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Full Length Research Paper

Rheological distinctiveness of food gum

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The rheological characteristics (consistency and flow behavior indices) of food gum (C*issus populnea)* exudates obtained from the fresh leaves and stem as well as dried leaves and stem were determined at 20, 30, 40, 50 and 60°C using a rotational viscometer at shear rates of 0.1, 0.2, 0.5, 1.0 and 1.5 rpm for effective design and simulation of its momentum transfer process and system. The experimental design used for the study of consistency and flow behavior indices of *C. populnea* at 20 - 60°C was Randomized Complete Block Design (RCBD). The study revealed that consistency index (K) of C. *populnea* exudates generally increased with increase in temperature. The K values for the fresh were generally higher than the dried materials. The K values of the fresh stem exudates, which is more viscous, were significantly ($P< 0.05$) different from the less viscous fresh leaves exudates, but did not show significant (P 0.05) difference with the dried leaves which became concentrated due to drying.

The flow behavior index did not show any defined trend with changes in temperature, and was not significantly (P 0.05) different. The exudates generally exhibited pseudoplastic behavior at all the temperatures studied. A study of the apparent viscosity of the exudates between temperatures of 20 - 150°C shows that apparent viscosity increased with increase in temperature below the boiling point of 70°C. However, above the boiling point, the apparent viscosity decreased with increase in temperature. The viscosity-temperature data were fitted in Arrhenius-type equation and yielded activation energies between 0.997 to 2.431 KJ/mol°C, corresponding to temperature range between 20 - 70°C and 1.632 to 2.580 KJ/mol with K corresponding to temperature range between 70 - 150°C.

Key words: Rheological characteristics, consistency index, flow behavior index, C*issus populnea.*

INTRODUCTION

The plant, C *issus populnea* is also called Food Gum (Chukwu and Okpalalzima, 1989) and Okoho (Idoma) or Ager (Tiv) which are some local dialects spoken in Nigeria. It contains 79% carbohydrate, 11% moisture, 3% crude protein, 3% crude fibre, 2% ether extract and 2% ash (Steffe et al. 1983). There are wide ranges of possible application of C. *populnea*. The gum is used for soup and as soup thickener. It is also widely used as medicine for the treatment of venereal diseases and indigestion and as drug binder (Iwe and Atta, 1993).

An important quality index of *C. populnea* is sliminess or cohesiveness (degree of gelling or firmness). The sliminess of *C. populnea* is associated with the freshness or wholesome product by users. In quantitative terms, sliminess can be measured in terms of consistency index or viscosity. Knowledge of the rheological characteristics of *C. populnea* at different temperatures is crucial for effective design and simulation of its momentum transfer process and system. In particular, rheological characteristics are important in the determination of such design parameters as pipe diameter, pump selection and power requirement for its transport (Mohsenin, 1986).

The rheological characteristics of many foods such as kunu zaki (Sapode and Kassum, 1992), tilapia fish homogenate (Ariahu et al., 2001), tomato (Alakali and Ijabo, 2003), canarium oil (Alakali et al., 2003) have been reported in literature. However, very little is known about the rheological characteristics of *C. populnea.* The objectives of this study are: (a) To investigate the rheological characteristics of *C. populnea* exudates from fresh leaves and stem, as well as dried leaves and stem; (b) To characterize the flow behavior of the *C. populnea* exudates

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and (c) To study the effect of temperature on the apparent viscosity of *C. populnea* exudates.

THEORY

The rate of flow (g) is related to applied shear stress (τ) by the power law (Equation 1), often referred to as Newton's law of internal friction for Newtonian fluids (Lewis, 1990):

$$t = mg \qquad (1)$$

Where; μ is viscosity or consistency index (Ns/m^2).

The power law model for non-Newtonian fluids approximates shear rate-shear stress relationship using equation (2):

$$t = Kg^{n} \qquad (2)$$

Where; K and n are consistency index and flow behaviour index, respectively.

When n<1, the consistency index decreases with increasing shear stress. Materials exhibiting these characteristics are said to be pseudoplastic. Conversely, when n>1, the consistency index increases with increase in shear rate and the materials are said to be dilatants. The two-parameter power law model suffers theoretical credibility because the dimensions of consistency index (K) depend on the flow behaviour index (n). Nevertheless, the model enjoys wide practical application with a large number of materials, especially in the food industry, obeying it. The power law model has the appeal for mathematical simplicity (Satimehin et al., 2003).

Sapode and Kassum (1992) used an empirical equation derived from the power law model for characterizing the flow behaviour of fluid foods. This equation expresses apparent viscosity (μ_a) as a power function of the consistency index in the manner shown in equation 3):

$$m_a = Kg^{n-1} \qquad (3)$$

Where; μ_a = apparent viscosity (Ns/m^2), K = empirical consistency index (Ns/m^2), g is rotational shear rate (s^{-1}). A log – log plot of μ_a verses g gives a straight line of slope (n-1) and intercept (log K). Many researchers have investigated the temperature dependency of viscosity of food materials such as palm oil (Satimehin et al., 2003), sausage from broiler chicken (Awonorin, 1993) and fluid foods (Rao and Anantheswaran, 1982). These authors observed that viscosity generally decreases with increase in temperature. An Arrhenius - type relationship generally represents the viscosity- temperature relationship as shown in Equation 4:

$$K = K_o \exp\left(-\frac{E_a}{RT}\right) \qquad (4)$$

where K_o is consistency index at absolute zero temperature; E_a is the activation energy (KJ/mol), T is absolute temperature, R is the universal gas constant (8.314 x 10^{-3} KJ/ mol).

Plate 1. *Cissus populnea* (a) fresh leaves; (b) dry leaves; (c) fresh stem strips; and (d) dry stem strips.

MATERIALS AND METHODS

Materials

C. populnea fresh stem and leaves, dry stem and leaves (Plate 1), sieve, Brookfield rotational viscometer (Model LV8 Viscometer UK Ltd), water bath (Grant Instrument Ltd model SUZ Cambridge, UK), calorimeter cup and distilled water.

Methods

Sample preparation

The leaves and stems of *C. populnea* used in this work were obtained from the forest around the University of Agriculture Makurdi, Nigeria, and thoroughly washed to remove adhering dirts and foreign materials.

The leaves were divided into two lots. Lot 1, which is fresh leaves, was squeezed between the palms in distilled water of one litre for 20 min to obtain exudates. The sample was filtered through a sieve to produce Fresh Leave Exudate (FLE) of 54% Total Solids (TS). Lot 2 was left to dry under natural conditions in the sun for three days. The dried leaves were pounded into powder using mortal and pistil. The powder was dissolved in warm distilled water of one litre at 55^{o}C and filtered using a sieve to produce Dry Leaves Exudates (DLE) of 54% TS.

The fresh stem was cleaned by scrapping with a kitchen knife. The 'fleshy' bark was removed and cut into fine strips and divided into two lots. Lot 1 was soaked in one litre of distilled water at 55^{o}C for 20 min. Afterwards the strips were squeezed under the water to remove the exudates. The sample was filtered through a sieve to produce Fresh Stem Exudate (FSE) of 54% TS. Lot 2 was allowed to dry for three days under natural conditions and the strips pounded into powder. The powder was dissolved in one litre distilled water and filtered to produce Dry Stem Exudate (DSE) of 54% TS.

Viscosity measurement

A Brookfield rotational viscometer (Model LV8 Viscometer UK Ltd)

Table 1. Consistency (K) and flow behavior (n) indices of *C. populnea* at 20-60°C.

Sample	Temperature °C	Consistency index (K)	Flow behavior index (n)	R^2
	20	3.530^{a}	0.923^{e}	0.949
	30	3.700^{a}	0.922^{e}	0.928
FSE	40	3.800^{a}	0.911^{e}	0.972
	50	4.040^{ab}	0.927^{e}	0.930
	60	4.220^{b}	0.926^{e}	0.983
	20	2.530^{c}	0.914^{e}	0.984
	30	2.740^{c}	0.917^{e}	0.994
DSE	40	2.910^{c}	0.906^{e}	0.989
	50	3.130^{d}	0.950^{e}	0.953
	60	3.420^{d}	0.939^{e}	0.951
	20	2.210^{c}	0.935^{e}	0.942
	30	2.430^{c}	0.916^{e}	0.964
FLE	40	2.630^{c}	0.950^{e}	0.990
	50	2.870^{cd}	0.944^{e}	0.928
	60	3.110^{cd}	0.934^{e}	0.957
	20	1.810^{c}	0.900^{e}	0.943
	30	2.280^{c}	0.955^{e}	0.945
DLE	40	2.510^{c}	0.933^{e}	0.977
	50	2.690^{c}	0.931^{e}	0.902
	60	3.000^{d}	0.936^{e}	0.980

Mean values within a row followed by different letters are significantly (P 0.05) different. Values are means of three replicated measurements. FSE; Fresh Stem Exudate, DSE; Dried Stem Exudate, FLE; Fresh Leaves Exudate, DLE; Dried Leaves Exudate, R^2; Regression Coefficient.

Table 2. Summary of ANOVA for consistency index (K) and flow behaviour index (n) for *C. populnea* at five levels of temperature.

Source of variation	Degrees of freedom	Consistency index (K)	Flow behavior index (n)	5%	1%
C. populnea sample	3	279.0728**	0.825057^{NS}	3.49	5.95
Temperature	4	72.47835**	1.035919^{NS}	3.26	5.41
Error	12				

**Highly significant (P=0.01); ^{NS} Non significant.

was used for measuring the viscosities of the four samples (FLE, DLE, FSE and DSE) at 20, 30, 40, 50 and 60°C and five shear rates (0.1, 0.2, 0.5, 1.0 and 1.5 rev/min), using spindle two of the viscometer. Viscosity readings were in centipoises (10^{-3} Ns/m^2). About 20 ml of the sample under consideration was measured in a calorimeter cup. It was then heated to 55°C and immediately transferred into the viscometer cup which was already maintained at a constant temperature in a water bath (Grant Instrument Ltd model SUZ Cambridge, UK). For every temperature and shear rate, viscosity readings were replicated three times. The experimental design used for the study of consistency and flow behavior indices of *C. populnea* at 20 - 60°C was Randomized Complete Block Design (RCBD).

Effect of temperature

Three hundred and fifty (350) ml each of the samples FLE, DLE, FSE and DSE was heated from 20 to 150°C in a calorimeter cup using a hot plate. The viscosity reading of each sample was taken at a regular interval of three minutes until the temperature of 150°C was attained.

Statistical analysis

All statistical analyses were performed using SPSS for Microsoft Windows Release 6.0 and GenStat. Means were analyzed for variance and separated using Duncan Multiple Range Tests. The non-linear regression procedure of SPSS was used to determine regression parameters K, K_o, n and E_a in equations 3 and 4, respectively.

RESULTS

The values of consistency (K) and flow behaviour (n) indices of the four samples of *C. populnea* (Table 1) were obtained from log – log plot of μ_a versus$g$. The analysis of variance (ANOVA) is presented in Table 2 while linear

Table 3. Regression equations for consistency index (K) and flow behaviour index (n) for *C. populnea* in the temperature range of 20-60°C.

C. populnea sample	Consistency index (K)				Flow behavior index (n)			
	a	b	R^2	r	a	b	R^2	r
FSE	3.17	0.0172	0.986	0.993	0.9174	0.00011	0.074	0.273
DSE	2.078	0.0217	0.991	0.995	0.892	0.00083	0.504	0.710
FLE	1.754	0.0224	0.999	0.999	0.9254	0.000665	0.102	0.319
DLE	1.342	0.0279	0.971	0.985	0.9118	0.00048	0.147	0.384

a = intercept; b = slope; R^2 = coefficient of determination; r = correlation coefficient; = standard deviation.

Table 4. Regression parameters of Arrhenius relationship between consistency and flow behavior indices of *C. populnea* at 20 – 70°C.

Regression parameters	*C. populnea* sample			
	FSE	DSE	FLE	DLE
N	6	6	6	6
Gradient (B)	0.122	0.173	0.228	0.299
E_a (KJ/ml)	0.977	1.408	1.852	2.431
Intercept (In K_o)	1.402	1.112	0.904	0.975
K_o	4.063	3.040	2.469	2.171
R^2	0.966	0.976	0.900	0.970

FSE, Fresh Stem Exudate; DSE, Dried Stem Exudate; FLE, Fresh Leaves Exudate; DLE, Dried Leaves Exudate; N, number of observations; E_a, Activation Energy; K_o, Temperature factor at absolute zero (intercept); R^2, Regression coefficient.

Table 5. Regression parameters of Arrhenuis relationship between consistency and flow behavior indices of *C. populnea* at 70 – 150°C.

Regression parameters	*C. populnea* sample			
	FSE	DSE	FLE	DLE
N	8	8	8	8
Gradient	0.201	209	0.228	0.266
E_a (KJ/mol)	1.691	1.701	1.920	2.580
Intercept (In K_o)	1.620	1.414	1.298	1.119
K_o	5.053	4.112	3.661	3.062
R^2	0.850	0.87	0.812	0.700

FSE, Fresh Stem Exudate; DSE, Dried Stem Exudate; FLE, Fresh Leaves Exudate; DLE, Dried Leaves Exudate; N, number of observations; E_a, Activation Energy; K_o, Temperature factor at absolute zero (intercept); R^2, Regression coefficient.

regression analysis is presented in Table 3. Figure 1 shows the plot of apparent viscosity versus shear rate for FLE, FSE, DLE and DSE. Figure 2 shows the shear stress - shear rate relationship. The apparent viscosity versus temperature relationship is shown in Figure 3. Figures 4a and 4b show the linearized semi-log plots of consistency index versus the inverse of absolute temperature between 20-70 and 70-150°C, respectively. The results of activation energies between 20-70 and 70 150°C are presented in Tables 4 and 5, respectively.

DISCUSSION

The values of consistency (K) and flow behaviour (n) indices for the four samples (FLE, DLE, FSE and DSE) obtained from log – log plot of μ_a versus g show that n was consistently less than one (n<1) indicating pseudo-plasticity. This is consistent with other fluid food such as tomato paste (Alakali and Ijabo, 2003), palm oil

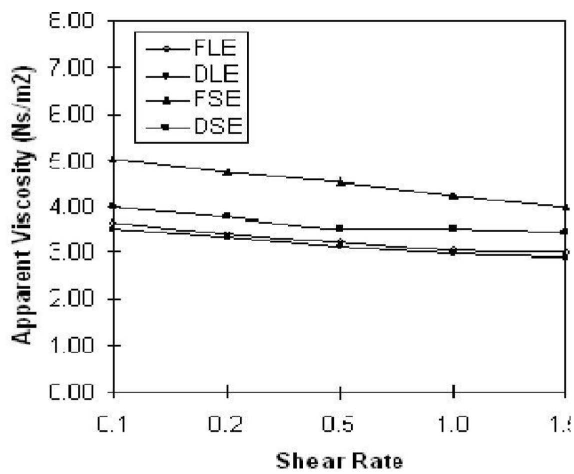

Figure 1. Apparent viscosity versus shear rate at 60°C.

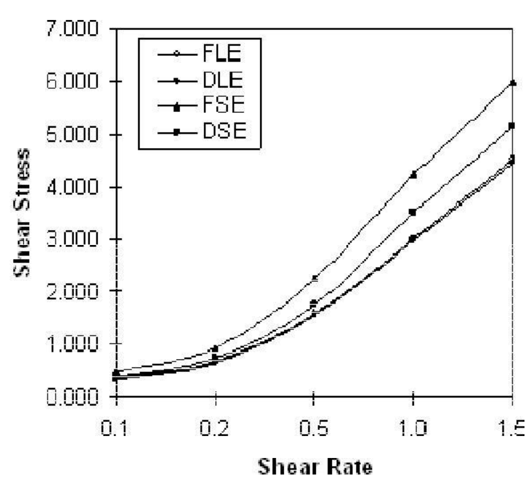

Figure 2. Shear stress versus shear rate at 60°C.

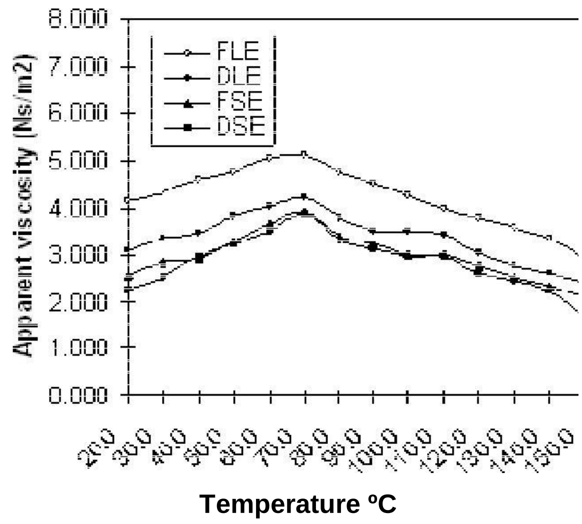

Figure 3. Apparent viscosity versus temperature.

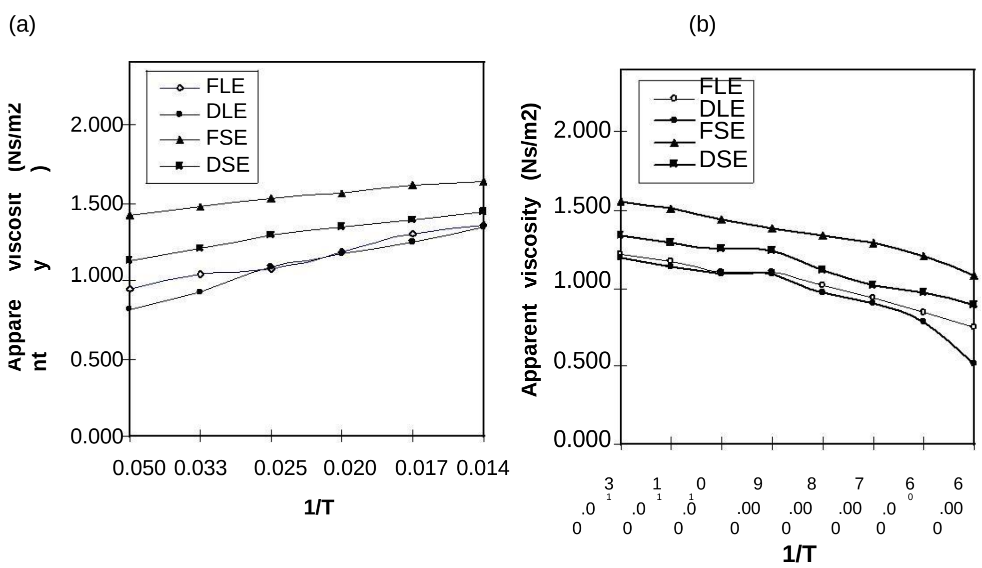

Figure 4. Plot of apparent viscosity (ln k) versus inverse of absolute temperature (1/T) (a) up to the boiling point (20-70^{0}C) and (b) above the boiling point (70-150^{0}C).

(Satimehin et al., 2003), Kunu Zaki and Kunu Gyada (Sapode and Kassum, 1993). The analysis of variance (Table 2) indicates highly significant (p< 0.5) *C. populnea* sample and temperature effect on consistency index (K) while flow behaviour index (n) is non-significant. Values of K increased with increase in temperature with very high positively correlated r values whereas values of n did not show any defined trend with increase in tempe-rature (Table 3).

The apparent viscosity of *C. populnea* exudates as indi-cated by consistency index (K) increased with increase in temperature between 20-60^{0}C (Table 1 and Figure 3). However, at temperatures beyond the boiling point of *C. populnea* (70-150^{0}C), the apparent viscosity decreased with increasing temperature (Figure 3). Usually, viscosity decreases with increase in temperature (Awonorin, 1993; Ariahu et al., 2001; Alakali et al., 2003). However, *C. populnea* exudate showed a reverse trend at tempera-tures below the boiling point (T $\leq$ 70 ^{0}C). This behavior is said to be due to its system of binding. These authors explained that before the boiling point of *C. populnea*, the elements are closely bound together such that the bonds are only totally broken after the boiling point (Iwe and Atta, 1992). Bourne (1982) observed that certain foods exhibit this characteristic.

The apparent viscosity of *C. populnea* decreased as shear rate increased (Figure 1). Similar trends were observed by Alakali and Ijabo (2003) for tomato pastes; Alakali et al. (2003) for canarium oil; Satimehin et al. (2003) for palm oil; Ariahu et al. (2001) for Tilapia fish homogenate; Awonorin (1993) for smoked sausage made from broiler chicken and Sopode and Kassum (1992) for

Kunu Zaki and Kunu Gyada. This behavior indicates shear thinning and is to be expected because an increase in rotational speed increases molecular alignment in the direction of flow, reducing resistance to flow and hence viscosity. This is typical of pseudoplastic fluids. This phenomenon has been widely reported to be common with hydrocolloid solutions and food pastes with sensitive structures (Awonorin, 1993). The shear stress-shear rate relationship (Figure 2) shows increase in shear rate as the shear stress increased. Comparing the shear stress-shear rate relationship with the classification chart by Moshenin (1986), it was further established that *C. populnea* is non-Newtonian pseudoplastic.

Exudates from fresh sample materials were observed to have higher values of consistency index than the dried samples. For example, the mean value of K for Fresh Stem Exudate (FSE) was 3.860 Ns/m^2 compared to 2.950 Ns/m^2 for Dried Stem Exudate (DSE). Similarly K for Fresh Leaves Exudate (FLE) was 2.650 Ns/m^2 compared to 2.460 Ns/m^2 for Dried Leaves Exudate (DLE). This result was expected as drying may have tampered with the binding properties of the gum and reduced its cohesiveness. The K values for FSE were significantly ($p \leq 0.05$) different from FLE. However, K values for DSE did not show significant ($p \geq 0.05$) difference with DLE.

Predictive models

The predictive equations based on the power law model (equation 2) for the four samples are as follows:

FSE: $\tau = 3.860\, g^{0.92}$ ($R^2 = 0.950$) (5)

DSE: $\tau = 2.950\, g^{0.93}$ ($R^2 = 0.970$) (6)

FLE: $\tau = 2.960\, g^{0.94}$ ($R^2 = 0.960$) (7)

DLE: $\tau = 2.450\, g^{0.93}$ ($R^2 = 0.950$) (8)

The high R^2 values indicate that the power law model is appropriate for describing the rheological characteristics of *C. populnea.* The suitability of equations 5 to 8 for predictive purposes was verified using the percentage root mean square of error (%RMS), which were found to be generally low (< 10%). According to Wang and Brennan (1991), low percentage of RMS values indicate good fit and suitability of a model for practical purpose. According to these authors, the smaller the percentage RMS, the better a model fits experimental data.

The relationship between temperature and viscosity of *C. populnea* was investigated using Arrhenius equation (Equation 3) for temperature range of 20 to 150°C. Linearized semi-log plots of consistency index against the inverse of absolute temperature (Figures 4a and b) gave straight lines which characteristically broke into two segments at the boiling point. The slope of each line segment gave the corresponding activation energy. The activation energies were determined between 20 - 70 and 70-150°C. It was observed that the activation energies of the exudates were low in the lower than the higher temperature ranges. At lower temperatures (below the boiling point), the gums were more viscous, hence more heat was needed to break intermolecular bond. The relative higher activation energies corresponding to the higher temperature range indicate that the lower viscosities above 70°C were more sensitive to heat.

Conclusions

Apparent viscosity decreased with increasing shear rate, indicating shear-thinning behavior. The flow behavior index did not show major change with temperature and its value was generally below one, hence *C. populnea* can be said to exhibit pseudoplastic behavior. Both apparent viscosity and consistency index of *C. populnea* were found to increase with increasing temperature below its boiling point. Above the boiling point, apparent viscosity decreased with increase in temperature. Activa-tion energies were found to be higher at temperatures above the boiling point ($T > 70^oC$).

REFERENCES

Alakali JS, Ijabo OJ (2003). Effect of processing method on the viscosity, PH and colour of tomato (*Lycoporsicum escusentum*) pastes. J. Sustainable Trop. Agric. Res. 5: 55-60.

Alakali JS, Ijabo OJ, Satimehin AA (2003). Rheological characteristics of canarium (*Canarium Schweinfurhii*) oil. J. Pure Appl. Sci. 6 (2): 298-303.

Ariahu CC, Risikat B, Tiamiyu OI (2001). Influence of soyflour and temperature on tilapia fish homogenate. Afr. J. Environ. Stud. 2:138-141.

Awonorin SO (1993). Rheological and mechanical properties of B-vitamin retention and sensory characteristics of sausage made from broiler chicken and guinea fowl. Lebensmittal-Wess-U-Techol. 20: 291-300.

Bourne ME (1982). Food texture ad viscosity concept and measurements. New York Academic Press pp. 199-219.

Chukwu A, Okpalalzima C (1989). Primary evaluation of *C. populnea* gum as a binder in Sodium Sachy late tablet formulation. Drug Dev. Ind. Pharm. 15(2): 325-330.

Iwe MO, Atta C (1993). Functional properties of the active ingredients of *C. populnea.* Crill. Perr. pp. 29-53.

Lewis MJ (1990). Properties of foods and food processing systems. 2nd ed. Chi Charter Eillies Horwood Ltd. pp. 108-1136.

Mohsenin N (1986). Physical properties of plants and animal materials Vol. 1 structure, physical characterization and mechanical properties. Science Publishers, West Port NY. pp. 899-900.

Rao MA, Anantheswaran RC (1982). Rheology of fluids in food processing. Food Technol. 37:116-126.

Sapode PA, Kassum AI (1992). Rheological characterization of Nigeria liquids and semi liquid foods. Kunu Zaki, and Kunu Gyada. Niger. Food J. 10: 23-33.

Satimehin AA, Akinemi OM, Ijabo OJ (2003). Rheological behavior of palm oil. J. Pure Applied Sci. 6 (2): 291 –297.

Steffe JF, Mohammed IO, Food EW (1983). Rheological properties of fluid foods. ASAE. 83: 781-783.

Wang A, Brennan JC (1991). Moisture sorption characteristic of potato at four temperatures. J. Food Eng. 14: 269-274.