH/g)	2.811
Acid value after oil pretreatment (mgKOH/g)	0.380
Free Fatty Acid as Oleic (%)	1.400
Free Fatty Acid after oil pretreatment (%)	0.630
Ash content (%)	1.011
Viscosity (mm^2/s)	1.654
Smoke point	40.00
Flash point	157.02
Cloud point	-2.00

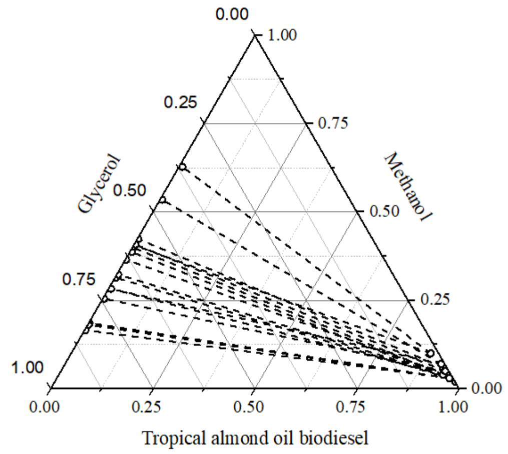
Figure 1: A) Tropical almond fruits, B) Dried seeds, C) Grinded seeds and D) Tropical almond seed oil (TASO)

Table 2: Comparison of physicochemical parameters of the tropical almond biodiesel (TAB) with the different standards

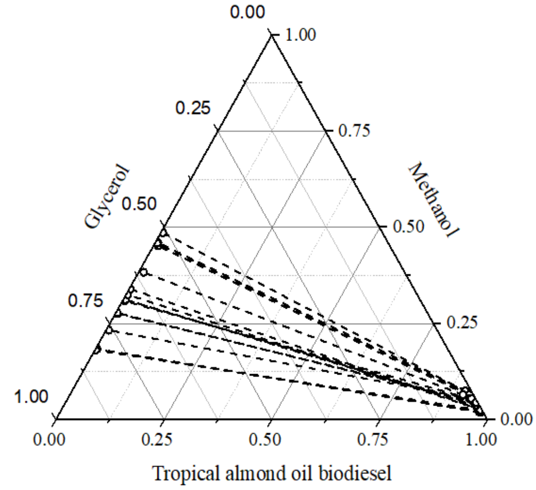
Parameters	TAB	ASTM D9751	ASTM D6751	EN 14214
Density (g/cm^3)	0.849	0.850	0.880	0.860-0.900
FFA (%)	0.230	0.31	0.25	0.25
Acid value (mgKOH/g)	0.460	0.062	0.50	0.50
Moisture content (%)	0.02	-	-	-
Ash content (%)	0.10	0.01	0.02	0.02
Conductivity (us/cm)	140	-	-	-
Refractive index	1.4402	-	-	-
Viscosity (mm^2/s)	3.52	2.6	1.9-6.0	3.5-5.0
Saponification value (mgKOH/g)	161.05	-	-	-
Iodine value (Wij's)	28.02	42-46	-	120max
Peroxide value (Meq/Kg)	4.37	-	-	-
Flash point (°C)	136	60-80	100-170	120
Fire point (°C)	40	-	-	-
Cloud point (°C)	-2	-20	-3 to 12	-
Pour point (°C)	-6	-35	-15 to 16	-
Smoke point (°C)	34	-	-	-

Table 3: Tie line data in mass composition for tropical almond oil biodiesel (w_1) + methanol (w_2) + glycerol (w_3) at temperatures of (20 and 30) °C and different time intervals

Temperature	Time Interval	Overall Feed Composition			Biodiesel-Rich Phase Composition (extract phase)			Glycerol-Rich Phase Composition (raffinate phase)		
T/°C	t/min	w_1	w_2	w_3	w_1	w_2	w_3	w_1	w_2	w_3
20	2.00	0.25	0.22	0.53	0.94	0.04	0.02	0.002	0.284	0.714
	4.00	0.27	0.40	0.33	0.92	0.07	0.01	0.005	0.535	0.460
	6.00	0.30	0.43	0.27	0.88	0.10	0.02	0.008	0.628	0.364
	8.00	0.35	0.35	0.30	0.95	0.04	0.01	0.002	0.365	0.633
	10.00	0.40	0.27	0.33	0.93	0.06	0.01	0.002	0.424	0.574
	12.00	0.42	0.30	0.28	0.96	0.03	0.01	0.003	0.314	0.683
	14.00	0.41	0.32	0.27	0.88	0.10	0.02	0.002	0.406	0.592
	16.00	0.45	0.35	0.20	0.94	0.04	0.02	0.004	0.323	0.673
	18.00	0.44	0.34	0.22	0.94	0.04	0.02	0.003	0.399	0.598
	20.00	0.38	0.28	0.34	0.92	0.07	0.01	0.006	0.283	0.711
	22.00	0.41	0.34	0.25	0.94	0.05	0.01	0.003	0.408	0.589
	24.00	0.39	0.39	0.22	0.98	0.02	0.00	0.005	0.387	0.608
	26.00	0.43	0.39	0.18	0.94	0.05	0.01	0.003	0.255	0.742
	28.00	0.49	0.33	0.18	0.96	0.03	0.01	0.002	0.186	0.812
	30.00	0.48	0.28	0.24	0.96	0.03	0.01	0.002	0.166	0.832
	32.00	0.47	0.30	0.23	0.96	0.03	0.01	0.002	0.181	0.817
30	2.00	0.23	0.37	0.40	0.92	0.07	0.015	0.011	0.452	0.537
	4.00	0.26	0.39	0.35	0.92	0.07	0.010	0.007	0.460	0.533
	6.00	0.25	0.37	0.38	0.91	0.08	0.015	0.005	0.486	0.509
	8.00	0.30	0.27	0.43	0.95	0.04	0.010	0.002	0.313	0.685
	10.00	0.41	0.29	0.30	0.93	0.07	0.010	0.005	0.459	0.536
	12.00	0.38	0.32	0.30	0.96	0.03	0.010	0.003	0.340	0.657
	14.00	0.40	0.28	0.32	0.91	0.07	0.025	0.012	0.383	0.605
	16.00	0.44	0.28	0.28	0.93	0.06	0.015	0.004	0.309	0.687
	18.00	0.37	0.40	0.23	0.94	0.05	0.010	0.005	0.276	0.719
	20.00	0.43	0.29	0.28	0.94	0.06	0.010	0.006	0.233	0.761
	22.00	0.41	0.29	0.30	0.96	0.04	0.005	0.005	0.312	0.683
	24.00	0.48	0.26	0.26	0.98	0.03	0.000	0.004	0.325	0.671
	26.00	0.36	0.30	0.34	0.95	0.05	0.005	0.003	0.278	0.719
	28.00	0.35	0.25	0.40	0.98	0.02	0.005	0.004	0.184	0.812
	30.00	0.32	0.33	0.35	0.97	0.02	0.010	0.002	0.183	0.815
	32.00	0.29	0.40	0.31	0.97	0.03	0.005	0.002	0.181	0.817



A



B

Figure 2: Tie line plot for tropical almond oil biodiesel/glycerol/methanol system at A) 20 °C and B) 30 °C

This behavior implied that methanol readily solubilized the glycerol and so was more in the glycerol-rich phase than in the biodiesel-rich phase at the investigated conditions. It was also observed that there was a gradual decrease in the shape of the two-phase envelope or boundary as the temperature was increasing. As a result, the volume and shape of the homogeneous region was found to increase with increasing temperature. This phenomenon could be assumed to imply that methanol was favorably dispersed to solubilize glycerol in the glycerol-rich phase than in the biodiesel-rich phase, hence acting as a good solvent in this particular investigation [22]. The large homogeneous region observed indicated that biodiesel and glycerol were relatively still immiscible at higher temperatures even in the presence of methanol [17, 23]. From the figures, it could be seen that component withdrawal was dependent on time and temperature indicating that the phase composition at the particular temperature was a function of phase mixture constituents. This was in accord with studies conducted by other researchers [18, 24, 25].

Table 4 presents the binodal solubility curve data for the biodiesel ternary mixture at the investigated temperatures and time intervals.

Table 4: Binodal or solubility curve data in mass fractions for tropical almond oil biodiesel (w_1) + glycerol (w_2) + methanol (w_3) at temperatures of (20 and 30)°C and different time intervals

Temperature, T/°C	Time Interval (t/mins)	Mass Fraction of Tropical Almond Oil Biodiesel (w_1)	Mass Fraction of Glycerol (w_2)	Mass Fraction of Methanol (w_3)
	2.00	0.14	58.24	41.62
	4.00	0.48	46.42	53.10
	6.00	1.26	40.58	58.16
	8.00	2.40	20.19	77.41
	10.00	5.49	15.21	79.30
	12.00	8.28	10.12	81.60
	14.00	17.51	6.12	76.37
20	16.00	23.94	3.66	72.40
	18.00	39.17	1.52	59.31
	20.00	51.23	1.48	47.29
	22.00	59.02	1.38	39.60
	24.00	68.82	1.03	30.15
	26.00	79.79	0.98	19.23
	28.00	88.20	0.64	11.16
	30.00	94.48	0.47	5.05
	32.00	99.88	0.12	0.00
30	2.00	0.13	58.25	41.62
	4.00	0.47	47.89	51.64

Temperature, T/°C	Time Interval (t/mins)	Mass Fraction of Tropical Almond Oil Biodiesel (w_1)	Mass Fraction of Glycerol (w_2)	Mass Fraction of Methanol (w_3)
	6.00	1.20	39.53	51.64
	8.00	2.90	22.25	74.86
	10.00	5.26	17.43	77.32
	12.00	9.28	10.34	80.38
	14.00	16.39	8.12	75.49
	16.00	20.98	6.78	72.25
	18.00	32.01	5.10	62.90
	20.00	38.88	4.14	56.99
	22.00	46.62	3.60	49.79
	24.00	60.45	2.69	36.87
	26.00	69.11	2.15	28.75
	28.00	78.99	1.41	7.23
	30.00	91.73	1.04	7.23
	32.00	99.80	0.20	0.00

Figure 3 presents the binodal solubility curve composition for the ternary mixture at the investigated conditions. From the figure, it could be observed that the miscibility of the biodiesel and glycerol phases was quite high with the methanol shown to be dispersed between the biodiesel phase and with more in the glycerol phase. This was in accord with studies conducted [17, 23]. The temperature influence was observed to be minimal as component concentration and solubility were observed to be constant at the temperatures investigated. From the figures of the binodal solubility curve composition, it was observed that the size of the splitting or two-phase region decreased slightly with increasing temperature. This was also found to be in agreement with researches conducted [24, 26]. The distribution coefficients, *K*, and selectivity, *S*, of the components are reported in Table 5. These were obtained from the following relationships [17 – 19].

$$K = \frac{mass\ fraction\ of\ methanol\ in\ the\ biodiesel-rich\ phase}{mass\ fraction\ of\ methanol\ in\ the\ glycerol-rich\ phase}$$

$$= \frac{mass\ fraction\ of\ glycerol\ in\ the\ biodeisel-rich\ phase}{mass\ fraction\ of\ glycerol\ in\ the\ glycerol-rich\ phase}$$

$$S = \frac{distribution\ coefficient\ of\ methanol}{distribution\ coefficient\ of\ glycerol}$$

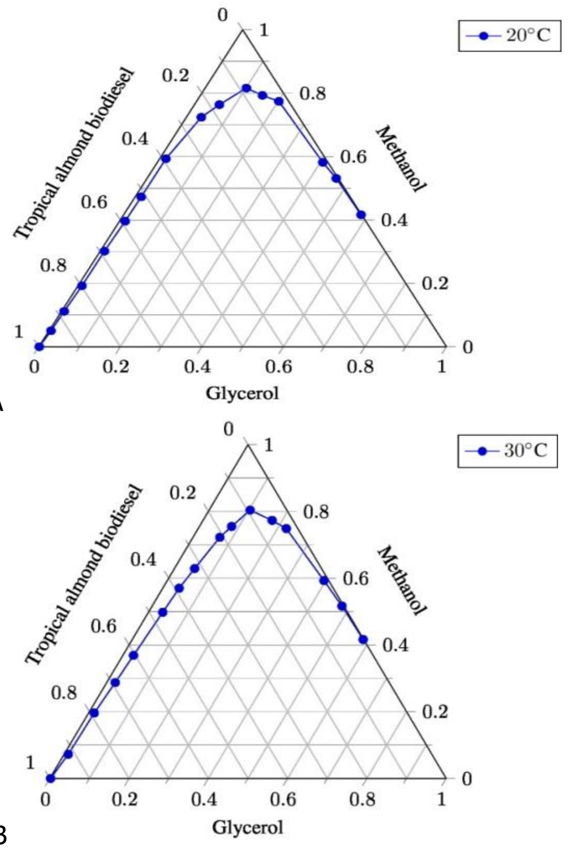


Figure 3: Binodal curve plot for tropical almond biodiesel/glycerol/methanol system at A) 20 °C B) 30 °C

Table 5: Distribution coefficients of glycerol ($K_{glycerol}$), methanol ($K_{methanol}$) and selectivity (S) at temperatures of (20 and 30) °C and different withdrawal time intervals for tropical almond biodiesel/methanol/glycerol phase composition

Temperature, *T/°C*	Time Interval, *t/min*	$K_{glycerol}$	$K_{methanol}$	*S*
20	2.00	0.0280	0.1410	5.0360
	4.00	0.0220	0.1310	5.9550
	6.00	0.0550	0.1590	2.8910
	8.00	0.0160	0.1100	6.8750
	10.00	0.0170	0.1410	8.2940
	12.00	0.0150	0.0960	6.4000

Temperature, *T/°C*	Time Interval, *t/min*	$K_{glycerol}$	$K_{methanol}$	*S*
	14.00	0.0340	0.2460	7.2350
	16.00	0.0300	0.1240	4.1330
	18.00	0.0330	0.0960	2.9090
	20.00	0.0140	0.2470	17.6430
	22.00	0.0170	0.1230	7.2350
	24.00	0.0020	0.0520	26.0000
	26.00	0.0130	0.1960	15.0770
	28.00	0.0120	0.1610	13.4170
	30.00	0.0120	0.1810	15.0830
	32.00	0.0120	0.1610	13.8330
30	2.00	0.0280	0.1440	5.1430
	4.00	0.0190	0.1520	8.0000
	6.00	0.0290	0.1540	5.3100
	8.00	0.0150	0.1280	8.5333
	10.00	0.0190	0.1420	7.4740
	12.00	0.0150	0.0880	5.8670
	14.00	0.0410	0.1700	4.1460
	16.00	0.0220	0.1780	8.0910
	18.00	0.0140	0.1810	12.9290
	20.00	0.0130	0.2360	18.1540
	22.00	0.0070	0.1120	16.0000
	24.00	0.0010	0.0770	77.0000
	26.00	0.0070	0.1620	23.1430
	28.00	0.0060	0.1090	18.1670
	30.00	0.0120	0.1090	9.0830
	32.00	0.0060	0.1380	23.0000

From Table 3, it could be observed that the selectivity (*S*) and distribution coefficients (*K*) were important in determining the nature of the solvent used in the liquid-liquid equilibrium process. It was observed that the *K*-values were all positive while the *S*-values were all greater than one implying that the methanol was effective and efficient for the investigated phase mixture composition. The result revealed a slight decrease in $K_{glycerol}$ with increasing temperature though the phenomenon was not readily noticeable. However, the methanol *K*-values was observed to be relatively low. This had little influence on the quantity of methanol required for the process. This was contrary to results obtained [27]. The selectivity (*S*) was observed to be dependent on the phase properties at the operating conditions. The distribution coefficient *(K)* was a function of the properties of the mixture. Generally, polar molecules like methanol and glycerol are observed to have high solubility indicators whereas, nonpolar molecules like biodiesels have low solubility indicators [28].

4. CONCLUSIONS

The mechanical extraction process for the TASO provided high quality oil free from contaminants and impurities. The subsequent characterization presented properties of the oil suitable for biodiesel production. The tropical almond biodiesel (TAB) produced had fuel properties that were found to compare favorably with acceptable standards. The tie lines and binodal solubility curve compositions for tropical almond biodiesel, methanol and glycerol ternary systems were determined at the investigated conditions and used in the construction of the relevant ternary phase diagrams. Distribution coefficient, *K*, and selectivity, *S*, analysis were performed with $K < 1$ and $S > 1$ at the investigated conditions. Based on the values of *K* and *S*, methanol was found to be an efficient and effective solvent for the phase separation and purification process at the different investigated temperatures and time intervals. This provided a strong basis for any large scale application. The ternary phase diagrams of the tropical almond biodiesel, methanol and glycerol system was found to provide the basis for determining and predicting the component distribution thereby enhancing the commercial viability of the process.

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7. COMPETING INTEREST
The authors declare no competing interest.

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