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Research Article

Rheological Modeling and Characterization of *Ficus platyphylla* Gum Exudates

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Ficus platyphylla gum exudates (FP gum) have been analyzed for their physicochemical parameters and found to be ionic, mildly acidic, odourless, and yellowish brown in colour. The gum is soluble in water, sparingly soluble in ethanol, and insoluble in acetone and chloroform. The nitrogen (0.39%) and protein (2.44%) contents of the gum are relatively low. The concentrations of the cations were found to increase according to the following trend, Mn>Fe>Zn>Pb>Cu>Mg>Cd>Ca. Analysis of the FTIR spectrum of the gum revealed vibrations similar to those found in polysaccharides while the scanning electron micrograph indicated that the gum has irregular molecular shapes, arranged randomly. The intrinsic viscosity of FP gum estimated by extrapolating to zero concentrations in Huggins, Kraemer, Schulz-Blaschke, and Martin plots has an average value of 7 dL/g. From the plots of viscosity versus shear rate/speed of rotation and also that of shear stress versus shear rate, FP gum can be classified as a non-Newtonian gum with characteristics-plastic properties. Development of the Master_s curve for FP gum also indicated that the gum prefers to remain in a dilute domain ($C < C^*$), such that $\eta_{sp} \alpha C^{1.2}$. The apparent activation energy of flow for FP gum (calculated from Arrhenius-Frenkel-Eyring plot) was relatively low and indicated the presence of fewer inter- and intramolecular interactions.

1. Introduction

Plant gums are essential in the pharmaceutical and food industries for controlling drug release and in modifying the texture of food [1]. Gums are also used in the food primarily as thickeners and gelling agent due to their ability to alter the rheological properties of the solvent in which they are dissolved [2]. Some gums such as guar gum has a number of applications in the mining and mineral processing industry [3]. In the froth floatation of base metal and platinum group metal ores, guar gum is used as a depressant of naturally hydrophobic waste mineral such as tale. The role of the polysaccharide is to adsorbed on the talc surface, render it hydrophilic and prevent its floatation.

Several researches have been carried out on gelling and rheological properties of gums and data obtained from such researches have assisted food manufacturer and other industrialist in selecting the required gum or gums for a given purpose [2–12]. However, literature is scanty on characterization and rheological properties of FP gum. Therefore, the aim of the present study is to characterize and model gum exudates taken from the *Ficus platyphylla* tree. *Ficus platyphylla* commonly called flake rubber tree, red Kano rubber tree, and gutta-percha tree in English, "ogbagba" in Nupe, belongs to the family, Moraceae. *Ficus platyphylla* is a tall tree of about 18 meters in height and about 6 meter in diameter. The tree is initially epiphytic, with a widely spreading crown of open and wooded savanna and it is believed to have migrated from Senegal to Northern and Southern Nigeria. In view of its geographical location and the possibility of utilizing FP gum for industrial and other purposes, there is serious need to study the physiochemical and rheological behavior of FP gum.

2. Materials and Methods

2.1. Collection of Samples. Crude *FP* gum was obtained as dried exudates from their parent trees grown in Falgore

Crude Ficus *platyphylla* gum

(a)

Purified Ficus *platyphylla* gum

(b)

Figure 1: Crude and purified FP gum.

forest in Doguwa LGA of Kano State, Nigeria. The gum was collected from the plant species by tapping during the mid of July and in the day time.

2.2. Purification of the Gum. The procedure adapted for the purification of the gum was that of Femi-Oyewo et al. [13]. The crude sample of the gum was dried in an oven at 40°C for 2 hrs and grounded using a blender. It was hydrated twice using chloroform water (in a ration of 70 : 30 for water : chloroform) for five days with intermittent stirring to ensure complete dissolution of the gum and then strained through a 75 μm sieve to obtain particulate free slurry which was allowed to sediment. Chloroform is capable of interacting with water to form chloroform hydrate, which has an extensive hydration power. Thereafter, the gum was precipitated from the slurry using absolute ethanol, filtered and defatted with diethyl ether. The precipitate was redried at 40°C for 48 hours. The dried flakes were pulverized using a blender and stored in an air tight container. Figure 1 presents photographs of crude and purified samples of FP gum.

2.3. Physiochemical Analysis. In order to characterize the gums, it was subjected to the following physiochemical tests.

2.3.1. Determination of Percentage Yield of the Purified Gums. The dried, precipitated, and purified gum(s) obtained from the crude dried exudates were weighed and the percentage yields were expressed in percentage using the weight of the crude gum(s), as the denominator.

2.3.2. Determination of Water Sorption and Swelling Property. In order to determine the water sorption capacity of the gum, dried evaporating dishes were weighed and 2.0 g of each of the gum samples was weighed into the different dishes. The final weight of the dishes was noted and placed over water in desiccators. After 5 days, the dish was transferred to another desiccator over activated silica gel (desiccant) for another 5 days. The percentage sorption was calculated by difference in weight.

In order to study the swelling property of the gum, the sample (1.0 g) was placed in a 15 mL plastic centrifuge tube and the volume occupied was noted. Distilled water (10 mL) was added from a 100 mL measuring cylinder and stopper. The contents were shaken thoroughly for 2 minutes and further allowed to stand for 10 mins. Each sample was centrifuged at 1000 rpm for 10 minutes on a bench centrifuge. The supernatant was then decanted and the volume of sediment obtained was measured. The swelling index of the gum was calculated by dividing the volume occupy by the gum after hydration by the volume before hydration.

2.3.3. Determination of Solubility. The solubility of the gum was determined in cold and hot distilled water, acetone, chloroform, and ethanol. 1.0 g sample of the gum was added to 50 mL of each of the above mentioned solvents and left overnight. 25 mL of the clear supernatants were taken in small preweighted evaporating dishes and heated to dryness over a digital thermostatic water bath. The weights of the residue with reference to the volume of the solutions were determined using a digital top loading balance (Model.XP-3000) and expressed as the percentage solubility of the gums in the solvents.

2.3.4. Determination of Concentration of Metals. Concentrations of Mg, Ca, Mg, Mn, Fe, Cu, Cd, and Pb were determined using Perkin Elmer atomic absorption spectrophotometer. Calibration curve for each metal was prepared and the concentration of the metal was in the analyte was estimated by extrapolation.

2.3.5. Determination of Nitrogen and Protein Content. The nitrogen content of the gum was determined using the Kjedahl method and the protein content was estimated by multiplying the nitrogen content by a conversion factor of 6.25.

Table 1: Physicochemical and rheological properties of FP gum.

Parameters	*Ficus platyphylla*
Colour	Yellowish-brown
Odour	Odourless
Taste	Sweet
pH	5.70
Solubility %w/v in	
Cold water	3.80
Hot water	12.60
Acetone	0.00
Chloroform	0.00
Ethanol	0.01
Nitrogen (%)	0.39
Protein (%)	2.44
Percentage yield (%w/w)	52.00
Swelling capacity	98.00

Table 2: Cationic composition of FP.

Cation	Concentration
Mg (%w/w)	2.54
Ca (%w/w)	0.41
Zn (ppm)	23.80
Mn (ppm)	97.10
Fe (ppm)	29.80
Cu (ppm)	6.70
Cd (ppm)	1.79
Pb (ppm)	9.60

2.3.6. Determination of pH. This was done by shaking a 1% w/v dispersion of the sample in distilled and deionized water (pH = 6.98) for 5 minutes and the pH was determined using a precalibrated Oaklon pH meter (Model 1100).

2.4. Viscosity Measurements. The intrinsic viscosity of ALgum samples was determined in distilled water using a Cannon Ubbelohde capillary viscometer (Cannon Instruments, model I-71) which was immersed in a precision water bath maintained at 25°C. The apparent viscosity of the mucilage was measured using a digital Brookfield DV I prime viscometer while shear rate was measured using Schott Iberica, S.A 18549 rotational viscometer.

2.5. Scanning Electron Microscopy. The morphological features of the gums were studied with a JSM-5600 LV scanning electron microscope (SEM) of JEOL, Tokyo, Japan. The dried sample was mounted on a metal stub and sputtered with gold in order to make the sample conductive, and the images were taken at an accelerating voltage of 10 kV.

3. Results and Discussions

3.1. Physiochemical Properties. Table 1 presents the physiochemical properties of FP gum. The analyzed parameters included physical properties (colour, taste, odour, pH, and solubility ion water and other solvents) and chemical properties (nitrogen content and protein content). The results for cationic composition of the gum are presented in Table 2.

The colour of the gum was found to be yellowish brown. The gum is odourless but has a sweet taste which may be ascribed to its polysaccharide content. From the measured pH, it can be deduced that FP gum is mild acidic. The solubility of FP gum in water was found to increase with increasing temperature. The sparing solubility of the gum in ethanol and the nonsolubility in acetone and chloroform indicate that the gum is ionic. As a rule, ionic compounds are soluble in water and other solvent that have high-dielectric constant. The dielectric constant of ethanol is higher than that of chloroform and acetone, hence the preferential solubility of the gum in ethanol and not acetone or chloroform.

The purification yield for FP gum was 52.0%. According to Cunha et al. [14], purification yield of a given gum depends on the method of processing. This is because processing has the tendency of withdrawing some constituents of the gum. Literature is scanty on the nitrogen and protein contents of FP gum; however, values obtained from the present study are comparable to those reported for most food gums.

From Table 2, it can be seen that FP gums display a decreasing trend in concentrations of elements as follows. Mn > Fe > Zn > Pb > Cu > Mg > Cd > Ca. It is significant to note that elements such as Mn, Ca, Zn, Cu, Fe, and Mg are useful for the biochemical functions of living organism. However, Pb and Cd are toxic at certain concentration. However, concentrations of Pb and Cd obtained from this work are below the tolerance limit [15]. Figure 2 shows plot for the variation of water absorption properties. The figure reveals that the water absorption capacity increased progressively up to the fifth day of immersion (i.e., 100% RH over water) and dropped sharply within 24 hours when subjected to action of desiccant. By the fifth day in desiccant environment, water content of the gums had reduced considerably to between 1–4%. From the results obtained, it is indicative that if the gums are stored in a damp environment, the gums will quickly be hydrated and also have the tendency to rapidly loose such water molecules in the presence of desiccants (within five days). The observed results are consistent with the findings of Abdulsamad et al. [16] for cashew and acacia gums Generally, susceptibility to microbial and physicochemical deterioration as a result of high-moisture content may be some of the factors that can be associated with the water sorption potentials of the studied gums. Therefore, FP gum can better be preserved in an air-tight container.

3.2. Rheological Study. The viscosity of FP gum was found to increase with increasing pH (Figure 3) indicating that the emulsifying properties of the gum is pH dependent and that the gum is ionic [17]. Also the increase in viscosity of FP gum with increasing concentration (plot not shown) can be explained as follows. Viscosity of a liquid depends on the strength of attractive forces between molecules, which depend on their composition, size, and shape and also on the kinetic energy of the molecules, which depend on the temperature. Therefore, any factor that can affects

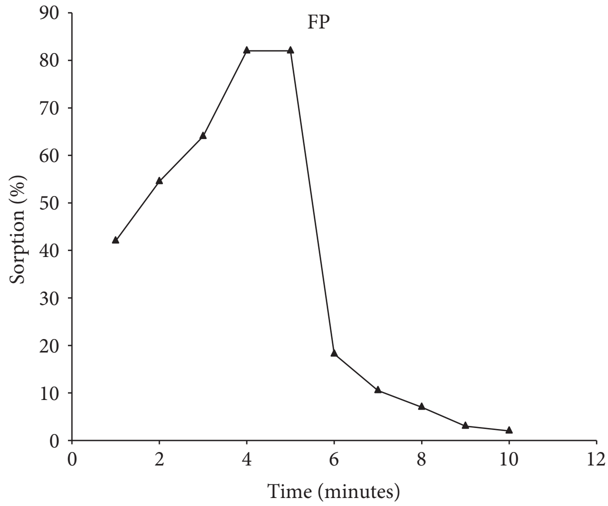

FIGURE 2: Variation of water sorption capacity of FP gum with time.

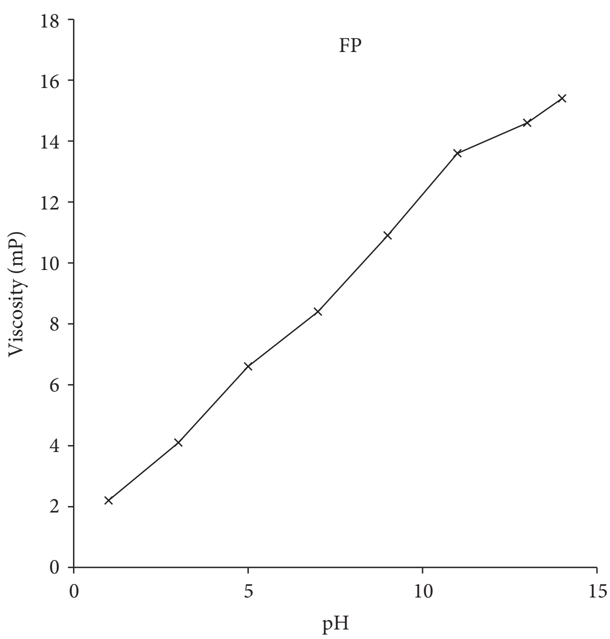

FIGURE 3: Variation of viscosity with pH for *Ficus platyphlla* (FP) gum.

composition, molecular shape and kinetic behavior will certainly affect viscosity. Increasing concentration implies increase in composition hence increase in viscosity.

3.2.1. Effect of Temperature on Viscosity. Viscosity measures the ease in which a molecule can move with respect to one another. Temperature can affect the kinetic motion of FP gum hence its viscosity. Factors that can be used to explain the expected trend for the variation of the viscosity of a fluid such as FP gum are (i) the energy needed to overcome the potential energy barrier (activation energy of flow) upon transition from one equilibrium to the next; (ii) degradation of polymer; (iii) conformational (ordered-disordered) transition. For similar reasons, the viscosity of FP gum exhibited an inverse proportionality relationship with temperature. No degradation was observed since the viscosity measured upon heating and cooling were the same [18]. The most appropriate model that best explains the dependence of viscosity of macromolecules on temperature is the Arrhenius-Frenkel-Eyring equation which can be written as follows [19]:

TABLE 3: Arrhenius parameters for FP gum.

C (g/L)	Slope	Intercept	E_a (J/mol)	R^2
2	1.408	0.542	26.96	0.817
5	9.502	0.455	181.94	0.825

$$\eta = A \exp\left(\frac{E_a}{RT}\right), \tag{1}$$

where A (Pas) is a constant, which is related to the degree of orderliness or disorderliness of the system, T is the temperature, and R is the gas constant. From the logarithm of (1), (2) was obtained as follows:

$$\log(\eta) = \log A + \left(\frac{E_a}{RT}\right). \tag{2}$$

From application of Arrhenius-Frenkel-Eyring equation, a linear dependence of $\log(\eta)$ with $1/T$ was observed for FP gum concentrations of 2 and 5 g/L indicating that there is no order-disorder transition [20]. From slopes of the plots (Figure 4), calculated values of E_a were 26.96 and 181.94 J/mol for 2 and 5 g/L, respectively (Table 3). The results indicate that the apparent activation energy of flow tend to increase with increasing concentration, hence the strength of intra- and intermolecular interactions involving hydrogen bonding and FP gum is expected to increase with increasing concentration. It has been established that E_a is affected by factors that determine the flexibility and interaction of macromolecules. The activation energy of flow is also dependent on the solute concentration [20].

3.2.2. Intrinsic Viscosity Measurements. With regard to solution and solvent viscosities of a macromolecules such as gum, the following relationships are significant,

$$\text{Relative viscosity}: \eta_{\text{rel}} = \frac{\eta_{\text{solution}}}{\eta_{\text{solvent}}} \tag{3}$$

$$\text{Specific viscosity}: \eta_{\text{sp}} = \eta_{\text{rel}} - 1. \tag{4}$$

$$\text{Intrinsic viscosity}: [\eta] = \lim_{C \to 0} \frac{\eta_{\text{sp}}}{C}. \tag{5}$$

Intrinsic viscosity is a measure of the hydrodynamic volume occupied by a macromolecule, which is closely related to the size and conformation of the macromolecular chain in a particular solvent [21]. $[\eta]$ can be obtained using a linear regression graphic double-extrapolation procedure (GDEP) which involves extrapolating the course of specific viscosity

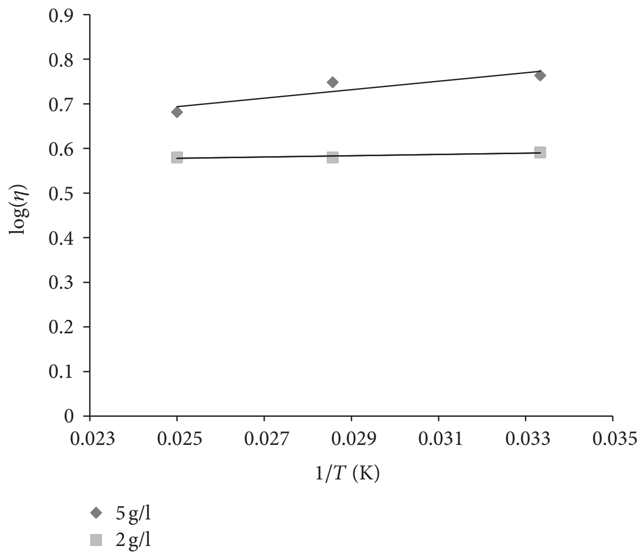

FIGURE 4: Arrhenius-Frenkel-Eyring plots for 2 and 5% concentrations of FP gum.

to infinite dilution. The intrinsic viscosity of a polymer, which can be determined experimentally, is a power series in concentration and can be written as follows,

$$\frac{\eta_{\text{spec}}}{C} = [\eta] \backslash + k_1[\eta]^2 C + k_2[\eta]^3 C^2 + k_3[\eta]^4 C^3 \cdots + K_n[\eta]^{n+1} C^n, \tag{6}$$

where $k_1, k_2, k_3, \ldots$ are dimensionless constants. Since η_{sp}/C is a reduced viscosity, which at $C \rightarrow 0$ becomes the intrinsic viscosity, the above power series is often truncated to a linear approximation known as the Huggins equation [22],

$$\eta_{\text{red}} = [\eta] + k_1[\eta]^2 C, \tag{7}$$

where k_1 is the Huggins constant, which is a dimensionless constant. Figure 5 shows Huggin plot for FP gum. Values of Huggins parameters deduced from the plot are presented in Table 4. The results revealed a high degree of linearity for the plot and calculated k' value was 0.84. According to Higiro et al. [23], k_1 value larger than unity indicates polymer-polymer aggregation hence there is an absence of polymer-polymer aggregation in FP gum.

The intrinsic viscosity can also be obtained from the Kraemer equation which can be expressed as follow [23],

$$\frac{\ln(\eta_{\text{rel}})}{C} = [\eta] + k_2[\eta]^2 C, \tag{8}$$

where k_2 is also a dimensionless constant called Kraemer constant. Kraemer plot and parameters for FP gum are also presented in Figure 5 and Table 4, respectively. Interestingly, the $[\eta]$ calculated from Huggins and Kraemer plots were approximately the same (i.e, $[\eta] \approx 7.0$) indicating agreement between the two models. However, calculated value of k_2 was lower than that of k_1. Two conditions are essential in considering the significant of Kraemer and Huggins constants, namely [24];

TABLE 4: Huggins, Kraemer, Schulz-Blaschke and Martin parameters.

	Slope	$[\eta]$	$[\eta]^2$	Constant	R^2
Huggins	40.03	6.89	47.40	0.845	0.9880
Kraemer	5.453	7.04	49.49	0.110	0.8518
Schulz-Blaschke	0.551	7.09	50.30	0.551	0.9580
Martin	4.683	7.00	48.91	1.945	0.9760

(i) the sum of k_1 and k_2 should be equal to $0.5 \pm 10\%$;

(ii) both lines must extrapolate to the same intercept at zero concentration.

From the results of our study, the sum of the constant ($k_1 + k_1 = 0.845 + 0.110 = 0.955$) is less than the critical value. Also Kraemer and Huggins plots (Figure 5) did not extrapolate to the same intercept at zero concentration. This suggests the interference of other effects (such as ionic strength, molecular aggregation, etc.) in the viscosity behavior of FP gum. In order to support and compare the results obtained from Huggins and Kraemer plots, values of intrinsic viscosity were also compared with those obtained from Schulz-Blaschke equation (9), Martin equation (10),

$$\frac{1}{\eta_{\text{red}}} = \frac{1}{[\eta]} - k_{\text{SB}} C, \tag{9}$$

$$\ln(\eta_{\text{red}}) = \ln[\eta] + k_{\text{M}}[\eta] C, \tag{10}$$

where k_{SB} and k_{M} are Schulz-Blaschke and Martin dimensionless constants. In Figure 5, we also present Schulz-Blaschke and Martin plots for FP gum while values of intrinsic viscosity and other parameters deduced from the plots are also presented in Table 4. From the results obtained, it can be seen that calculated values of $[\eta]$ are comparable to each other and are also comparable to those obtained from Huggins and Kraemer plots. High degree of linearity was obtained for all the plots. Therefore, the average value of $[\eta]$ for FP gum is 7.0.

3.2.3. Flow Behavior of FP Gum. Base on the relationship between viscosity and shear rate or shear stress, gums can be classified as Newtonian or non-Newtonian. The behaviour of Newtonian colloids can be highlighted as follows [25]:

(i) the only stress generated in simple shear flow is the shear stress σ, the two normal stress differences are zero;

(ii) the shear viscosity does not vary with shear rate;

(iii) the viscosity is constant with respect to the time of shearing and the stress in liquid falls to zero immediately the shearing is stopped;

(iv) the viscosities measured in different types of deformation are always in simple proportion to one another.

Non-Newtonian fluids are those that show deviation from the above listed features. The velocity gradient, *dv/dx*, is a

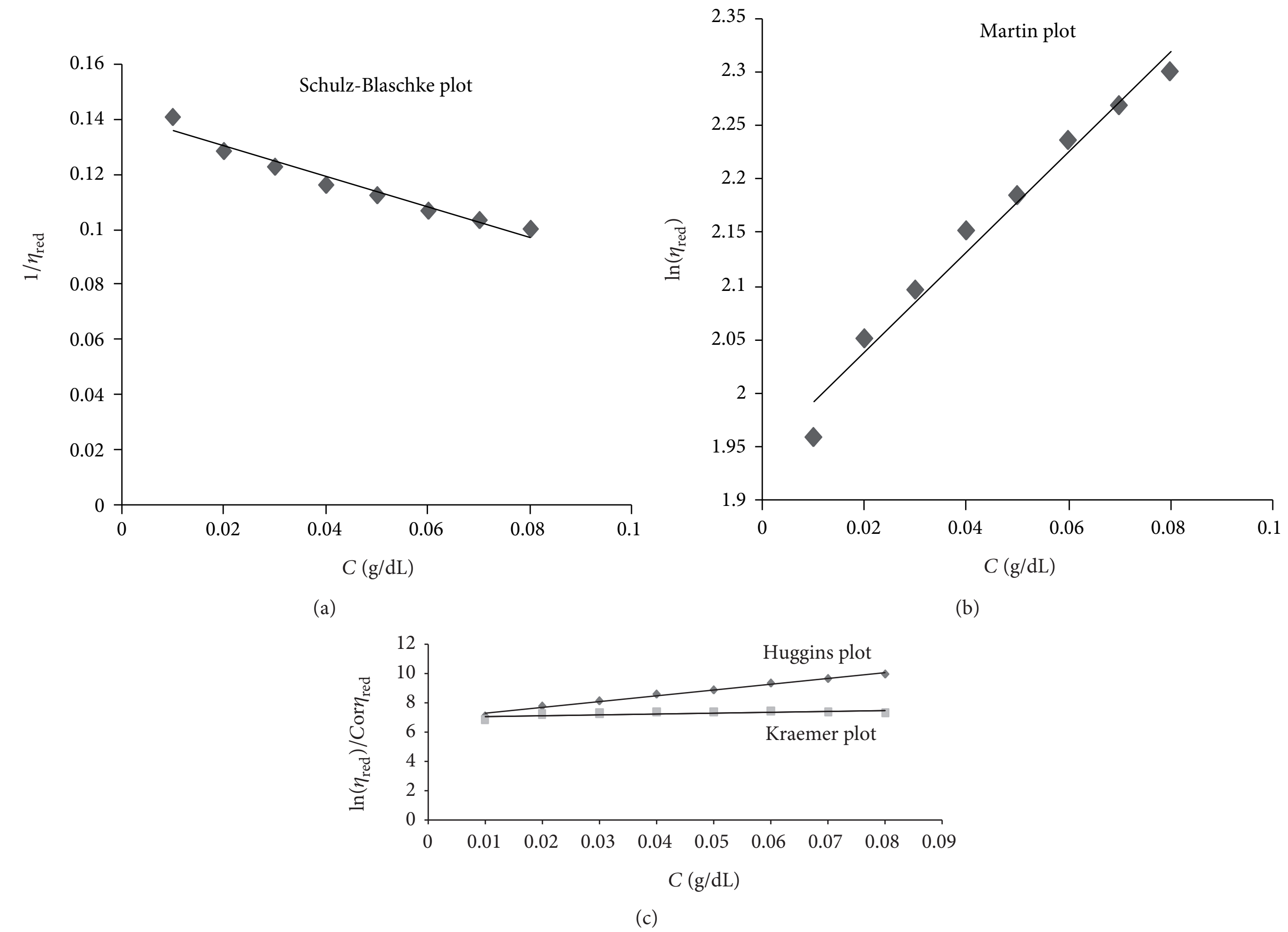

Figure 5: Huggins, Kraemer, Schulz-Blacschke, and Martin plots for FP gum.

measure of the speed at which the intermediate layers move with respect to each other. It describes the shearing the liquid experiences and is called shear rate (Υ). Shear stress is the force per unit area required to produce the shearing action. Therefore, viscosity can be defined as the ratio of shear stress to shear rate. In order to characterize FP gum as Newtonian or non-Newtonian fluid, several tests were employed. One of the methods for analyzing non-Newtonian flow involves the construction of a plot of viscosity versus spindle speed using same spindle. If such plots are linear, then the fluid is said to be non-Newtonian [25]. Figure 6(a) shows the variation of viscosity of FP gum with the speed of rotation ($R^2 > 0.8$). The plot indicated that FP gum is a non-Newtonian fluid. Also from the plots, the yield stress (i.e., the amount of force needed to be applied to the gum before it can flow) was estimated by extrapolating to zero rpm (Table 5). The results indicated that the yield stress (12.64 and 8.292 for 2 and 5% FP gum) for FP gum is concentration dependent. The power law index ($N = \tan(\theta)$) was also calculated through the angle the plot made with the y-axis (θ). It has been found that if θ is less than 45 degrees, the fluid is pseudoplastic but if greater than 45 degrees then it is dilatant. From the calculated values of θ for 2 and 5% concentrations, it is indicative that FP gum is a pseudoplastic fluid.

Table 5: Some flow parameters for FP gum.

C (g/L)	Slope	Yield stress	θ (°)	N	R^2
2	0.059	12.64	3.38	1.52	0.897
5	0.048	8.292	2.75	1.52	0.820

The fluid behavior of FP gum was also analyzed using the relationship between shear stress (σ) and shear rate (Υ), which can be expressed as follows,

$$\sigma = k\Upsilon^n, \tag{11}$$

where k is the consistency coefficient and n is the flow behavior index. Taking the logarithm of both sides of (11) yields (12)

$$\log(\sigma) = \log k + n \log \Upsilon. \tag{12}$$

From (12), a plot of $\log(\sigma)$ versus $\log \Upsilon$ should be linear with slope and intercept equal to n and $\log k$. Figure 6(b) show the variation of $\log(\sigma)$ with $\log \Upsilon$ for 2 and 5 g/L concentrations of FP gum. Values of k (2.86 and 1.81) and n ($0.255 \approx 0.3$ & $0.328 \approx 0.3$) deduced from the plots indicated that FP gum is a non Newtonian fluid. According to Chin et al. [26], for

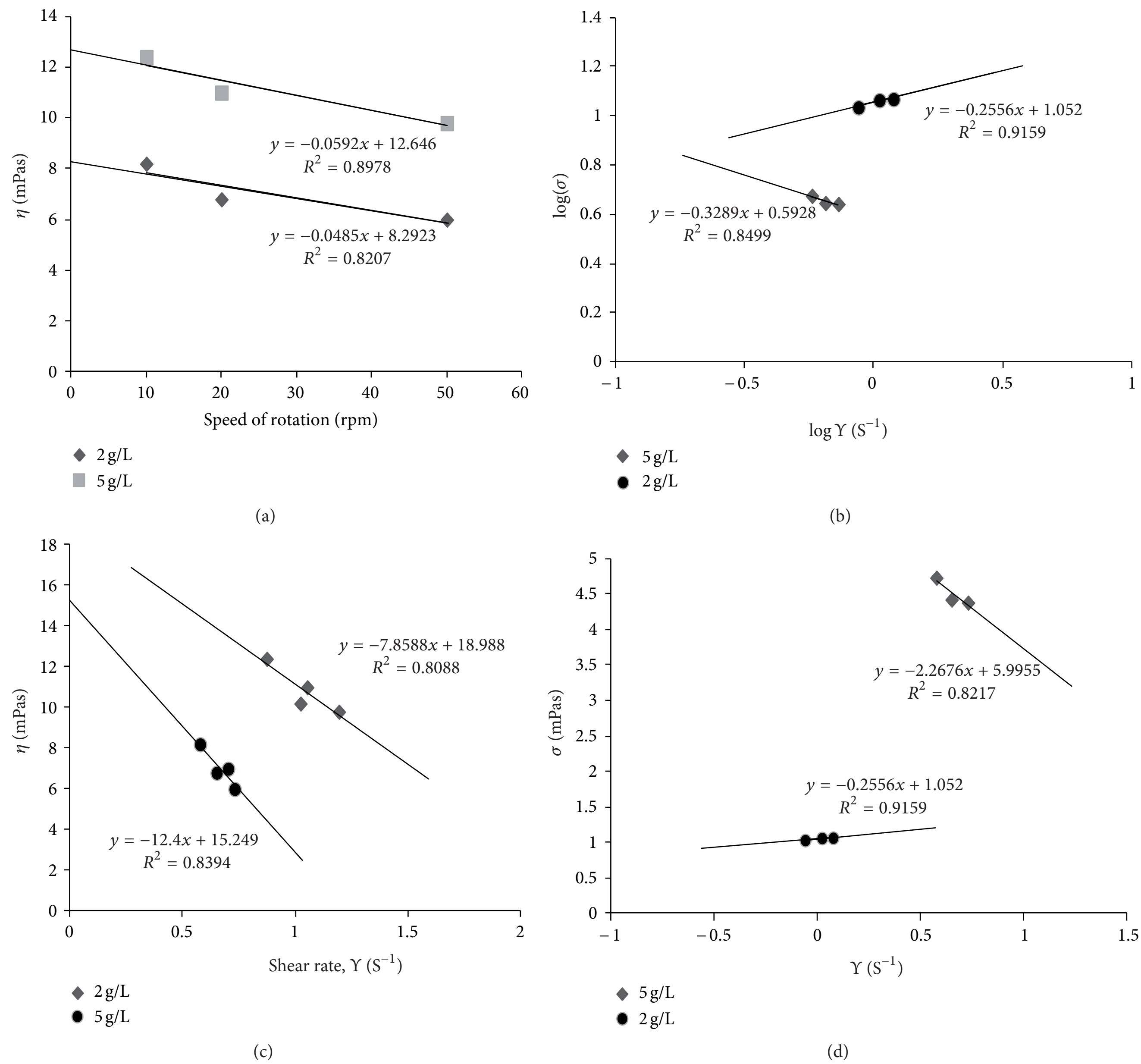

Figure 6: Variation of (a) viscosity with speed of rotation (b) log(shear stress), with log(shear rate), (c) viscosity with shear rate and (d) shear stress with shear rate for FP gum.

a non-Newtonian fluid, the apparent flow behavior index (n) is not equal to unity. Also plots of shear stress versus shear rate (Figure 6(d)) and viscosity versus shear rate (Figure 6(c)) were also developed. From the plots, it can be seen that FP gum display plastic behaviour.

The power law equation relating specific viscosity and concentration can be expressed as follows [23],

$$\eta_{\text{spec}} = aC^b. \tag{13}$$

Taking logarithm and rearranging (13), (14) is obtained

$$\ln\left(\eta_{\text{sp}}\right) = \log(a) + b\,\log C. \tag{14}$$

From (14), a plot of $\ln(\eta_{\text{sp}})$ versus $\log C$ should give a straight line with slope and intercept equal to "b" and "a", respectively. Figure 7 shows the power-law plots for FP gum. From the plot, it can be seen that the "b" value is 1.168 According to Lai et al. [27]; b value is an index that can be used to predict the conformation of a polymer. It has been found that b value greater than unity is associated with random coil conformation or entanglement, whereas b value less than unity is associated with rod like conformation [21]. Therefore, FP gum is more random coil like than rod like.

3.2.4. Coil Overlaps Parameter of FP Gum. In dilute solution, polymer coils are separated from each other and relatively

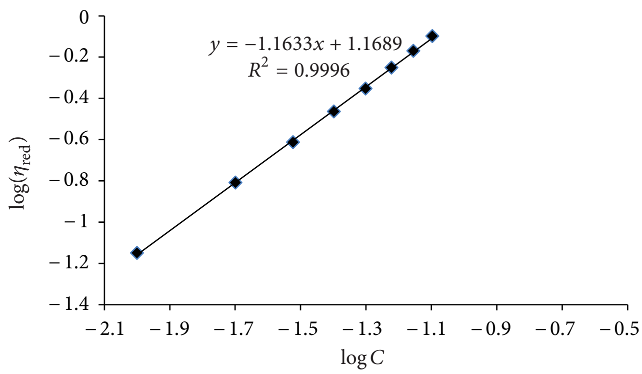

Figure 7: Variation of $\log(\eta_{sp})$ with log(concentration) for FP gum (the power law plot).

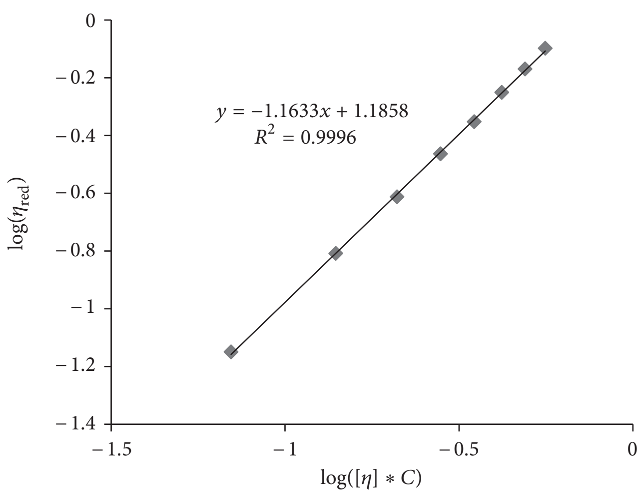

Figure 8: Double log plot for the variation of $\log(\eta_{sp})$ with $\log([\eta] * C)$ for FP gum (The master's curve).

free to move independently [28]. However, with increasing concentration, the coil may overlap and interpenetrate each other. The transition from dilute solutions to concentrated solutions is usually accompanied by a pronounced change in the concentration dependence of solution viscosity and the corresponding viscosity is called critical or coil overlap concentration (C^*). Morris et al. [29], found that for a random coil like, the slope of double logarithm plots of η_{sp} versus $C^*[\eta]$ was close to 1.4 in a dilute solution but increased to 3.3 in concentrated regime. These changes were characterized with a C^* transition at $C^*[\eta] \approx 4.0$ and $\eta_{sp} \approx 10$. Figure 8 shows a plot of $\log(\eta_{sp})$ versus the coil overlap parameter ($C^*[\eta]$) for FP gum (the master's curve). From the plot, it is evident that there was no change in slope of the double logarithm plot indicating that no molecular entanglements were obtained. The slope value (1.163, which approximate the value of 1.168 obtained for "b" value from the power law equation) is lower than the threshold value stated by Morris et al. [29], indicating that FP gum is in the dilute domain ($C < C^*$), hence the relationship between specific viscosity and concentration of FP gum is $\eta_{sp} \alpha C^{1.2}$.

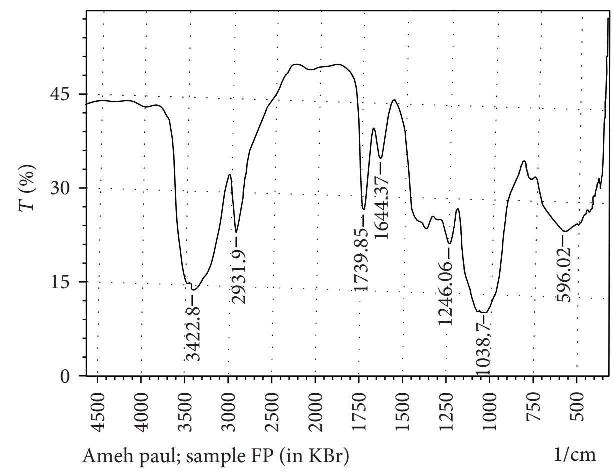

Figure 9: FTIR of FP gum.

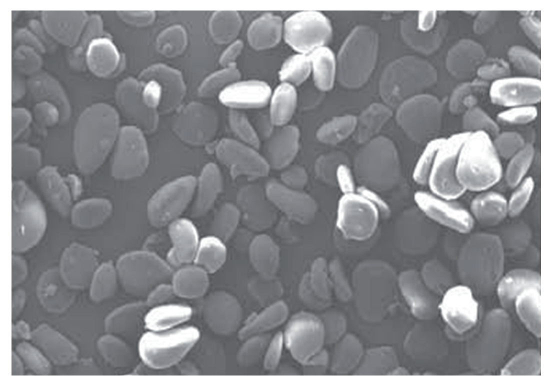

Figure 10: Scanning electron micrograph of *Ficus platyphylla* gum.

Our results compares favourable with those obtained for some food gums [29].

3.3. FTIR Absorption Bands in FP Gum. Figure 9 shows the FTIR spectrum of FP gum. The common features in the FTIR spectrum of the studied gum is the appearance of bands and peaks that are typical of polysaccharides. The 2800–3000 cm^{-1} wave number range is associated with the stretching modes of C–H bonds of methyl groups ($-CH_3$). The broad bands around 3400 cm^{-1} are consequence of the presence of –OH groups. However, in FP gum, this band is shifted to 3422.80 cm^{-1}. The shifts may be due to dissociating carboxylic acid. The 900–1200 cm^{-1} range represents various vibrations of C–O–C glycosidic and C–O–H bonds.

3.4. Surface Morphology of FP Gum. Figure 10 shows scanning electron micrograph of FP gum. The SEM was taken at 500 x magnification and 50 μm scale. SEM is a strong analytical instrument that can be used to study the morphology of polymers such as gums and from the Figures, it is evident that the moleculea FP gums are irregular, tiny granules and slightly elongated with rugged appearance. The micrograph is indicative of an amorphous material. The shape and structure or surface topography of the polysaccharide gums may be affected by the method of extraction and purification or preparation of the products.

4. Conclusions

From the results and findings of our study, the following conclusions are made

(i) FP gum is a mild acidic and ionic gum that may be useful in the food, pharmaceutical industries;

(ii) the viscosity of the gum increases with increase in concentration and with increasing pH but decreases with increasing temperature. Calculated value of the gum's intrinsic viscosity is 7.0 dL/g;

(iii) surface morphology of FP gum consists of irregular and amorphous shaped molecules. The gum is more of random coillike and there is an absence of molecular entanglement within the gum;

(iv) FP gum is in the dilute domain indicating that $C < C^*$, and $\eta_{sp} \alpha C^{1.2}$;

(v) FTIR spectrum of FP gum is closely related to those of polysaccharides;

(vi) FP gum is a non-Newtonian fluid with plastic behavior. Calculated apparent flow activation energy of FP gum is relatively low at low concentration and reflects fewer intra- and intermolecular interaction. However, these properties tend to increase with increasing concentration.

In view of the above, it can be stated that FP gum possesses properties that are closely related to gums whose industrial utilization has been ascertained. Therefore, FP gum has industrial potentials.

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