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ORIGINAL ARTICLE

Chrysophyllum albidum mucilage as a binding agent in paracetamol tablet formulations

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Abstract *Chrysophyllum* mucilage obtained from the fruit of *Chrysophyllum albidum* (Family Sapotaceae) has been characterised and evaluated as a binding agent in comparison with methylcellulose in paracetamol tablet formulations. *Chrysophyllum* mucilage was characterised using elemental and proximate analyses as well as material properties. The Heckel and Kawakita plots were used to assess the compressional properties and the tablet properties were evaluated using tensile strength, friability, disintegration and dissolution times. The results showed the presence of calcium, magnesium, potassium, sodium, manganese, iron, copper, zinc and absence of heavy metals from the mucilage. The mucilage exhibited excellent flow and swelling properties, but poor water solubility. The viscosity of *chrysophyllum* mucilage increased with decrease in temperature in a similar manner with methylcellulose. *C. albidum* mucilage when used as a binder in paracetamol tablet formulation induced faster onset of plastic deformation and higher amount of total plastic deformation than methylcellulose. The results of the tablet properties showed that the tensile strength, disintegration and dissolution times, increased with increase in binder concentration while friability decreased. Tablets containing c*hrysophyllum* mucilage as binder also had lower tensile strength, disintegration and dissolution times but higher friability values than those containing methylcellulose. However, tablets containing c*hrysophyllum* mucilage at low concentrations conformed to pharmacopeial standard on disintegration indicating its potential usefulness as binder for immediate release tablets. Thus, *C. albidum* mucilage could be used as an alternative binding agent in pharmaceutical tablets.

Keywords *Chrysophyllum albidum* mucilage · Methylcellulose · Binding property · Tablet compression · Release

Introduction

The quest for new excipients has led researchers to the continued search for excipients from materials obtained from local sources with the hope of finding better and cheaper alternatives. Among these excipients are binding agents, which may be added either dry or in wet form to improve the cohesiveness of powders and granules, ensuring the formation of intact tablets with acceptable mechanical strength (Odeku 2013). The quantity of binder used however, has considerable effect on the characteristics of the compressed tablets. Surplus binder could lead to excessive wear of punches and dies as well as production of hard tablets with slow disintegration rate while insufficient would produce tablets that are highly friable. The choice of binder is dependent on the binding force required to form granules and its subsequent compatibility with other ingredients in the formulation (Shailendra et al. 2012).

Chrysophyllum albidum G. Don (Family: Sapotaceae) known as African or white star apple and locally called Udara (Igbo) or Agbalumo (Yoruba) in Nigeria, is found in many Central, East and West African countries (Adepoju and Adeniji 2012). The fruit of *C. albidum* is a large berry containing 4–5 flattened seeds which are not eaten

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(Ugwu and Umeh 2015). The juice of the fruit is a milky pinkish emulsion consumed by a number of people while fleshy pulp of the fruit is eaten as snacks and relished by both young and old for its nutritional properties and the ability of the fruit to form a gum on chewing (Ige and Gbadamosi 2007). The fruit has been found to contain iron and the ascorbic acid content is 1000–3330 µg per 100 g of edible fruit, or about 100 times that of oranges and 10 times that of guava or cashew (Adepoju and Adeniji 2012).

Chrysophylum albidum was listed in an FAO report as one of the under-utilized plant species in Nigeria (FAO 1996). The leaves, bark and seed of the plant are used in ethno-medicine for skin eruptions, diarrhoea, stomach-ache; yellow fever, malaria; vaginal and dermatological infections (Okoli and Okere 2010). The ethanol extract of the leaves and stem has shown antimicrobial activity while the root bark has antifertility property (Kamba and Hassan 2011; Onyeka et al. 2012). The fleshy pulp of the fruit containing the juice when chewed turns to gum (similar to bubble gum) indicating the presence of a polymeric material, which could be potentially useful as an excipient in pharmaceutical formulations. Thus, in the present study *C. albidum* mucilage has been evaluated as a binding agent in paracetamol tablet formulations in comparison with methylcellulose.

Materials and methods

Materials

Paracetamol, corn starch, lactose and xylene were obtained from BDH (London, UK). Ethanol and diethyl ether were purchased from Sigma (St Louis, MO, USA). Methylcellulose was bought from Colorcon Co. (Kent, UK) and *C. albidum* from Ojoo (Ibadan, Nigeria). All other reagents were of analytical grade.

Extraction and purification of *Chrysophyllum albidum*

Fruits of *C. albidum* G. Don were purchased from Ojoo market in Ibadan Oyo state, South-West Nigeria and washed with distilled water. The fruit was cut and the juice squeezed out manually. The extraneous materials were removed by straining the juice through a muslin cloth. To the filtrate, absolute ethanol (96 % $^{v}/_{v}$) was added to precipitate the polymeric material. The precipitated mucilage was filtered, washed with diethyl ether, dried in a hot air oven (Laboratory oven TT-9083; Techmel and Techmel, TX, USA) at 40 °C, milled and sieved with 250 µm sieve (Bamiro et al. 2010).

Characterization of *Chrysophyllum albidum* mucilage

Physicochemical analysis of the Mucilage

Chrysophyllum albidum mucilage was analyzed for fourteen elements using Atomic Absorption Spectrophotometer (AAS, Model 2500 Torontech Inc., Toronto, ON, Canada) and proximate composition (crude protein, ash content, crude fiber, crude fat, dry matter and moisture contents) was determined using established procedures (AOAC 2000).

The particle size and size distribution were determined using a light microscope (Leitz Labourlux II, Wetzlar, Germany), while scanning electron microscope, SEM (Hitachi Model S, 2460N, Tokyo, Japan) was used to observe the morphology and surface characteristics of *Chrysophylum albidum* mucilage and methylcellulose particles.

Material properties

Viscosity analysis

The viscosities of aqueous dispersions (1 % $^{w}/_{v}$) of the polymers at varying temperatures were determined using a Brookfield viscometer (model RVVDV-II + P, Brookfield Eng Labs Inc., Middle Boro, MA, USA) at 100 rpm using spindle 2.

Determination of Swelling Index

Polymer (5 g) was transferred into a 100 mL measuring cylinder and the volume occupied noted (V_1). Distilled water (90 mL) was then added gradually with agitation for 5 min and then made up to 100 mL. The dispersion was allowed to stand for 24 h before the volume occupied on settling (V_2) was measured and swelling index calculated.

$$\text{Swelling index} = \frac{v_2}{v_1} \quad (1)$$

Solubility test

The solubility of the polymers was determined using hot (80 °C) and cold (room temperature, 30 °C) water. For hot water determination, the polymer (1 g) was weighed into a 100 mL conical flask (w) and 15 mL of distilled water was added and shaken for 5 min, then placed in a water bath and heated at 80 ± 2.5 °C for 1 h with constant stirring. For room temperature determination, the polymer was allowed to hydrate for 1 h after which it was thoroughly

mixed. The polymer was transferred into a pre-weighed centrifuge tube (w_1) and 7.5 mL of distilled water was added and centrifuged at 2200 rpm for 20 min. The supernatant was carefully decanted into a tarred dish (w_2) and dried at 100 °C to constant weight (w_3), then cooled in a desiccator. The solubility was calculated using Eq. (2)

$$\text{Solubility } (\%) = ((w_2 - w_3)/w) \times 100 \quad (2)$$

Density measurements

The particle density of *C. albidum* mucilage and methylcellulose was determined using helium pycnometer (AccuPyc 1330 Pycnometer, Micromeritic GmbH, Mönchengladbach, Germany).

The Bulk density at zero pressure was determined by pouring the powder at an angle of 45° through a funnel into a glass measuring cylinder with a diameter of 22 mm and volume of 50 mL (Akin-Ajani et al. 2014).

The tapped density was measured by applying 100 taps to mucilage powder in a measuring cylinder at a standardized rate of 38 taps per minute (British Standard 1460). The bulk and tapped densities were calculated as the ratio of weight to volume. Determinations were done in triplicates.

Flow properties

The Carr's index was calculated from the bulk and tapped densities using the formula:

$$\text{Carr's index} = (\rho\text{tapped} - \rho\text{bulk}/\rho\text{tapped}) \times 100 \quad (3)$$

while Hausner's ratio was obtained from the ratio of tapped density to bulk density.

The angle of repose was determined by pouring the polymer (30 g) through a funnel under the force of gravity to form a conical heap (Okunlola and Odeku 2009). The angle of repose was calculated using Eq. 4:

$$\text{Tan}\theta = \frac{h}{r} \quad (4)$$

where h is the height of powder and r is the radius of the base of the cone. A mean of three determinations were taken.

Preparation of granules for tableting

Batches (100 g) of paracetamol granules with a basic formulation of paracetamol (60 % w/w), corn starch (10 % w/w) and lactose (30 % w/w) were prepared by wet granulation. The powders were dry-mixed using a mixer (Type PRS, Erweka Apparatebau GMBH, Heusenstamm, Germany) for 10 min. Different concentrations (2, 3 and 4 % w/w) of binder was prepared by adding one-third of the required amount of boiling water to the weighed polymer, when it was thoroughly hydrated, the remainder of the water was added in the form of ice with stirring until homogenous (Colorcon 2009). The mucilage was incorporated into the powder-mix and massing continued for 5 min. The wet mass was granulated manually by passing through a no. 12 mesh sieve (1400 μm) and dried in a hot-air oven (Laboratory oven TT-9083, Techmel and Techmel, TX, USA) at 50 °C for 6 h. Dry screening was done through a No. 16 mesh sieve (1000 μm) before storing in an air-tight container.

Preparation of tablets

The granules (500 mg) were compressed into tablets using a single punch Carver hydraulic hand press (Model C, Carver Inc., Wisconsin, USA). Compression was done at different pressures for 30 s using a 10.5 mm die and flat faced punches lubricated with 1 % $^{w}/_{w}$ magnesium stearate in acetone. The tablets were then stored over silica gel for 24 h to allow for elastic recovery before measurements were taken to prevent falsely low yield values.

Compressional characteristics

The compressibility studies were done using the Heckel and Kawakita plots (Kawakita and Ludde 1970/71; Akin-Ajani et al. 2014). Values of relative density (ρ) of prepared tablets were calculated from the weights and dimensions determined to within ±1 mg and 0.01 mm, respectively, and the particle density of the solid material (Akin-Ajani et al. 2014).

Tablet properties

Tensile strength

The tensile strength of the tablets was computed using the equation (Okunlola and Odeku 2009):

$$\text{Tensile strength} = 2F/\pi dt \quad (5)$$

where F is the load (MN) required to cause fracture while d and t are tablet diameter (m) and thickness (m), respectively.

Drug release properties

The disintegration time of the tablets was determined in distilled water at 37 ± 0.5 °C using the Erweka disintegration test unit (Model: Copley ZT2, Erweka Apparatebau GMBH, Heusenstamm, Germany). All determinations were made in triplicates.

Tablet dissolution was carried out using the USP XXIII basket method in a dissolution test apparatus (DA-6D, Veego Scientific Devices, Mumbai, India). The basket was rotated at 100 rpm in 900 mL of 0.1 N HCl, maintained at a temperature of 37 ± 0.5 °C. Samples (5 mL) of the dissolution medium were removed from the glass vessel at specific time intervals and replaced simultaneously with an equal volume of fresh dissolution medium. The amount of paracetamol released was determined using a UV spectrophotometer at a wavelength of 243 nm. All measurements were made in triplicate.

Results and discussion

Physicochemical properties

Chrysophylum albidum mucilage was observed to be brown in colour, with a pleasant odor. The result of the elemental analysis of c*hrysophyllum* mucilage is presented in Table 1. The result showed the presence of calcium, magnesium, potassium, sodium, manganese, iron, copper and zinc, which are not harmful to the body, while heavy metals such as lead, cadmium, cobalt, chromium and nickel were absent. The high content of iron indicates the nutritional value of the mucilage, making it potentially useful as food or drug additive.

Table 1 Elemental constituents and proximate composition of *chrysophyllum* mucilage

Constituents	Composition (%)	
Elements	Calcium	0.35
	Magnesium	0.08
	Potassium	1.66
	Sodium	25.20
	Manganese	1.10
	Iron	26.42
	Copper	1.51
	Zinc	3.55
	Lead	0.00
	Cobalt	0.00
	Chromium	0.00
	Cadmium	0.00
	Nickel	0.00
Proximate	Crude protein	6.30
	Carbohydrate	90.60
	Fat	1.10
	Ash	2.00
	Moisture	9.88

The proximate composition of *chrysophyllum* mucilage is presented in Table 1. The result showed the presence of protein, carbohydrate and fat. The moisture content of *chrysophyllum* mucilage was 9.88 % $^{w}/_{w}$. Gums and mucilages absorb moisture from the air depending on the environment and physicochemical properties of the material. The Pharmacopoeial limit of moisture content of natural gums and mucilages has been set at ≤15.0 % $^{w}/_{w}$ (Odeku et al. 2013). Excess moisture in a material could lead to activation of enzymes and may encourage the growth of micro-organisms thereby causing deterioration in polymer quality (Williams and Phillips 2004; Odeku et al. 2013).

Material properties

The material properties of c*hrysophyllum* mucilage and methylcellulose are presented in Table 2 while the SEM is shown in Fig. 1. C*hrysophyllum* mucilage showed irregularly-shaped particles with a rough surface while methylcellulose showed smooth needle-like particles. The particle size and shape of a material have been shown to affect the density and powder flow (Fuentes-gonzÁlez and Villafuerte-robles 2014). The particle size of *chrysophyllum* mucilage was significantly higher ($p < 0.05$) than that of methylcellulose. Particle size reflects the change in surface area of a material and is a crucial factor in hydration mechanism. Materials with small particle size have higher surface area that ensures faster dissolution. It has also been reported that as the particle size of gums and mucilages increases, the dispersion becomes easier while hydration reduces (Muazu et al. 2014).

Table 2 Material properties of *chrysophyllum* mucilage and methylcellulose (Mean ± SD, n = 3)

Property	*Chysophyllum*	Methylcellulose
Particle size (μm)	74.20 ± 0.03	38.10 ± 0.02
Particle density (g/cm^3)	1.270 ± 0.270	1.321 ± 0.360
Bulk density (g/cm^3)	0.502 ± 0.004	0.247 ± 0.001
Tapped density (g/cm^3)	0.537 ± 0.003	0.358 ± 0.004
Carr's index (%)	6.82 ± 0.12	31.12 ± 0.25
Hausners ratio	1.07 ± 0.29	1.45 ± 0.02
Angle of repose (°)	29.60 ± 1.89	42.70 ± 1.35
Swelling index (%)	91.70 ± 2.09	365.70 ± 1.92
Solubility at 30 °C (% w/v)	27 ± 0.09	69 ± 0.11
Solubility at 80 °C (% w/v)	35 ± 0.05	11 ± 0.08

The results showed that methylcellulose had higher particle density than c*hrysophyllum* mucilage. Particle density affect compaction behavior of powders, as dense, hard materials may require higher compression pressure to produce cohesive but usually less friable tablets (Okunlola and Odeku 2009; Akin-Ajani et al. 2014).

The bulk and tapped densities gives an insight into the packing and arrangement of the particles and the compaction profile of the material (Okunlola and Odeku 2009). *Chrysophyllum* mucilage had higher values of both bulk and tapped densities than methylcellulose indicating greater ability in reduction of fill volume of the die.

The Carr's index of a powdered material gives an indication of the compressibility of the powder and it is a measure of the powder bridge strength and stability, while Hausner's ratio provides an indication of the degree of densification due to vibration of the feed hopper during tableting with high values predicting significant densification of powders while lower values suggest better flowability (Carr 1965; Hausner 1967; Akin-Ajani et al. 2014). Methylcellulose had higher Carr's index and Hausner ratio than c*hrysophyllum* mucilage suggesting that c*hrysophyllum* may possess excellent flow and compressibility properties (Table 2).

The angle of repose is a characteristic related to interparticulate friction or resistance to movement between particles. The angle of repose for c*hrysophyllum* mucilage was significantly lower ($p < 0.05$) than that of methylcellulose. The result indicates that c*hrysophyllum* mucilage exhibited better flow property than methylcellulose. Powder flowability has been found to depend on three general characteristics: the physical properties of the particle (i.e., shape, size, compressibility), the bulk powder properties (i.e., size distribution, compaction), and the processing environment (i.e., storage, humidity) (Okafor et al. 2001).

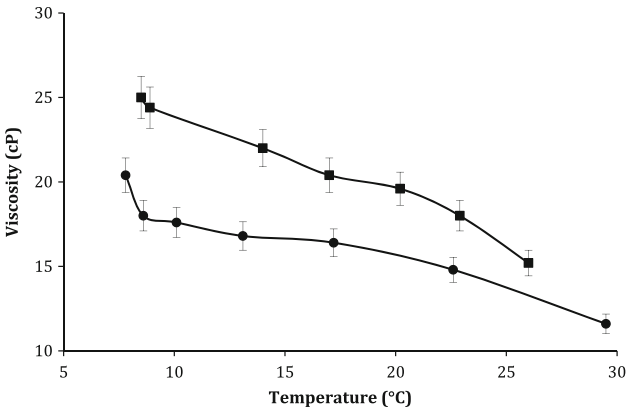

Fig. 2 Viscosity profile for 1 % $^{w}/_{w}$ polymer at different temperatures, *filled circle Chrysophyllum albidum* mucilage; *filled square* methylcellulose

The results showed that the swelling index of methylcellulose was significantly higher ($p < 0.05$) than that of c*hrysophyllum* mucilage. *Chrysophyllum* mucilage was more soluble in hot water than in cold water while methylcellulose was more soluble in cold water than in hot water. The viscosity profile of 1 % $^{w}/_{w}$ polymers at different temperatures is shown in Fig. 2. The polymers showed an increase in viscosity with decrease in temperature with methylcellulose showing significantly higher ($p < 0.05$) viscosity values.

Compressional properties

Representative Heckel plots for paracetamol formulations containing 3 % $^{w}/_{w}$ binding agents are shown in Fig. 3, while the parameters derived from the plots for the different formulations are presented in Table 3. The mean yield

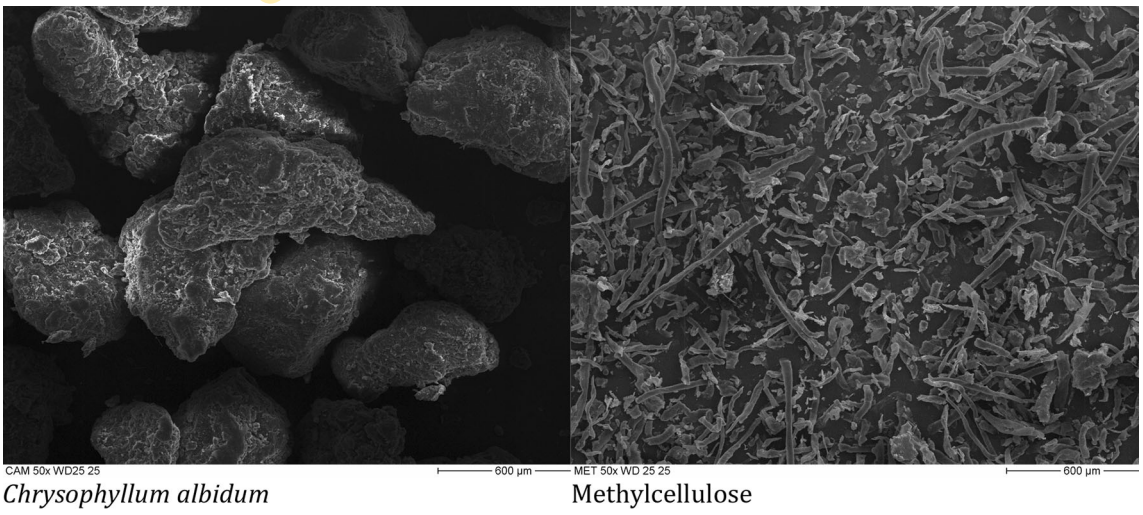

Fig. 1 SEM of *Chrysophyllum albidum* mucilage and methylcellulose (Mag. ×50)

pressure (P_y) for the paracetamol formulations were calculated from the slope of the Heckel plots with correlation coefficient > 0.961, and the intercept, A, was determined from the extrapolation of the linear region (Akin-Ajani et al. 2014). The linearity of the plots shows that the polymers deform mainly by plastic deformation.

The values of the relative density at zero pressure, ρ_0, which represents the degree of packing in the die as a result of die filling, increased with increase in the concentration of the binders. Formulations containing c*hrysophyllum* mucilage showed higher values than those containing methylcellulose, indicating a higher degree of packing in the die for formulations containing c*hrysophyllum* mucilage.

The relative density at low pressure, ρ_b, represents the phase of particle rearrangement in the early stages of compression (Dare et al. 2006). The values of ρ_b indicate the degree of fragmentation of particles or granules, although fragmentation can occur concurrently with plastic and elastic deformation of constituent particles (Akin-Ajani et al. 2014). The ρ_b values for the formulations containing c*hrysophyllum* mucilage were generally higher than those for the formulations containing methylcellulose. This indicates that c*hrysophyllum* mucilage facilitates better particle rearrangement.

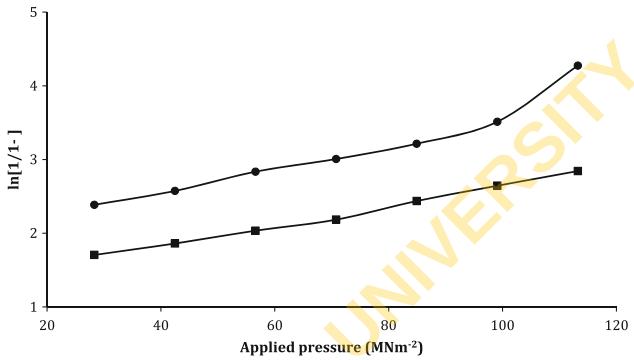

Fig. 3 Heckel plots for paracetamol formulations containing 3 % $^{w}/_{w}$ binder, *filled circle* c*hrysophyllum* mucilage; *filled square* methylcellulose

The values of the total relative precompression density, ρ_a, which represents the total degree of packing achieved at zero and low pressures, are higher for formulations containing c*hrysophyllum* mucilage than those containing methylcellulose. Thus, suggesting that c*hrysophyllum* mucilage exhibited greater total degree of packing.

The mean yield pressure, P_y, is inversely related to the ability of the formulations to deform plastically under pressure. The values of P_y for the formulations containing c*hrysophyllum* mucilage were significantly lower ($p < 0.05$) than those containing methylcellulose. This signifies that formulations containing c*hrysophyllum* mucilage exhibited faster onset of plastic deformation during compression than formulations containing methylcellulose and would deform more readily under pressure on a high speed tablet machine (Dare et al. 2006; Akin-Ajani et al. 2014). This in agreement with the results of Odeku and Patani (2005) obtained for mucilage extracted from the seed of dika nut used as binding agent in metronidazole tablet formulations.

Representative Kawakita plots for paracetamol formulations containing 3 % $^{w}/_{w}$ binder are presented in Fig. 4. A linear relationship was obtained at all compression pressures employed with the correlation coefficient of ≥0.999 for the formulations, while parameters from the plots are presented in Table 4. Values of 1—*a* gave the initial relative density of the formulation, ρ_i.

The values of ρ_i, which is a measure of the packed initial relative density of the formulation with the application of small pressure or tapping (Akin-Ajani et al. 2014), was found to increase with increase in binder concentration with formulations containing c*hrysophyllum* mucilage generally exhibiting higher values.

The P_k value, which is an inverse measure of the total amount of plastic deformation occurring during the compression process for formulations containing c*hrysophyllum* mucilage was lower than those containing methylcellulose. This implies that formulations containing c*hrysophyllum* mucilage exhibited a higher amount of total

Table 3 Parameters derived from Heckel and Kawakita plots for paracetamol tablets

Polymer	Concentration (% w/w)	Heckel				Kawakita	
		ρ_0	P_y	ρ_a	ρ_b	$\rho_i(1-a)$	P_k
	0.0	0.324	84.75	0.717	0.393	0.328	4.027
Chrysophyllum	2.0	0.328	48.08	0.856	0.528	0.321	1.600
	3.0	0.359	50.00	0.817	0.458	0.354	2.345
	4.0	0.535	35.46	0.859	0.324	0.417	1.682
Methylcellulose	2.0	0.317	78.12	0.834	0.517	0.320	1.808
	3.0	0.348	73.53	0.723	0.375	0.345	4.499
	4.0	0.407	113.64	0.747	0.340	0.421	5.816

plastic deformation during the compression process (Ayorinde and Itiola 2010).

Tablet properties

Mechanical properties

Tensile strength is a measure of the ability of the prepared tablets to withstand stress on handling without chipping or laminating especially during production (Okunlola and Odeku 2009). The results of the tensile strength of paracetamol tablets fit the general equation:

$$\text{Log T} = A\rho + B \quad (6)$$

with correlation coefficient >0.950, where ρ is the relative density of the tablets, A is the slope and B is a constant which depend on nature of polymer. Representative plot of log tensile strength versus relative density for formulations containing 3 % $^{w}/_{w}$ of binders are shown in Fig. 5 while values of tensile strength and friability at relative density of 0.90, which is representative of commercial tablets are presented in Table 4. Generally, there was an increase in tensile strength with increase in concentration of binder. The high compressional forces employed in tableting would force the binding agents into interparticulate spaces as a result of plastic deformation, thus resulting in increase in contact area between particles and formation of solid bonds leading to increase in tensile strength of the tablets (Akin-Ajani et al. 2014). The result showed that formulations containing methylcellulose which showed significantly higher ($p < 0.05$) viscosity than *chrysophyllum* mucilage also produced tablets with higher tensile strength. This is in agreement with previous studies where polymers with high viscosity have been shown to possess high adhesive strength yielding tablets with high tensile strength (Adenuga et al. 2008).

Friability is a measure of tablet weakness and the values of friability for the formulations are presented in Table 4. The results showed that the friability of the tablets generally decreased with increase in the concentration of binding agent with methylcellulose showing lower friability. This was probably due to stronger binding property exhibited by methylcellulose. All tablets met the official requirement of <1 % loss of tablet except tablets containing methylcellulose 2 % $^{w}/_{w}$ (BP 2012).

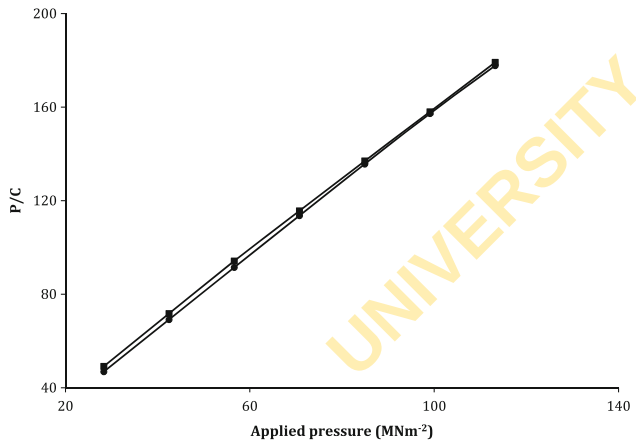

Fig. 4 Kawakita plots for paracetamol formulations containing 3 % $^{w}/_{w}$ binder, *filled circle* c*hrysophyllum* mucilage; *filled square* methylcellulose

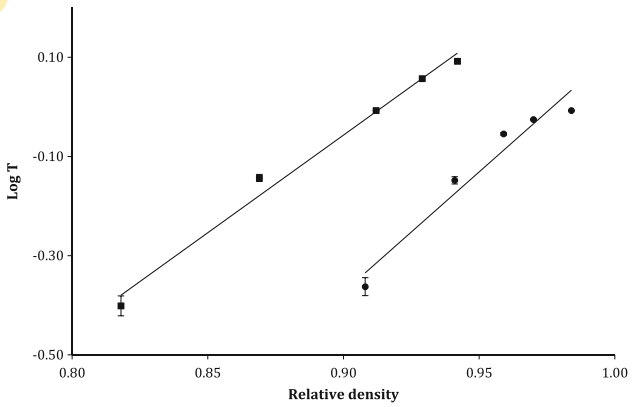

Fig. 5 Log tensile strength versus relative density for paracetamol tablets containing 3 % $^{w}/_{w}$ binder. *Filled circle* c*hrysophyllum* mucilage; *filled square* methylcellulose

Table 4 Mechanical and drug release properties of paracetamol tablets at relative density of 0.90

Polymer	Concentration (% w/w)	Tensile strength (MNm^{-2})	Friability (%)	D_T (min)	$t_{50\ (min)}$	$t_{80\ (min)}$	$t_{1\ (min)}$	k_1	k_2
–	0.0	0.475	2.00	0.99	4.7	7.3	5.8	0.141	0.543
Chrysophyllum	2.0	0.570	1.38	7.76	26	46	20	0.037	0.079
	3.0	0.711	1.30	12.11	28	48	30	0.024	0.085
	4.0	0.922	1.02	31.68	32	50	30	0.022	0.030
Methylcellulose	2.0	0. 917	1.15	8.53	32	52	40	0.013	0.128
	3.0	0.983	0.92	22.15	38	52	40	0.026	0.069
	4.0	0.922	0.89	40.10	45	54	40	0.018	0.021

Drug release properties

Representative plots of disintegration time (D_T) versus relative density for paracetamol tablets containing 3 % $^{w}/_{w}$ of the binding agents are shown in Fig. 6, while the disintegration time at relative density of 0.90 is presented in Table 4. The disintegration time of the tablets generally increased with increase in relative density and binder concentration. As relative density increases, more solid bonds occur between the particles forcing the binding agent into interpaticular spaces leading to formation of additional solid bonds leading to a reduction in the size of the capillary spaces between the particles, which reduced the rate of the penetration of water into the tablet to effect bond separation (Adenuga et al. 2008). Tablets containing *chrysophyllum* mucilage showed significantly lower ($p < 0.05$) disintegration time. In addition, tablets containing 2 and 3 % $^{w}/_{w}$ *chrysophyllum* mucilage conformed to the Pharmacopoeial standard for disintegration of uncoated tablets (≤15 min) while tablets containing methylcellulose did not conform to the pharmacopoeial requirements especially at high concentration (BP 2012).

Representative drug release profiles for tablets containing 3 % $^{w}/_{w}$ binding agent are presented in Fig. 7. From the plots, the values of t_{50} and t_{80} (the time required for 50 and 80 % of the paracetamol to be released) were determined and the values are presented in Table 4. The dissolution times (t_{50} and t_{80}) increased with increase in the concentration of the binding agent with tablets containing *chrysophyllum* mucilage exhibiting lower dissolution times than methylcellulose.

The integrated form of Noyes–Whitney equation shown in Eq. 7 was used to further characterize the dissolution rates of the formulations (Noyes and Whitney 1897; Adenuga et al. 2008).

$$In(Cs/(Cs - C) = kt) \quad (7)$$

where C_s is the concentration of the solute at saturation, C is the concentration at time t, and k is a dissolution rate constant. Values of $\ln(C_s/(C_s - C))$ were plotted versus t and representative plots for 3 % $^{w}/_{w}$ binder are shown in Fig. 8. Tablets containing both polymers presented two straight regression lines with slopes k_1 and k_2. The time at which the lines intersect is denoted by t_1 and the results are also presented in Table 4. The result showed that values of D_T, t_{50}, t_{80} and t_1 generally increased with increase in binder concentration while values of k_1 and k_2 generally decreased. The values of k_1 were less than k_2 implying faster drug dissolution rate after t_1. It has been shown that the change in dissolution rate from k_1 to k_2 at time t_1 is due to a change in the surface area created by tablet break up into fragments (Kitazawa et al. 1975; Itiola and Pilpel 1986). The values of t_1 were generally higher than D_T at low binder concentration which could be attributed to the greater agitation

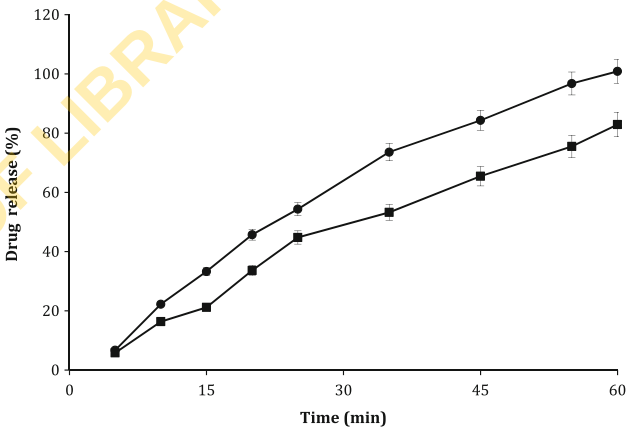

Fig. 7 The amount of paracetamol released (%) versus time for tablets containing 3 % $^{w}/_{w}$ binder. *Filled circle chrysophyllum* mucilage; *filled square* methylcellulose

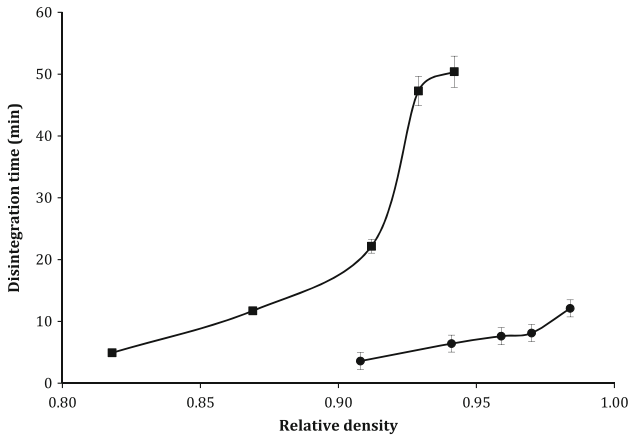

Fig. 6 Disintegration time (min) versus relative density for paracetamol tablets containing 3 % $^{w}/_{w}$ binder. *Filled circle chrysophyllum* mucilage; *filled square* methylcellulose

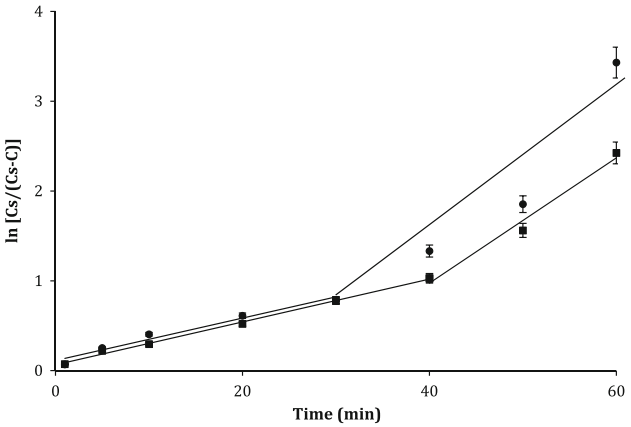

Fig. 8 ln[Cs/(Cs − C)] versus time plots to determine dissolution rate constants for paracetamol tablets containing 3 % $^{w}/_{w}$ of binder. *Filled circle Chrysophyllum albidum*; *filled square* methylcellulose

employed during disintegration test in comparison to dissolution test (Adenuga et al. 2008). On the other hand, at higher binder concentration (4 % $^{w}/_{w}$) $t_1 \approx D_T$ probably because polymers such as methylcellulose used as binders have been shown to also act as disintegrant or disintegrant activator to control the rate of drug release from tablets (Itiola and Pilpel 1986). Thus, *C. albidum* mucilage appeared to possess properties similar to methylcellulose when used as a binder in tablet formulations.

Conclusion

The results of the present study show that *C. albidum* mucilage is a hydrophilic polymer, free of heavy metals with similar swelling and viscosity properties to methylcellulose. When used as a binding agent in tablet formulation, *chrysophyllum* mucilage induces faster onset of plastic deformation and higher amount of total plastic deformation but produced tablets with lower tensile strength and faster drug release properties than methylcellulose. Thus, *C. albidum* mucilage could be used as binding agent in pharmaceutical tablets.

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