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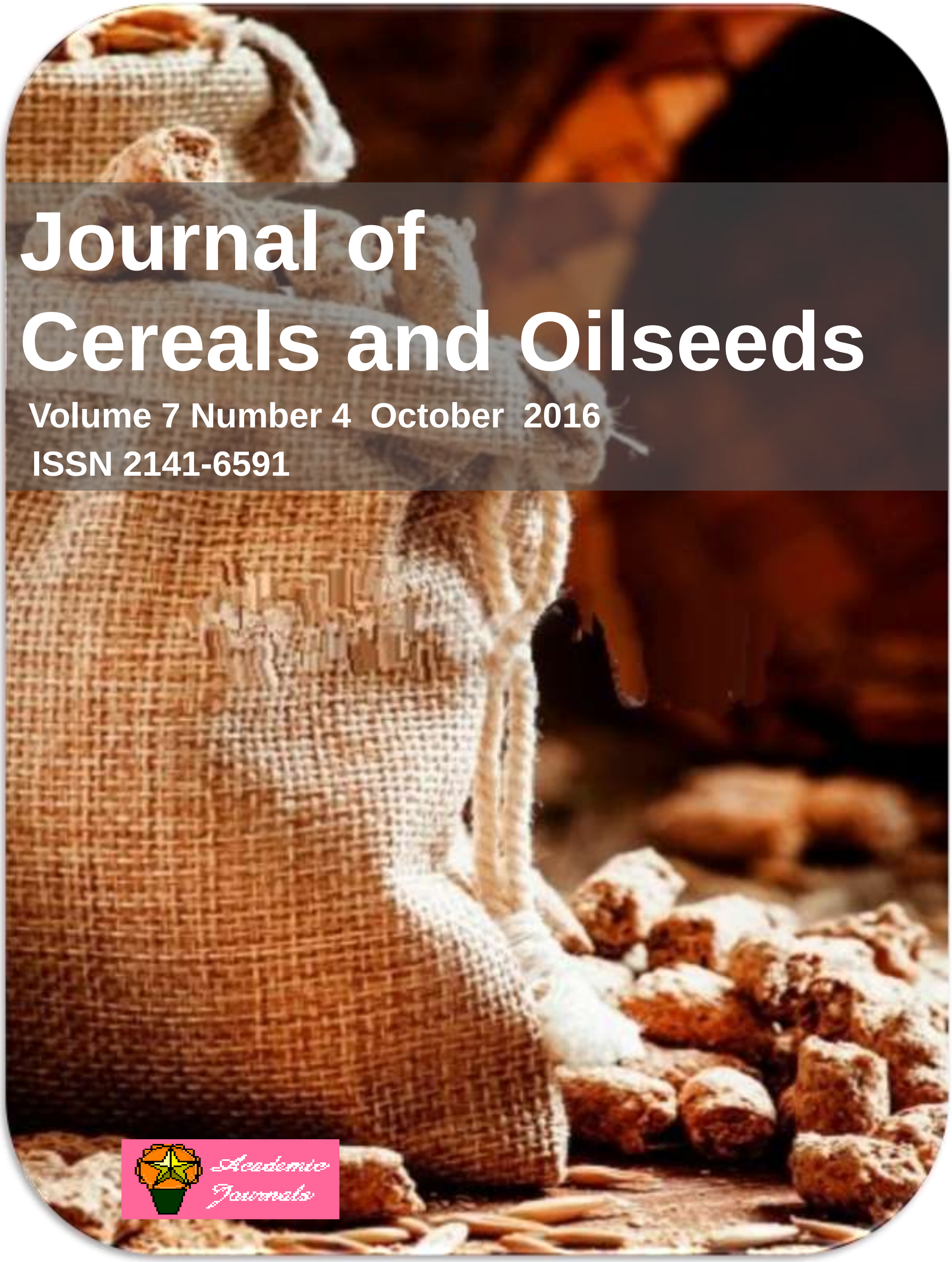

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Full Length Research Paper

Rheological characteristics and fatty acid compositions of *Afzelia africana* and *Detarium microcarpum* seed oils

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The rheological characteristics of oils isolated from the seeds of *Afzelia africana* and *Detarium microcarpum* were studied and compared with rapeseed oil. The effects of shear rate and temperature on the flow characteristics were evaluated. The shear stress- shear rate rheological models: Herschel-Bulkley, Power law, Binghan, Newtonian and Casson were used to determine the flow characteristics. All the oils exhibited non-Newtonian behaviour at shear rates < 10 s^{-1}as indicated by the presence of yield stress. The viscosities of the oils were in the order: Afzelia oil > rapeseed oil > Detarium oil. The activation energy of viscous flow followed the same order as viscosity of the oils. The most abundant fatty acids in *A. africana* oil were cis-11-eicosenoic acid (39 .06%), linolelaidic acid (18.38%) and nervonic acid (10.20%) and in *D. microcarpum* oil cis-13,16-dicosadienoic acid (20.51%) and linoleic acid (20.37%) and undecanoic acid (14.24%). *A. africana* contained higher amount of unsaturated fatty acids (92.26%) and long chain fatty acids (C ≥15; 96.00%) than *D. microcarpum* (unsaturated fatty acids, 66.27%; C ≥ 15; 79.41%). *A. africana* oil with the greater amount of long chain fatty acids had higher viscosity and activation energy of viscous flow.

Key words: *Afzelia africana*, oil, rheological properties, fatty acid composition, *Detarium microcarpum*

INTRODUCTION

Afzelia africana and *Detarium microcarpum* are tropical leguminous plants of the Caesalpiniaceae family. The seed endosperms of these plants are used to thicken soups in sub-Saharan Africa especially Nigeria. The chemical composition of the *A. africana* seed endosperm (Balogun and Fetuga, 1986; Ejikeme et al., 2010; Adesina and Osobamiro, 2012) and *D. microcarpum* (Balogun and Fetuga, 1986; Akpata and Miachi, 2001) have been well studied. The polysaccharide constituents have been extracted and characterized (Ren et al., 2005; Nwokocha and Williams, 2012). Seed oil has been isolated from *D. microcarpum* at a yield of 5 -15% (Akpata and Miachi, 2001; Okorie et al., 2010) and from *A. africana* at a yield of 15.92 - 34.57% (Ajiwe et al., 1995; Ejikeme et al., 2010; Igwenyi et al., 2011). Since the oils are edible they can be used as cooking oil and in food processing. The performance in these processes is determined by the composition and properties. The physicochemical characteristics and fatty acid composition of *D. microcarpum* oil (Njoku et al., 1999; Okorie et al., 2010; Adesina and Osobamiro, 2012) and *A africana* oil (Ejikeme et al., 2010; Igwenyi et al., 2011)

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have been reported. However, we have not found any report on the rheological properties of the oils. In this work we determined the flow characteristics of *D. microcarpum* and *A. africana* seed oils at different temperatures using different shear stress- shear rate rheological models and compared them with those of rapeseed oil. We also determined the fatty acid composition of *A. africana* and *D. microcarpum* seed oils and correlated the fatty acid composition with the rheological properties to understand how this would influence the performance of the oils in real time application.

MATERIALS AND METHODS

Extraction and purification

The *A. africana* and *D. microcarpum* seeds were purchased from a local market in Abakiliki, Ebonyi State, Nigeria. The seeds were cracked, soaked in warm water to enable easy removal of the hull. The endosperm was air dried to ambient moisture and then pulverized. The seed oils were extracted separately from pulverized seed endosperm by soxhlet extraction for 8 h with hexane solvent. The oil was concentrated on a steam bath using a Rotavapor, then transferred into a weighed sample bottle and the remaining solvent removed by drying in a convention oven at 60°C.

$$Yield\ (\%) = \frac{weight\ of\ oil\,(g) \times 100}{Weight\ of\ seed\ flour\ (g)} \quad (1)$$

The oil was treated with excess amount of anhydrous sodium sulphate and centrifuged to remove traces of moisture and the dry oil stored. The yields of the oils were 8.43% for *D. microcarpum* and 22.9% for *A. africana*.

Rheological characterization

The rheological measurements were carried out on a controlled stress Rheometer (AR 500, TA Instruments Ltd, USA) with cone and plate geometry (40 mm, 2° steel cone and 53 µm gap). The oil was placed on the peltier plate by means of a spatula spoon, the gap was set and the excess oil trimmed off. The sample was allowed to equilibrate for 30 s at a given temperature before measurement.

Effect of shear rate and temperature on apparent viscosity

The effect of shear rate was determined by performing a stepped flow procedure in the shear rate range from 0.01 to 1000 s^{-1} at different temperatures of 30 - 90°C. The flow characteristics were determined according to the following shear stress-shear rate rheological models (Equations 2 to 6):

Herschel-Bulkley ($\sigma = \sigma_Y + \eta \dot{\gamma}^n$) (2)

Power Law ($\sigma = \eta \dot{\gamma}^n$) (3)

Bingham ($\sigma = \sigma_Y + \eta \dot{\gamma}$) (4)

Newtonian ($\sigma = \eta \dot{\gamma}$) (5)

Casson ($\sigma^{0.5} = \sigma_Y{}^{0.5} + (\eta \dot{\gamma})^{0.5}$) (6)

Where σ = shear stress (Pa); η = viscosity (Pas); $\dot{\gamma}$ = shear rate (s^{-1}); σ_Y = yield stress (Pa) and n = rate index.

Temperature ramp

A temperature ramp step procedure was carried out on the oil from 30 to 100°C at a shear rate of 50 s^{-1} for 10 min. The flow curves fitted to the Arrhenius equation (Equation 7) give an approximation of this behavior.

$$\eta = c * \exp(b/T) \quad (7)$$

Where η = viscosity (Pas), c = viscosity coefficient (Pas), equivalent to viscosity at infinite temperature $\eta_{T\infty}$; b = temperature coefficient (K), equal to E_a/R; T = temperature (K). Thus Equation 6 can be rewritten as Equation 8 to enable the calculation of the activation energy, E_a. R = gas constant (8.314 J/mol/K)

$$\eta = \eta_{T\infty} \exp(\frac{E_a}{RT}) \quad (8)$$

Fatty acid composition

Fatty acid methyl esters (FAME) were prepared by standard IUPAC method 2.301 (Anonymous, 1979). Sample of the raw oil (1000 mg) was accurately weighed, placed in 50 ml round bottom flask, followed by the addition of 1 M methanolic sodium hydroxide (5 ml). The samples were refluxed at 70°C for 20 min. After cooling, hexane and water (10 ml of each) were added. The mixture was vortex mixed for 15 min and the upper phase (hexane layer) containing the fatty acid methyl esters was recovered and analysed by gas chromatography. The GC was conditioned for 30 min and 0.2 ml of the methylated sample was injected into the capillary column (VF-1 ms, 30 m, 0.25 mm, 0.25 µm; Part number CP8912) of the Varian Chromopack GC (Model- CP3380, USA) (injection temperature 260°C, detector temperature 260°C). The carrier gas was nitrogen (flow rate 30 ml/min) and flowed through the air drier at 571°C, coolable oven at 100°C which increases with time and the Front FID at 260°C. The sample was allowed to run in the GC for about 1 h 37 min.

Data analysis

The rheological data were analyzed using the Thermal Advantage Data Analysis Software version V.5.1.42 (TA Instruments, USA).

RESULTS AND DISCUSSION

Dependence of viscosity on shear rate and temperature

The shear stress- shear rate flow profiles of *A. africana* and *D. microcarpum* and rapeseed oils measured at

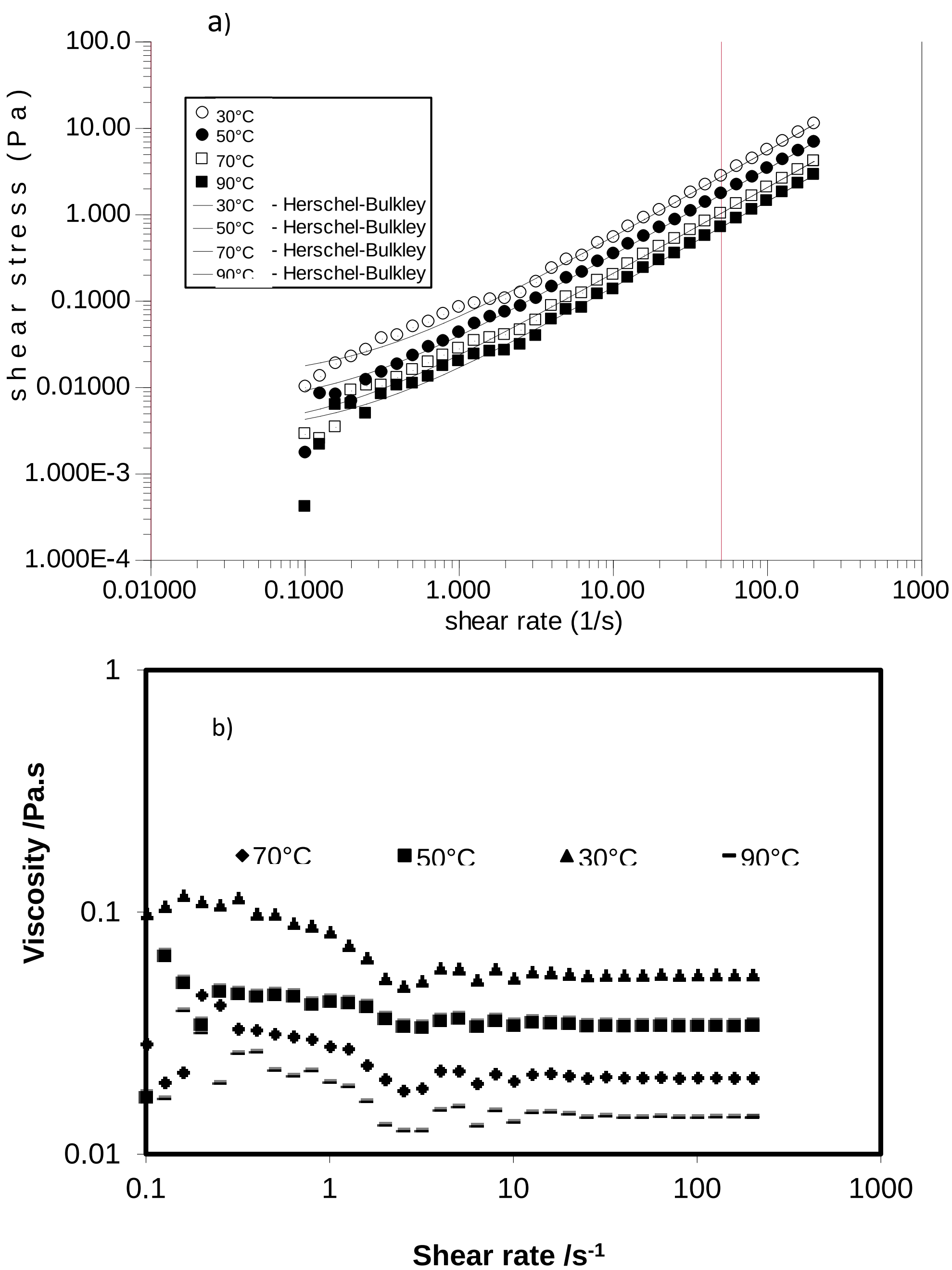

Figure 1. (a) Shear flow profiles of *Afzelia africana* oil at different temperatures fitted to the best fitting shear stress-shear rate models. (b) Viscosity-Shear rate profile of *Afzelia* oil at different temperatures.

different temperatures are presented in Figures 1a, 2 and 3, respectively. The profiles showed two distinct regions: a non-linear or non-Newtonian region at low shear rates (< 10 s^{-1}) where shear stress did not vary linearly with shear rate, and a linear or Newtonian region (> 10 s^{-1}) where shear stress varied linearly with shear rate. At low shear rates, the oils indicated presence of some structures which were broken down as a result of the shearing action.

These are mainly the fatty acid crystals and were responsible for the non-Newtonian flow. At shear rates > 10 s^{-1}, all the structures had been destroyed and flow became Newtonian (Ennouri et al., 2005; Santos et al., 2005). The shear thinning characteristics of the oils at < 10 s^{-1} is illustrated in the viscosity-shear rate profiles of *A. africana* oil (Figure 1b). The analysis parameters

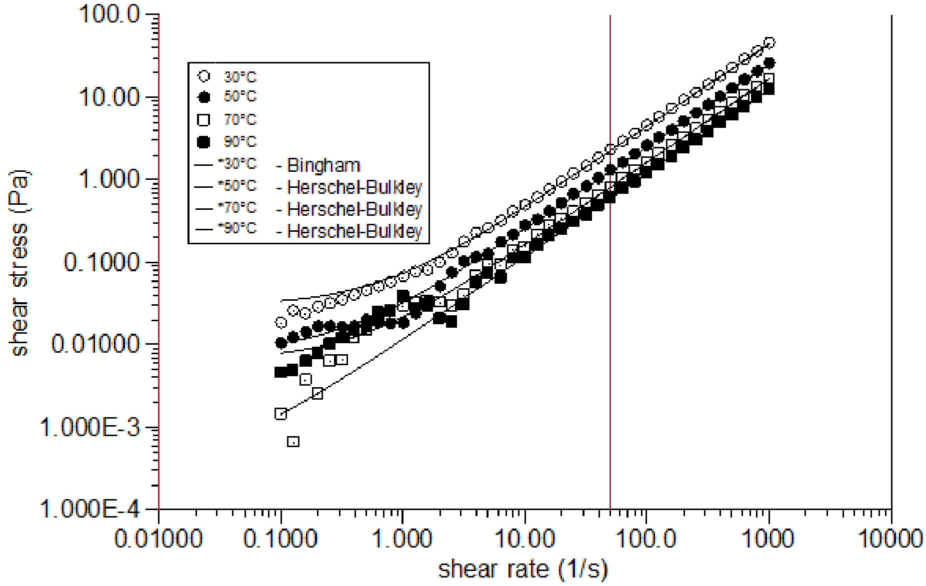

Figure 2. Shear flow profiles of *Detarium microcarpum* oil at different temperatures fitted to the best fitting shear stress-shear rate models.

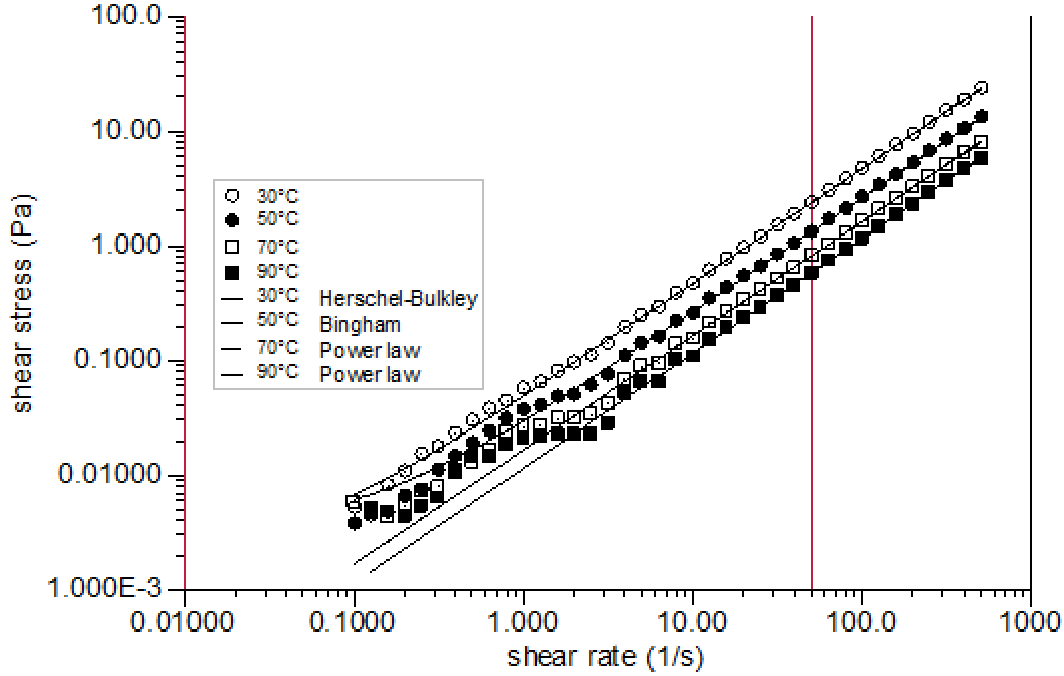

Figure 3. Shear flow profiles of rapeseed oil at different temperatures fitted to the best fitting shear stress-shear rate models.

obtained by fitting different shear stress- shear rate models to the flow profiles are shown in Tables 1, 2 and 3.

All the models applied were suitable in describing the flow properties of *A. Africana, D. microcarpum* and rapeseed oils because the standard error of estimates was less than 20 except that Casson model failed at 70°C for Afzelia oil and 70 and 90°C for rapeseed oil. At 30°C, *A. africana* oil had the highest viscosity (5.6 x 10^{-2} Pas), followed by rapeseed oil (4.7 x 10^{-2} Pas) while *D.*

Table 1. Analysis parameters of viscosity-shear rate curves of *Afzelia africana* oil according to different rheological models.

Model	Parameter	30°C	50°C	70°C	90°C
Herschel-Bulkley	σ_Y	5.894E-3	5.895E-3	3.039E-3	2.887E-3
	η	0.05598	0.03391	0.02084	0.01418
	n	0.9976	1.001	0.9992	1.002
	s.e	0.2430	0.8441	1.228	1.739
Power law	η	0.05613	0.03445	0.02113	0.01445
	n	0.9972	0.9983	0.9967	0.9985
	s.e	0.2585	1.045	1.334	1.882
Bingham	σ_Y	0.01489	5.572E-3	3.715E-3	2.549E-3
	η	0.05509	0.03412	0.02076	0.01433
	s.e	0.3521	0.5602	1.236	1.758
Newtonian	η	0.05509	0.03417	0.02076	0.01433
	s.e	0.4316	1.086	1.490	1.942
Casson	σ_Y	1.914E-3	4.356E-4	3.163E-4	6.845E-6
	η	0.05430	0.03351	0.02036	2.617E-4
	s.e	0.9773	1.914	2.263	327.6

σ_y = shear stress (Pa), η= viscosity (Pas), n = rate index (dimensionless), s.e = standard error.

Table 2. Analysis parameters of viscosity-shear rate curves of *Detarium microcarpum* oil according to different rheological models.

Model	Parameter	30°C	50°C	70°C	90°C
Herschel-Bulkley	σ_Y	0.01958	0.008086	0.006421	3.358E-4
	η	0.04451	0.02457	0.01545	0.01142
	n	1.000	1.0004	1. 011	1.011
	s.e	0. 4350	0.5191	0.6447	0.9242
Power law	η	0.04502	0.02477	0.01560	0.01144
	n	0.9988	1.003	1.011	1.011
	s.e	0.6666	0.6203	1.334	0.9367
Bingham	σ_Y	0.02952	2.847E-3	9.380E-3	3.956E-3
	η	0.04460	0.02528	0.01672	0.01203
	s.e	0.4163	0.7367	1.759	1.811
Newtonian	η	0.04468	0.02528	9.316E-5	0.01230
	s.e	0.6963	0.7440	1.551	1.811
Casson	σ_Y	9.295E-3	1.549E-4	9.316E-4	1.6499E-5
	η	0.04302	0.02514	3.576E-4	1.930E-4
	s.e	3.139	1.080	256	258.3

σy = shear stress (Pa), η= viscosity (Pas), n = rate index (dimensionless), s.e = standard error.

microcarpum (4.5 x 10^{-2} Pas) was lowest. The viscosity of *D. microcarpum* is similar to 4.6 x 10^{-2} Pas reported for

Table 3. Analysis parameters of viscosity-shear rate curves of Rapeseed oil according to different rheological models.

Model	Parameter	30°C	50°C	70°C	90°C
Herschel-Bulkley	σ_Y	2.042E-3	1.493E-3	3.667E-3	4.008E-4
	η	0.04708	0.02631	0.01596	0.01092
	n	1.001	0.9995	1. 002	1.012
	s.e	0. 3264	0.5255	1.128	1.417
Power law	η	0.04718	0.02639	0.01657	0.01148
	n	1.000	0.9990	0.9960	1.003
	s.e	0.3329	0.5475	0.9643	1.288
Bingham	σ_Y	1.043E-3	3.528E-3	5.405E-3	1.627E-3
	η	0.04725	0.02623	0.01617	0.01169
	s.e	0.3326	0.5176	0.9720	1.341
Newtonian	η	0.04725	0.02623	01617	0.01169
	s.e	0.3352	0.5748	1.154	1.365
Casson	σ_Y	1.143E-3	2.286E-4	3.078E-5	2.791E-6
	η	0.04716	0.02598	3.333E-4	1.743E-4
	s.e	0.3877	1.012	273.8	273.6

σy = shear stress (Pa), η= viscosity (Pas), n = rate index (dimensionless), s.e = standard error.

canola oil but less than 4.1 x 10^{-2} Pas reported for soybean oil at 30°C (Diamante, and Lan, 2014). The presence of yield stress in the oils observed with Herschel-Bulkley, Binghan and Casson models indicated a range of non-Newtonian behaviour of the 'oil'. The non-Newtonian behaviour at low shear rates indicates the presence of large aggregates of fatty acid crystals in the vegetable oil (Murthukumarappan et al., 2016). The yield stress decreased as temperature increased. Shearing and temperature destroyed this structural state and gave rise to a homogeneous stable suspension. This explains why the flow behaviour index (n) is close to unity at all the temperatures.

Activation energy of flow

The activation energy of viscous flow of the oils was estimated from the temperature ramp (30 to 100°C) at 50 s^{-1} by applying the Arrhenius equation (Figure 4a) the parameters of flow are presented in Table 4a. The curves gave good fits as indicated by the low values of the standard error of estimates (11.31-14.29).

Afzelia oil had slightly higher E_a (23.25 kJ/mol) than rapeseed oil (23 kJ/mol) while Detarium oil (20.88 kJ/mol) was lowest. Correlating E_a with the viscosity of the oils, Afzelia oil with the highest viscosity had the highest E_a. We also estimated the activation energy of flow, E_a', at 50.12 s^{-1} in the Newtonian region of the shear flow profiles for the different oils (Figures 1a, 2 and 3). We calculated the viscosity from the relationship ($\eta = \sigma/\dot{\gamma}$) and used it to estimate E_a' from the plot of η versus 1/T, (R^2 = 0.994 - 0.998) (Figure 4b, Table 4b). In comparison E_a' values are less than E_a. This is expected because E_a covered the entire flow profile and included the energy used to breakdown fatty acid structures in the oils while E_a' was obtained after Newtonian flow had been attained and was devoid of contribution from the fatty structures. It was observed that the E_a' for rapeseed oil (21.4 kJ/mol) > E_a' for *A. africana* (20.77 kJ/mol). This did not follow the pattern observed with the E_a for the two oils. This difference can be explained by considering the yield stress values, σ_γ, and their contribution to resistance to flow. The σ_γ for *A. africana* (5.894E-3 Pa) is more than twice for rapeseed oil (2.042E-3 Pa) indicating the contribution of σ_γ to E_a is higher in *A africana*. For E_a', all the fatty structures and σ_γ had been overcome and the values reflected the activation energy for the oil alone. The activation energies are in the range of values reported for other oils (Giap, 2010).

Fatty acid composition

Tables 5 and 6 show the identified fatty acids in *A. africana* and *D. microcarpum* oils, respectively. The most abundant fatty acids in *A. africana* oil in order of abundance were cis-11-eicosenoic acid (39.06%), linolelaidic acid (18.38%) and nervonic acid (10.20%) while in *D. microcarpum* were cis-13,16-dicosadienoic

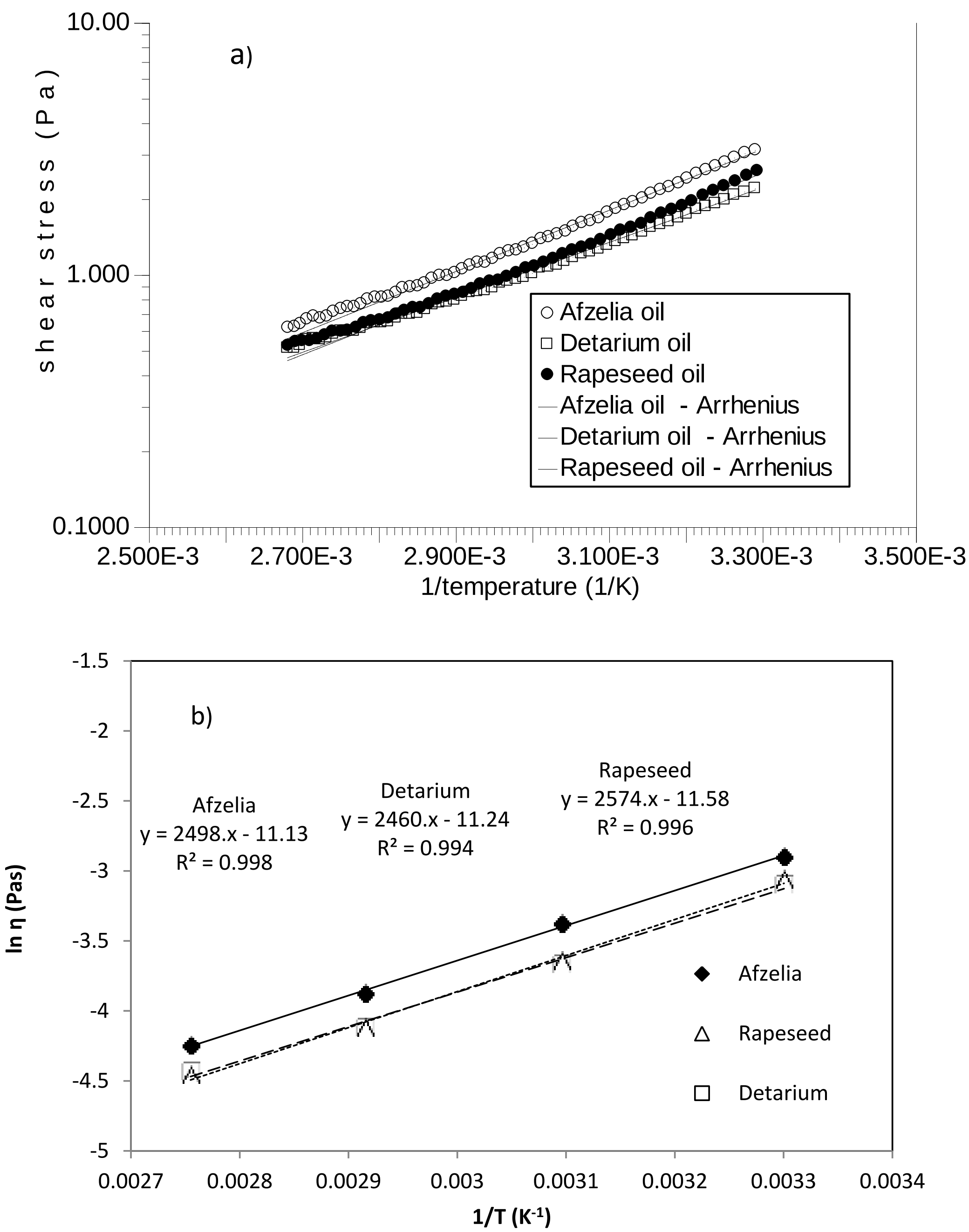

Figure 4. (a) Flow curves of the temperature ramp from 303K to 373K at shear rate of 50 (1/s) for *Afzelia africana, Detarium microcarpum and Rapeseed* oils*.* (b) Plot of apparent viscosity versus inverse of absolute temperature at shear rate of 50.12 (1/s) for estimation of activation energies of *Afzelia africana, Detarium microcarpum and Rapeseed* oils*.*

Table 4a. Parameters of flow curves of *Afzelia africana, Detarium microcarpum* and *Rapeseed* oils subjected to temperature ramp from 30°C to 100°C at shear rate of 50 (1/s) fitted to Arrhenius equation

Oil	E_a (kJ mol^{-1})	η_{T_∞} (Pas)	s.e
Afzelia oil	23.25	6.235E-6	11.87
Detarium oil	20.88	1.125E-5	11.31
Rapeseed oil	23.00	5.524E-6	14.29

Table 4b. Analysis parameters of apparent viscosity versus inverse of absolute temperature at shear rate of 50.12 (1/s) of *Afzelia africana, Detarium microcarpum* and Rapeseed oils.

Oil	E_a' (kJ/mol)	$\eta_{T\infty}$ (Pa s)	R^2
Afzelia	20.77	7.40E-12	0.998
Detarium	20.45	5.75E-12	0.994
Rapeseed	21.40	2.63E-12	0.996

Table 5. Fatty acids present in *Afzelia africana seed* oil, their percentages and retention times

Peak name	**Fatty** acid present	Retention time	Percentage fatty acid
C4:0	Butyric Acid	3.474	0.04
C8:0	Caprylic Acid	4.437	0.01
C11:0	Undecanoic Acid	10.031	0.05
C12:0	Lauric acid	13.817	0.15
C13:0	Tridecanoic Acid	16.580	2.43
C14:0	Myristic Acid	20.255	0.03
C14:1	Myristoleic Acid	21.560	1.49
C15:0	Pentadecanoic Acid	23.173	0.02
C16:0	Palmitic acid	26.561	1.61
C16:1	Palmitoleic acid	27.841	5.54
C18:0	Stearic acid	31.524	1.02
C18:1 (n9t)	Elaidic acid	32.968	0.15
C18:1 (n9c)	Oleic acid	35.762	0.45
C18:2 (n6t)	Linolelaidic acid	37.157	18.38
C18:2 (n6c)	Linoleic acid	37.685	8.88
C18:3n6	Gamma-Linolenic acid	38.415	0.05
C20:1	Cis-11-Eicosenoic acid	40.910	39.06
C20:0	Arachidic acid	43.648	0.07
C18:3 (n3)	Linolenic acid	47.960	0.33
C20:3n6	Cis-8,11,14-Eicosatrienoic acid	51.378	0.67
C22:1n9	Erucic acid	51.802	0.44
C20:3n3	Cis-11,14,17-Eicosatrienoic acid	52.491	1.67
C22:0	Behenic acid	55.035	1.92
C20:4 (n6)	Arachidonic acid	62.083	0.41
C23:0	Tricosanoic acid	67.811	0.21
C22:2	Cis-13,16-Dicosadienoic acid	70.410	3.32
C20:5n3	Cis-5,8,11,14,17-Eicosapentanoic acid	77.588	0.46
C24:0	Lignoceric acid	83.249	0.18
C24:1	Nervonic acid	85.173	10.20
C22:6 (n3)	Cis-4,7,10,13,16,19-Docosahexaenoic acid	91.201	0.75

acid (20.51%) and linoleic acid (20.37%) and undecanoic acid (14.24%). The odd carbon fatty acids were present in the oils. They occurred in very low amounts in *Afzelia africana* seed oil, however, the compositions of undecanoic acid and Heptadecanoic acid present in *D. microcarpum* were unusually high to be neglected. We have not found reports of odd fatty acids in both *A. africana* and *D. microcarpum* but these have been reported in negligible amounts in several vegetable oils (Vingering et al., 2010; Orsavova et al., 2015). Igwenyi et al. (2011) have reported the three most abundant fatty acids in *A. africana* oil as linoleic acid (41.25%), palmitic acid (33.65%) and oleic acid (12.65%). However, Njoku et al. (1999) have reported that the C-18 fatty acids predominate in both *A. africana* and *D. microcarpum* oils.

Table 7 shows a comparison of the fatty acid profiles of

Table 6. Fatty acids present in D*etarium microcarpum seed* oil, their percentages and retention times.

Peak name	Fatty acid present	Retention time	Percentage fatty acid
C4:0	Butyric acid	3.332	0.24
C6:0	Caproic acid	4.118	0.08
C8:0	Caprylic acid	4.579	1.92
C10:0	Capric acid	7.989	0.02
C11:0	Undecanoic acid	10.081	14.24
C12:0	Lauric acid	13.481	0.23
C13:0	Tridecanoic acid	16.923	0.02
C14:0	Myristic acid	20.035	4.05
C15:0	Pentadecanoic acid	23.340	0.03
C15:1	Cis-10-Pentadecenoic acid	24.524	0.32
C16:0	Palmitic acid	26.698	0.02
C16:1	Palmitoleic acid	27.560	4.38
C17:0	Heptadecanoic acid	29.997	3.16
C18:0	Stearic acid	31.702	0.06
C18:1 (n9t)	Elaidic acid	32.876	0.09
C18:1 (n9c)	Oleic acid	34.974	1.87
C18:2 (n6t)	Linolelaidic acid	36.536	3.47
C18:2 (n6c)	Linoleic acid	37.682	20.37
C18:3n6	Gamma-Linolenic acid	38.131	0.01
C20:1	Cis-11-Eicosenoic acid	39.957	1.50
C20:0	Arachidic acid	44.396	0.18
C18:3 (n3)	Linolenic acid	48.303	0.19
C21:0	Heneicosanoic acid	49.317	0.67
C20:2	Cis-11,14-Eicosadienoic acid	49.902	1.89
C22:1n9	Erucic acid	52.215	3.49
C20:3n3	Cis-11,14,17-Eicosatrienoic acid	53.033	0.02
C22:0	Behenic acid	54.662	2.81
C20:4 (n6)	Arachidonic acid	63.805	0.12
C23:0	Tricosanoic acid	68.035	0.01
C22:2	Cis-13,16-Dicosadienoic acid	71.009	20.51
C20:5n3	Cis-5,8,11,14,17-Eicosapentanoic acid	77.244	0.34
C24:0	Lignoceric acid	82.801	5.46
C24:1	Nervonic acid	84.968	8.11
C22:6 (n3)	Cis-4,7,10,13,16,19-Docosahexaenoic acid	91.230	0.15

A. africana and *D. microcarpum* seed oils. *A africana* had higher unsaturated fatty acids, UFA (92.26%) and monounsaturated fatty acids, MUFA (57.33%) than *D. microcarpum* (UFA, 66.27%; MUFA, 19.43%).

However *D. microcarpum* (45.32%) was higher in PUFA than *A. africana* (34.93%). *A. africana* had more long chain fatty acids (C ≥ 15) 96.00% than *D. microcarpum* (79.41%). Prickly pear seed oil consists of 88% unsaturated fatty acids with linoleic acid as the most abundant fatty acid (Giap, 2010).

A correlation of fatty acid composition and rheological properties of the oils indicates that *A. africana* oil with higher percentage of long chain fatty acids exhibited higher viscosity than *D. microcarpum* oil. This is in agreement with research findings which established viscosity as being directly influenced by molecular weight (Al-Assaf et al., 2005). Wang and Briggs (2002) have also corroborated this when they reported that oils with high oleic acid content have higher viscosity.

The presence of unsaturation in oils also affects its rheological properties though the relationship was not easily deduced in this study. According to Kim et al. (2010), viscosity decreases with increase in degree of unsaturation of fatty acids in the oil.

Conclusion

The oils extracted from the seeds of *A. africana* and *D. microcarpum* were studied for their rheological properties.

Table 7. Comparison of the fatty acid profiles of *A. africana* and *D. microcarpum* seed oils.

Composition	*Detarium microcarpum*	*Afzelia africana*
Saturated Fatty Acid (%)	15.07	5.03
Unsaturated Fatty Acid (%)	66.27	92.26
Monounsaturated Fatty Acid, MUFA (%)	19.43	57.33
Polyunsaturated Fatty Acid, PUFA (n≥2) (%)	45.32	34.93
Fatty Acid (C ≥15) (%)	79.41	96.00

The oils were non-Newtonian at shear rates < 10 s^{-1}. The activation energy of flow increased with the viscosity of the oils. The most abundant fatty acids in *A. africana* were cis-11-eicosenoic acid (39.06%), linolelaidic acid (18.38%) and nervonic acid (10.20%) while in *D. microcarpum,* they were cis-13,16-dicosadienoic acid (20.51%), linoleic acid (20.37%) and undecanoic acid (14.24%). *A. africana* oil contained higher unsaturated fatty acids (92.26%), long chain fatty acids (C ≥ 15; 96.00%) compared to *D. microcarpum* (unsaturated, 66.27%) and long chain fatty acids (C ≥ 15; 79.41%). The viscosity of the oils showed direct correlation with the percentage of long chain fatty acids present.

Conflict of Interests

The authors have not declared any conflict of interests.

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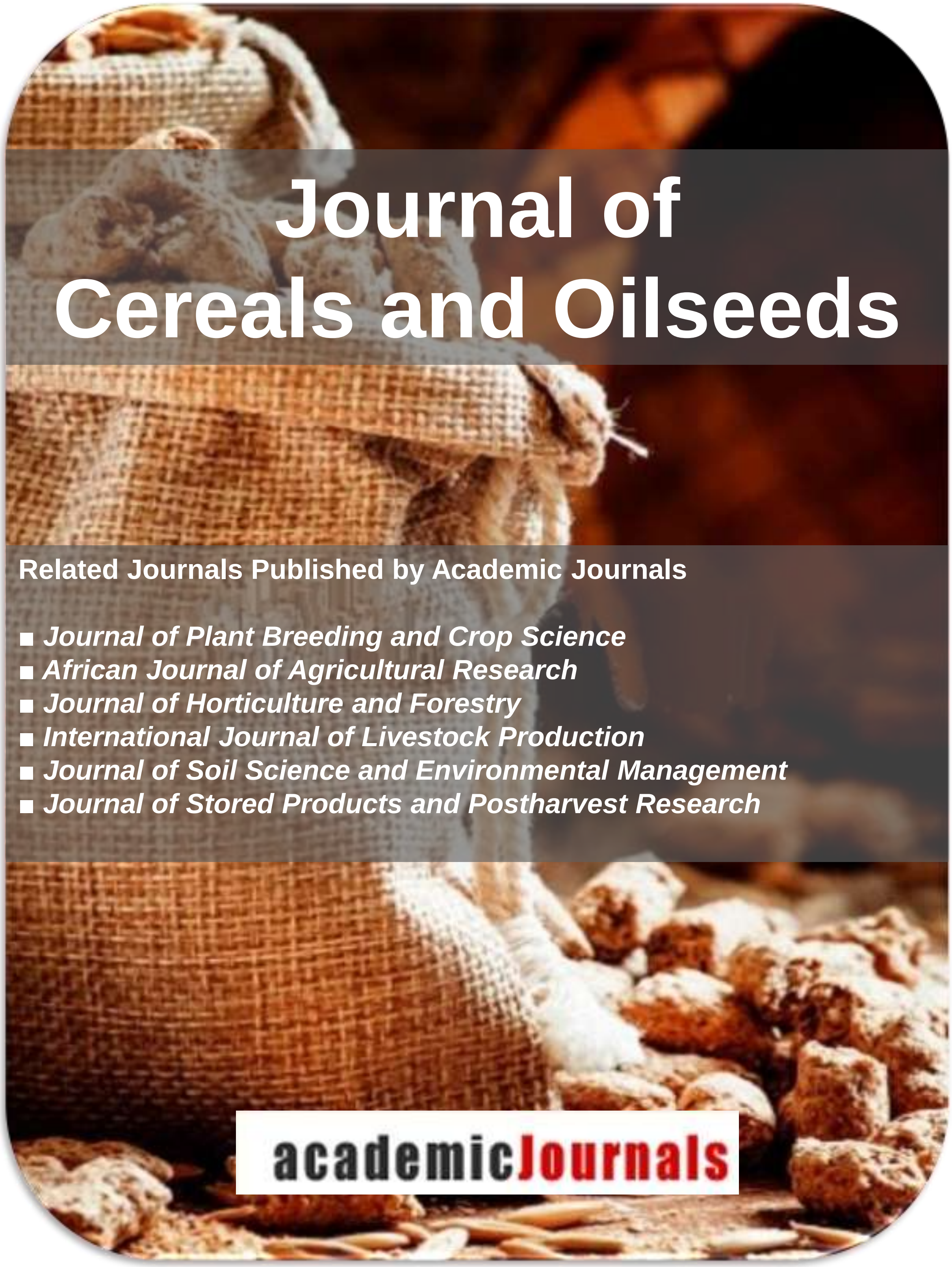
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