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Viscosity and biodiesel characteristics of wild *Canarium schweinfurthii* Engl. fruit oil

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Abstract

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The viscosity of two varieties of *Canarium schweinfurthii* Engl. fruits oil (large and long) were studied at four different temperatures (30, 40, 50 and 60°C) and three shear rates (7.91, 15.82 and 39.54 s^{-1}). SurgiFriend Medical (model NDJ-5S) viscometer was used to carry out the study. Biodiesel characteristics of the oil were also investigated. The results showed that variety had no effect ($P < 0.05$) on the viscosity of *Canarium schweinfurthii* Engl. fruit while temperature had especially at 50°C and above. The shear rate of 15.82 s^{-1} (12 rps) gave the lowest oil viscosity for both varieties. The oil from large fruit had the best temperature stability, low percentage viscosity (6.33%) variation and least activation energy (796.51 $J \cdot mol^{-1} \cdot K^{-1}$) while long variety had best biodiesel characteristic for safe handling. Temperature had no significant ($P < 0.05$) effect on the consistency coefficient and flow behaviour index of both varieties of *Canarium schweinfurthii* Engl. fruits oil. Besides, oil from both fruit varieties is Newtonian fluids.

Keywords: eonsistency; newtonian; behaviour index; biodiesel; activation energy

Canarium schweifurthii Engl. belongs to the family of Burseraceae. It is a forest tree crop that grows mostly in the equatorial forest regions of East, west and Central Africa (Tchouamo 2000; Tchiegang 2001; Orwa et al. 2009). The tree produces wood, resin and edible fruits all year round throughout Nigeria. The resin and wood are used industrially to produce adhesives and as timbers respectively while the fruits have both nutritional and pharmaceutical use. The fruit is made of three parts: flesh, nut and kernel. The flesh contains 30 to 50% oil when converted into pulp (Edou Engonga et al. 2012). The pulp contains 20.43% crude protein, 23% crude fat, 0.75% crude fiber, 20.10% carbohydrate, 11.8% cellulose and 3.25% ash (Onimawo, Adukwu 2003). The pulp is usually separated from the fruits for its oil which has been proven to contain fat soluble vitamins (vitamin A, D, E, and K) and have potentials for essential ingredient (linoleic and linolenic acid) that enhances growth. As a vegetable oil, it can be used industrially to produce skin care products, alkyd resin for paints and as high pressured biodiesel or lubricant (Ibemesi 1993; Foidl et al. 1996; Eromosele, Paschal 2003). Biodiesel has advantage over diesel fuel in that it has no negative environmental effect, non-toxic, biodegradable, sulphur-free, does not require any engine modification or transesterification stage before use and is mixable with other fuel (Tat, Van Gerpen 1999; Tat et al. 2007). The use of *Canarium schweinfurthii* fruit oil as an industrial raw material requires a comprehensive knowledge of its viscosity characteristics to determine its flow behaviour during handling. Physical property that relates to resistance to flow of fluid is called viscosity. It occurs when molecules of fluid exert friction force on each other as layer of fluid tend to slide against each other. Selection of fluid handling equipment and sizing require ade-

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quate knowledge of viscosity in order to determine the power needed to facilitate loading and discharging of fluid materials. In diesel engines, viscosity is needed to estimate atomization rate and whole engine efficiency (Knothe, Steidley 2005). Viscosity is temperature dependent among other physical factors like density (Yuan et al. 2000). Numerous researchers have studied the effect of temperature and shear rate on viscosity of oil extract from different agricultural products at temperature ranges of 10 to 100°C. Higher shear rates (64.5 to 4835 s^{-1}) effect on the absolute viscosities of different vegetable oils (avocado oil, canola oil, grape seed oil, macadamia nut oil, olive oil, peanut oil, rapeseed oil, rice bran oil, safflower oil, sesame oil, soybean oil, sunflower oil and walnut oil) at temperature range (26 to 90°C) was studied by Lemuel and Tianying (2014). They observed that all the vegetable oils studied exhibit Newtonian fluids characteristics. Rice bran and walnut oils are the most (0.0398 Pa·s at 38°C) and least (0.0296 Pa·s at 38°C) viscous, respectively among the oils studied while higher shear rate had no significant influence on the absolute viscosities of the vegetable oils at the different temperatures. The dependence of absolute viscosities of the vegetable oils on temperature fitted well with Arrhenius type relationship with activation energies that ranged from 21 to 30 kJ·mol^{-1}. The peanut oil had greater activation energy than other oils meaning that more energy is needed to effect a viscosity change in peanut oil. Altay and Ak (2005) reported the viscous behaviour of Tahin oil at temperatures range of 20 to 70°C and shear rates of 0.13–500 s^{-1}. Tahin oil was found to manifests Newtonian behaviour while its viscosity depend strongly on temperature with energy of activation of 35.7 kJ·mol^{-1}.

Esteban et al. (2012) studied the effect of temperature on density and viscosity of common vegetable oils in order to improve their combustibility for diesel engines. They reported that, at least 120°C preheating treatment is required to reduce the density and viscosity of the oils to burn well in automobile engines.

Others include: Abramovic and Klotutar (1998), five vegetable oils (unrefined sunflower oil, refine sunflower oil, olive oil, refined corn oil and unrefined pumpkin oil) at temperatures between 25–55.5°C; Eromosele and Paschal (2003), spondias mombin oil at 30–70°C; Santos et al. (2005), un-used and used vegetable cooking oils at 10–80ºC; Sadat and Khan (2007), groundnut, palm, sunflower and coconut oil at 20–60°C; Keshvadi et al. (2012), palm oil at 20–70°C. All these authors reported linear decrease in viscosity with temperature increase. In this study also, the effect of temperature and shear rate on viscosity, consistency index and flow index of two varieties of *Canarium schweinfurthii* were investigated of which no information has been reported in literature.

MATERIAL AND METHODS

Samples of *Canarium schweinfurthii* fruits used in this study were obtained from the local market of Ebonyi (6°15'N, 8°05'E) state of Nigeria. Two varieties (*Canarium schweinfurthii* large ($CSHT_{LG}$) and *Canarium schweinfurthii* long ($CSHT_{L}$)) were investigated. The mesocarps (flesh) of the fruits were dried fresh in the laboratory oven after cleaning the fruits and separating the mesocarp from the nuts. Oil from the dried mesocarps were extracted chemically and stored at room temperature for several hours. Water bath was used to condition and maintain the oil temperature. Viscosity of oil from each sample variety was tested in three replicates using a SurgiFriend Medical (model NDJ-5S, England) viscometer. The rotating speed of the spindle was varied from 6 rpm to 30 rpm. Shear stress and shear rate were calculated using Newtonian equations as, Eqs (1–2), (Mohsenin 1986; Steffe 1996; Wan Nik et al. 2005):

$$\sigma = \mu\gamma \tag{1}$$

$$\gamma = 1.318 \times S \tag{2}$$

where: μ – viscosity (Pa.s); σ – shear stress (Pa); γ – shear rate (s^{-1}); S – rotation speed of the spindle (rps)

Flow characteristics of *Canarium schweinfurthii* fruits oil were estimated using power law equations as in Eq. (3), (Simuang et al. 2004):

$$\sigma = C\gamma^{n} \tag{3}$$

where: C – consistency coefficient (Pa s^n), n – flow index of the oil

The influence of temperature on wild *Canarium schweinfurthii* oil viscosity was also determined using Arhenius equation as, Eq. (4), (Simuang 2004, Fasina, Colley 2008):

$$\mu = B_{\infty} \exp^{\frac{E_a}{TR}} \tag{4}$$

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Table 1. ANOVA summary of the effect of temperature and variety on the viscosity of *Canarium schweinfurthii* oil

Source of Variation	SS	df	MS	*F*	*P*-value	*F* crit
Temperature (°C)	49,557.25	3	16,519.08	9.98	0.0454	9.28
Variety	3,901.39	1	3,901.39	2.36	0.2223	10.13
Error	4,964.66	3	1,654.89			
Total	58,423.30	7				

$P < 0.05$; SS – sum of squares; df – degrees of freedom; MS – mean square; *F* – *F*-test ; *F* crit. – critical *F*-value

where: Ea – activation energy (J·mol–1); T – absolute temperature (K); R – universal gas constant (8.314 kJ·mol–1·K–1); B∞ – Arrhenius constant (Pa·sn)

The resulting slope from the plot of ln μ against 1/T is equal to the ratio of activation energy (E_a) to universal gas constant (*R*). This was determined for both oil varieties studied.

Biodiesel characteristic of *Canarium schweinfurthii* Engl. fruit oil was determined according to Cleveland Open Cup (COC) method (ASTM D 92) for flash point and fire point, ASTM D1322 for smoke point, ASTM D2500-9 for cloud point and ASTM D97 for pour point.

The data obtained from this experiment were analysed using Genstat, Matlab and Excel statistical packages.

RESULTS AND DISCUSSIONS

The effect of temperature on viscosity

Fig. 1 presents the effect of temperature on apparent viscosity of *Canarium schweinfurthii* Engl. fruit oil. The viscosity of long and large varieties decreased by 7.97% and 6.33% respectively, as the temperature increased from 30–60°C. This means that viscosity of oil from large fruit variety is more stable with temperature than the long variety. Wan Nik et al. (2005) reported similar observation (best and worst viscosity conditions) for sunflower and superolein seeds oil respectively, as temperature varies from 40–100°C. Noureddini et al. (1992) reported similar trend of decrease in viscosity of crambe, rapeseed, corn, soybean, milk-weed and coconut oil at temperature range of 24–110°C. Others include Esteban et al. (2012), Eromosele and Pascal (2003), and Simuang et al. (2004) for rape seed, soyabean, grapeseed, balanites aegytiaca, *Lophira lanceolata*, *Sterculia setigera*, *Khaya senegalensis*, *Ximenia americana* and *Sclereocarya birrea* seed oil and coconut milk. The decrease in viscosity with increase in temperature is as a result of increase in movement (interchange) of oil molecules which weakens the force of attraction between them.

The anova summary of Table 1 revealed that temperature had significant ($P < 0.05$) effect on the viscosity characteristics of both *Canarium schweinfurthii* Engl. oil especially at 50°C and above.

Consistency coefficient (*C*) also decreased with increase in temperature while flow behaviour index (*n*) is independent of temperature (Table 2). Tem-

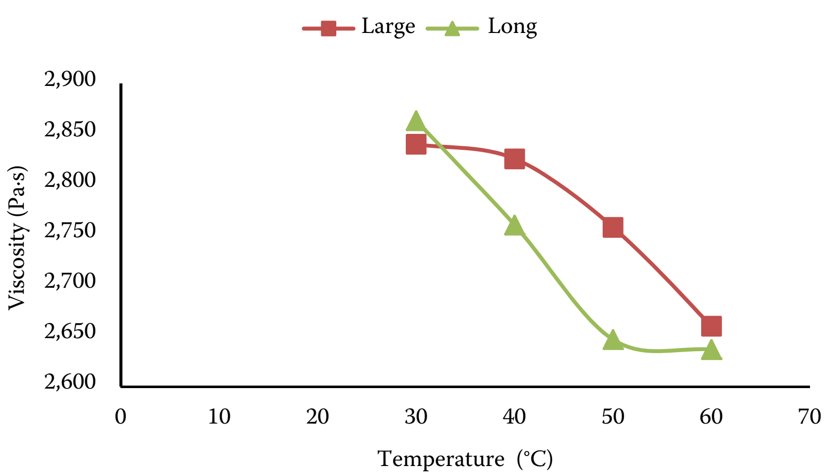

Fig. 1. The temperature dependent on the viscosity

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Table 2. Effect of temperature on *n* and *C* of *Canarium schweinfurthii* oil

Temperature (°C)	Long		Large	
	n	*C*	*n*	*C*
30	1.42	710.20	1.44	673.90
40	1.45	649.80	1.44	675.70
50	1.39	706.90	1.41	733.30
60	1.53	465.30	1.50	532.70

n – flow behavior index; *C* – consistency coefficient (Pa·s^n)

perature effect on n and *C* of oil from large and long fruits varieties are not significant ($P < 0.05$) (Table 3), while flow behaviour index (*n*) and consistency coefficient (*C*) of both oil had polynomial relationship with temperature. Altay and Ak (2005) observed a polynomial relationship of flow index (*n*) with temperature for Tahin oil.

Regression equations (Eqs 5 and 6) developed for predicting the viscosity of large and long varieties of *Canarium schweinfurthii* Engl. fruit oil showed good fit with high coefficient of determination (R^2) as 0.9980 and 0.9813 for large and long varieties respectively.

$$V_{LG} = -0.2083T^2 + 12.67T + 2,648.50 \quad (5)$$

$$V_L = 0.2333T^2 + 28.93T + 3527 \quad (6)$$

where: V_{LG} and V_L – viscosity (Pa·s) of large and long varieties of *Canarium schweinfurthii* Engl. fruit oil respectively; T – temperature (°C)

The effect of variety on the viscosity of the oil

The viscosity of oil from large *Canarium schweinfurthii* Engl. fruit was observed as higher than the long variety and their differences are not significant ($P < 0.05$) (Table 1) for all the temperatures studied. The values of flow behaviour index (*n*) of both varieties (Table 2), are more than 1 and are within the standard for Newtonian fluids. The consistency coefficient (*C*) of oil from large variety is higher than that of long variety while activation energy is less by 25.05% for large variety (796.51 J·mol^{-1}·K^{-1}) than the long variety (1,060.95 J·mol^{-1}·K^{-1}). This means that less heat is required to stir up the molecules of oil from large fruits than the long ones.

The effect of shear rate on the viscosity of the oil

Shear rate effect on the viscosity of two varieties of *Canarium schweinfurthii* Engl. fruit oil is shown in Fig. 2. The viscosity of both varieties for each temperature studied decreased as shear rate decreased up to 15.82 s^{-1} and increased at 39.54 s^{-1}. The decrease is because the shear applied in the oil breaks down the internal structure of the oil very rapidly especially at 15.82 s^{-1} and reverses at higher rate. This means that minimum energy input will be achieved during steady flow of *Canarium* oil with shear rate of 15.82 s^{-1}. The decrease in viscosity values with increasing shear rates was reported by Wan Nik et al. (2005) and Al-Zahrani and Al-Fariss (1998) for palm, coconut, canola, corn and sunflower oils and, waxy oil respectively while

Table 3. ANOVA summary of temperature effect on C and n of *Canarium schweinfurthii* oil

Variety	Flow behaviour index (*n*)			Consistency coefficient (*C*) (Pa sn)			
	MS	*F*	*P*-value	MS	*F*	*P*-value	*F*-crit
Large	1.8×10^{-5}	0.0015	0.9999	0.0048	0.0055	0.9993	4.07
Long	0.0005	0.0373	0.9895	0.0080	0.0095	0.9984	

$P < 0.05$; for explanations see Table 1

Table 4. ANOVA summary of the effect of shear rate on the viscosity of *Canarium schweinfurthii*Engl. fruit oil

Source of variation	df	MS	*F*	*P*-value	*F*-crit
Variety	1	11,704.17	0.8783	0.3611	4.41
Shear rate	2	7,487,259.72	561.84	0.0000	3.55
Interaction	2	1,593.06	0.1195	0.8880	3.55
Within	18	13,326.39			
Total	23				

$P < 0.05$; for abbreviations see Table 1

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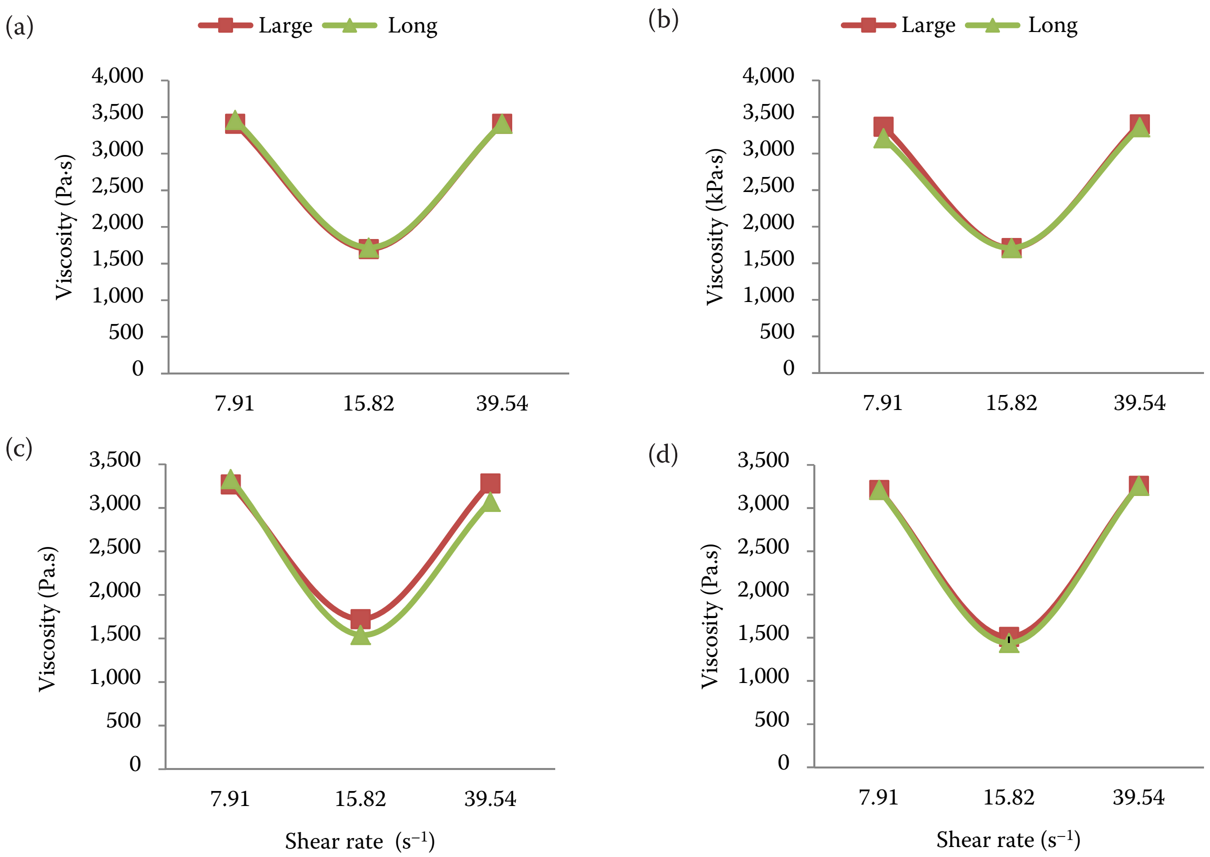

Fig. 2. The effect of shear rate on the voiscosity of *Canarium schweinfurthii*Engl fruit oil at (a) 30°C (b) 40°C, (c) 50°C and (d) 60°C

Diamante and Lan (2014) observed that higher shear rate does not affect viscosity of vegetable oil significantly. The change in viscosity of *Canarium schweinfurthii* Engl. fruit oil due to shear rate is highly significant ($P < 0.05$) for all the temperatures considered (Table 4) while interaction had no effect on the viscosity change of both varieties.

Biodiesel characteristics of wild *Canarium schweinfurthii* Engl. fruit oil

The summary of biodiesel characteristics of two varieties of *Canarium schweifurthii* Engl. fruit oil as presented in Table 5 revealed that the flash point of both varieties are higher than the fire point values. Long variety oil had higher flash points than the large variety by 8.16% while fire point decreased from long (221°C) to large (174°C). Flash point values are more than the recommended values for flammable fluids (< 37.80 to 60.50°C) and are also above min.value according to EN 590 and EN 14214 standard (120°C) (István, Ioan-Adrian 2011), hence Canarium oil is a combustible fluid and safer to handle than the petroleum diesel especially the oil of long variety. Demirbas (2008) reported that the flash point of beechnut oil, hazelnut oil and peanut oil as 533, 503, and 543°C respectively, which are approximately 50% higher than that of Canarium oil while *Jatropha curcas* oil had lower (148°C) flash point (Becker, Marrkar 2008). The low values of cloud and pour point of both varieties as shown in

Table 5. Biodiesel characteristics of *Canarium schweifurthii* Engl. fruit oil

Variety	Smoke point	Fire point	Flash point	Pour point	Cloud point
Large	145.0 ± 0.09^a	225.0 ± 0.21^d	174.0 ± 0.07^g	10.0 ± 0.01^k	13.0 ± 0.03^m
Long	210.0 ± 0.12^b	245.0 ± 0.08^e	221.0 ± 0.05^h	11.0 ± 0.04^k	12.0 ± 0.05^m

$P < 0.05$, values with similar letter along the same column are not sighificant; all parameters are in °C

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Table 5 are indication that the fatty acid content of the oil is low and transporting the oil at temperature range of 7–13°C and above will not plug or foul the pipeline. They are also within the range indicated in EN 590:2004 (cloud point is – 5°C to 17°C) and EN 14214:2008 standard (pour point is –15°C to 17°C) for biodiesel (István, Ioan-Adrian 2011). The cloud and pour point of cottonseed oil and linseed oil were also reported to range from 274–276°C and 257–259°C respectively and 276–279°C and 256–259°C respectively by Demirbas (2008). Besides, the smoke point of the varieties ranged from 128–210°C. The Institute of Shortening and Edible Oils has also analysed the smoke point of palm oil, coconut oil and peanut oil as 489, 385, and 446°C respectively. This means that Canarium oil will smoke faster than the cited bio-oil during heat treatment. Varietal difference of biodiesel characteristics values are significant ($P < 0.05$) except pour and cloud points.

CONCLUSION

It can be concluded that:

Temperature significantly reduces the viscosity of canarium oil from 50°C and above.

Large variety had lower activation energy and is more temperature stable than the long variety.

High mass transfer rate and low energy input during flow operation can successfully be achieved through shear rate of 15.82 s^{-1} (12 rps).

The oil from *Canarium schweinfurthii* Engl fruits are Newtonian fluids with behaviour index of above one. *Canarium schweinfurthii* Engl. oil is a combustible fluid and is safer to handle than the petroleum diesel.

The biodiesel characteristics of two varieties of *Canarium schweinfurthii* Engl. oil differ significantly ($P < 0.05$).

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