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# Compaction and Mechanical Properties of Cissus Populnea Gum

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ABSTRACT

The aim of this study was to evaluate the compaction characteristics of cissus gum extracted with two different solvents (acetone and water) as binder in direct compression tablet formulations in comparison with xanthan and sodium carboxymethylcellulose (SCMC). 400 mg of each of the adhesives was compressed into a compact on a hydraulic single press hand machine at six different compression pressures with a dwell time of 30 seconds. Direct compression method was employed in compact preparation. The compaction characteristics of the gums were evaluated using Heckel and Kawakita equations. Crushing strength and friability were used to assess mechanical properties. Data were analysed using GraphPad Prism 5 software. Cissus and xanthan gums had a quicker onset of plastic deformation and exhibited higher degree of plastic deformation compared with sodium carboxymethylcellulose. Xanthan gum compact had higher crushing strength than cissus gum and SCMC ($p < 0.05$). Also, water extract of cissus gum (CW) compact had higher crushing strength than acetone extract of cissus gum (CA) compact ($p < 0.05$).
Cissus gum formed a cohesive compact with a fast onset of plastic deformation and a high amount of plastic deformation which compares well with xanthan gum. It could therefore be used as binder in tablet formulations.

***Keywords:*** Cissus gum, xanthan, mechanical properties, compaction.

## Introduction

The term compaction, as applicable to a pharmaceutical powder, is an essential step in tablet manufacturing and it encompasses the simultaneous processes of compression (volume reduction and particle rearrangement), and consolidation (interparticulate bond formation) of a two-phase (particulate solid-gas) system due to an applied force.[1,2] This applied force tends to a finite change in the geometry of the powder depending upon the nature of the applied force. This change is called deformation.
During compression, the stress applied to bulk solid pharmaceutical formulation gives rise to a change in bed density, progressively constraining it to a diminishing volume, ultimately reaching that of the completed tablet if the bonds formed are strong enough to resist the forces generated by elastic recovery.[3,4]
Compaction of powders is generally used to describe the situation in which these materials are subjected to some level of mechanical force. The effects of such forces are of immense importance in the manufacture of tablets. Data obtained from the measurements of forces on the punches and the displacement of the upper and lower punches and other miscellaneous parameters have been used to assess the compaction behavior of a variety of pharmaceutical powders and formulations. Several mathematical descriptions of the compaction process have been compiled in the literature and these include those of Heckel, Kawakita and Ludde, and Adams, have been validated for pharmaceutical systems.

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Compression is a process of reduction in the bulk volume of material as a result of displacement of the gaseous phase as the applied force is increased. The compression of powdered material into a cohesive mass is a complex and irreversible dynamic process, in contrast to its apparent simplicity.[5]
The onset of loading is usually accompanied by closer repacking of the powder particles, and in most cases, this is the main mechanism of initial volume reduction. As the load increases, re-arrangement becomes more difficult and further compression involves in some type of particle deformation. The end of compressional process may be recognized as being the point at which all air spaces have been eliminated and porosity equals zero.
Consolidation is an increase in the mechanical strength of a material as a result of particle/particle interaction [2]. All of the deformation effects may be accompanied by the breaking and formation of new bonds between particles,[6] which gives rise to consolidation as the new surfaces are pressed together. These bonds however never act independently.[7]
The mechanisms by which powders consolidate are mainly cold welding and fusion bonding.
However, other mechanism may be involved such as attraction forces, mechanical interlocking and asperitic melting [7].
The Heckel equation is the most commonly used equation for relating the relative density, D, of a powder bed during compression to the applied pressure, P.[8] It is based on the assumption that increase in tablet density obeys a first-order kinetics type of reaction with applied pressure, with the interparticulate pores as the reactant and the densification of the powder bed as the product (Heckel). The Heckel equation is expressed as:

$$In\ (1/1\text{-}D) = KP + A \quad (1)$$

The measure of the plasticity of a compressed material, $P_y$, is obtained from the slope of the linear portion of the curve, K, and is the reciprocal of the mean yield pressure. A is a function of the initial compact volume and is related to the densification during die filling and particle re-arrangement before deformation and bonding of the discrete particles.[9]

Hence the mechanism of bonding in a powder compact can be elucidated using a Heckel plot.
The relative density, $D_A$, which represents the total degree of densification,[10,11] can be calculated from the value of A, using the equation:

$$D_A = 1\text{-}e^{-A} \quad (2)$$

$D_O$ is the relative density of the powder bed at the point where the applied pressure equals zero and is used to describe the initial re-arrangement phase of densification as a result of die filling. The value is obtained from the ratio of loose density to the particle density.
The relative density $D_B$, describes, the phase of re-arrangement of particles during the initial stages of compression. The extent of re-arrangement phase depends on the theoretical point of densification at which deformation of particles begin. $D_B$ is obtained from the difference between $D_A$ and $D_B$ i.e,

$$D_B = D_A - D_O \quad (3)$$

The Kawakita equation describes the relationship between the degree of volume reduction of powders and applied pressure during compression.[12] It is expressed as:

$$C = (V_0 - V_p)/V_0 = abP/(1+bP) \quad (4)$$

Where C is the degree of volume reduction of a powder compact at pressure *P*, $V_0$ is the initial bulk volume of the powder bed and Vp is the bulk volume after compression. The equation is usually written in the form.

$$P/C = P/a + 1/ab \quad (5)$$

The constants *a* and *b* can be evaluated from a plot of P/C versus P. The *a* value is indicative of the total volume reduction for the powder bed i.e. porosity of the powder bed before compression while *b* is a constant that is inversely related to the yield strength ($P_k$) of the particles i.e. plasticity of the material. The Kawakita and Heckel equations have been used together in recent times.[13,14]
Cissus gum is a natural, nonionic polysaccharide derived from the incised stem of the plant *Cissus polpunea Guill. & Perr.* (Vitaceae). The plant is a tall woody climber and it is widely found in savannah regions of northern Nigeria and in some part of Western Nigeria especially in Oyo, Ondo and Ogun States.
In this work the compaction properties of Cissus gum extracted with two different solvents were analyzed using density measurement, Heckel and Kawakita plots while mechanical properties were analysed using crushing strength and friability compared with xanthan, a natural gum, and sodium carboxymethyl cellulose, a semi-synthetic gum.

## Materials and Methods

*Materials*
The materials used in the investigation were Cissus gum obtained from the stem of *Cissus polpunea Guill. & Perr.* (Vitaceae), Xanthan gum (Jungbenzlauer Ges.M.B.H. Handelsgericht Wien, Germany), Sodium carboxymethylcellulose (S D. Fine Chemicals, Mumbai, India). All other solvents and chemicals used were of analytical-reagent grade.

*Extraction of cissus gum*
Fresh stem of *Cissus populnea* was fetched from a wild forest in Eruwa, Oyo State of Nigeria and authenticated with voucher specimen No. F.H.I: 10878 at the Forest Research Institute of Nigeria, Ibadan, Nigeria. The stem was subjected to extraction processes with two different solvents (acetone and water) to obtain the gum as previously described by Adeleye *et al.*[15] The gum was extracted by macerating 1 kg of sliced stem of *Cissus polpunea* in distilled water for 24 h, followed by filtration of the viscous solution with a muslin bag. Water extracted cissus gum (CW) was obtained by drying the viscous solution at 80ºC for 24 h while acetone extracted cissus gum (CA) was obtained by precipitating the viscous solution with acetone and drying at 50ºC for 24 h.

*Gum properties*
*Mean particle diameter*
The particle size distribution of the Cissus gum was determined by sieve analysis using standard sieves arranged in descending order of aperture sizes in the following order; 1.0 mm, 0.710 mm, 0.500 mm, 0.355 mm, 0.250 mm and the collection pan (receiver).
A 20-g quantity of each of the Cissus gum and other polymers were separately poured on the uppermost sieve and the cover was placed firmly in position and the stack of sieves shaken manually on a sieve shaker for 10 mins. The weight of material retained on each sieve (oversize) was determined using a mettler AB54 electronic balance (Mettler, A.G., Switzerland). The geometric particle diameter and the geometric standard deviations were determined statistically. The mean particle diameter was obtained from the particle size distribution analysis according to the method adopted by Oyi *et al.*[16]

*Particle density*
The particle densities of the cissus gum and other polymers were determined by the pycnometer method using liquid immersion technique with xylene as the displacement liquid. A 50-mL pycnometer bottle was weighed when empty (W). This was filled with xylene to the brim till it overflowed and the excess was wiped off. The weight was noted as ($W_1$). The difference between this weight and the first was recorded as ($W_2$). A 2-g quantity of the cissus gum was weighed ($W_3$) and quantitatively transferred into the pycnometer bottle. The excess solvent was wiped off and the bottle weighed again ($W_4$). The particle density, $P_t$, was calculated from the following Equation (6) according to Phani-Kumar *et al.*[17]:

$$P_t = W2\ W_3/50\ (W_3 - W_4 + W_2 + W) \quad (6)$$

*Bulk and tapped densities*
The bulk density of each of the gums at zero pressure (loose bulk density) was determined by modified method of Oyi *et al.*[16]
The bulk density of each of the cissus gum at zero pressure (loose density), $\rho_o$, was determined by sieving twenty-five (25) gram of each of the cissus gum through a 1,000 μm mesh screen to break up agglomerates which had formed during storage. This was then poured at an angle of $45^0$ through a funnel into a 100ml glass measuring cylinder and the sample leveled carefully (without compacting) in the cylinder [18]. The unsettled apparent volume was determined from the height (h) of the powder bed and the internal radius, r, of the cylinder using equation (7):

$$V = \pi r^2 h \quad (7)$$

The bulk density was calculated using the following equation:

$$\rho_o = m/v \quad (8)$$

Where m is the weight of sample in the cylinder in grams and v is the bulk volume ($cm^3$). This was carried out in triplicate and the final bulk density was the mean determination of the three values. The loose density was obtained in $g/cm^3$.
Tapped density was determined by subjecting 25g of Cissus gum to 100 taps in a graduated cylinder at a standardized rate of 38 taps per minute [19]. The test was also repeated for other polymers

*Preparation of polymer compacts*
A 400 mg sample of each of the gums was compressed with a dwell time of 30 seconds into tablet with pre-determined loads between 28.31 and 198.15 $MNm^{-2}$ on a Carver hydraulic press (Model C, Carver Inc., Menomonee Falls, WI) using a 10 mm die and flat-faced punches lubricated with a 1% dispersion of magnesium stearate in 96% ethanol before each compression. After ejection, the tablets were stored over silica gel for 24 h to allow for elastic recovery and hardening. The tablet weight and dimension were determined within $\pm$1 mg and $\pm$ 0.01 mm respectively. Determinations were made in triplicate for each batch of the tablet tested and the mean determined.
The volume of compacts was calculated using the equation 7 above.
Relative densities (D) were calculated using the equation.

$$D = W/V_t P_t \quad (9)$$

Where W is the weight of the tablet, $V_t$ is the volume of the compact ($cm^3$) and $P_t$ is the particle density of the material ($g/cm^3$).

*Determination of crushing strength of compacts*

The Force, F, required to break each compact diametrically into two halves was determined following the procedure of Fell and Newton[20] using a tablet hardness tester (DKB instrument, Mumbai. Model EH 01). The tablets were placed in between the spindle and the anvil, and the pressure was applied until the tablet fractured diametrically.

The crushing strength value was obtained as kgF and converted to Newton by multiplying by 9.8 (1 kg = 9.8N). Determinations were made in triplicate for each batch of the tablet tested and the mean determined.

*Determination of tablet friability*

The percentage friability of the compacts was determined using the Veego Tablet Friablity Apparatus (Veego Scientific Devices, Mumbai, India). The weights of 10 compacts were determined collectively and the tablets were placed in the friabilator which was then operated for 4 minutes at 25 revolutions per minute. The tablets were collected, dusted and weighed again. The percentage weight loss was calculated as the percent friability. Determinations were made in triplicate and the mean taken.

*Statistical analysis*

All the parameters were analyzed using Microsoft excel 2007 and GraphPad Prism 5 software. One-way ANOVA and t-test were applied to check significant differences in mean of the parameters. Differences were considered to be statistically significant at $p < 0.05$.

## Result and Discusion

*Density measurements*

The values of mean particle diameter (MPD), loose bulk density and particle density for the gums are presented in Table 1.

Bulk density of a powder gives a partial insight into the packing behaviour of materials [21]. Cissus gum which had higher MPD, had lower values of loose bulk than both SCMC and xanthan gum, however, acetone-extracted cissus gum had higher loose bulk than the water extract despite having same MPD. The differences in the bulk density values of all the gums could be due to differences in the MPD of the material which significantly affect packing arrangement of particles.

Particle density influences compressional characteristics of a powder.[22] It is expected that at any given pressure, powders with smaller particle density values should yield more cohesive compact than those with bigger values.[22] Xanthan gum had the least particle density and thus is expected to form a more cohesive compact than aqueous extract of Cissus gum with the highest particle density.

*Compaction properties*

Power compaction is a volume reduction process, and the Heckel and Kawakital equations are also based on volume change of a powder bed during compression. The Heckel and Kawakita plots (Figures 1 and 2) gave a general insight of the densification process of the gums. The parameters derived from these two plots are used to explain the deformation characteristics of the gums. Each of the plots is known to have its limitation. Heckel plot is known to generally exhibit linearity at high pressures while Kawakita plots generally exhibit linearity at low pressures.[23] The use of these two equations together in this study gave a more comprehensive understanding of the compression characteristic of cissus gum.

**Table 1:** Properties of acetone- and water-extracted cissus gum, xanthan and sodium carboxymethyl cellulose

| PROPERTIES | CA | CW | X | SCMC |
|---|---|---|---|---|
| Mean particle diameter (μm) | 430 | 430 | 375 | 350 |
| Bulk density (g/mL) | 0.3647 ± 0.02 | 0.3220 ± 0.14 | 0.4517 ± 0.05 | 0.6855 ± 0.01 |
| Particle density | 1.910 ± 0.33 | 2.096 ± 0.21 | 1.526 ± 0.46 | 1.874 ± 0.24 |

Values are mean ± Standard Deviation, n = 3.
CA, acetone extracted cissus gum, CW, water extracted cissus gum, X, xanthan, SCMC, sodium carboxymethyl cellulose.

**Table 2:** Parameters derived from density measurement and Heckel plots

| POLYMER | $P_y$ | $D_O$ | $D_A$ | $D_B$ |
|---|---|---|---|---|
| CA | 322.58 | 0.1909 | 0.5771 | 0.3862 |
| CW | 555.56 | 0.1536 | 0.4848 | 0.3312 |
| X | 227.27 | 0.2960 | 0.3916 | 0.0956 |
| SCMC | 769.23 | 0.3658 | 0.5954 | 0.2296 |

$P_y$, mean yield pressure, $D_O$, relative density when the applied pressure equals zero, $D_B$, relative density during the initial stages of compression, $D_A$, total degree of densification.

**Table 3:** Parameters derived from Kawakita plots

| POLYMER | A | $D_i$ (1-a) | B | $P_k$ |
|---|---|---|---|---|
| CA | 0.4706 | 0.5294 | 0.2654 | 3.7679 |
| CW | 0.5701 | 0.4299 | 0.1124 | 8.8968 |
| X | 0.5942 | 0.4058 | 0.5664 | 1.7655 |
| SCMC | 0.5984 | 0.4016 | 0.1005 | 9.9503 |

$D_i$, initial packed relative density, $P_k$, total amount of plastic deformation, a, porosity of the powder bed before compression, b, plasticity of the material.

The relative density of the powder at the point when the applied pressure equals zero, $D_O$, is used to describe the initial packing in the die as a result of die filling. SCMC with least MPD had the highest value of Do which implies that SCMC exhibited the highest degree of initial packing in the die as a result of die fill (Table 2).

The relative density $D_B$, which represents the particle re-arrangement phase in the early compression stages, tends to indicate the extent of particle fragmentation although fragmentation can occur concurrently with plastic and elastic deformation of constituent particles. CA had the highest $D_B$ value. The high $D_B$ value of CA may be due to particle desegmentation/shearing off of small individual particles. The $D_B$ values of both extracts of Cissus gum are higher than their corresponding Do values. This may be because of particle fragmentation and the subsequent filling of void spaces between the particles which occur extensively at low pressures to facilitate densification.

The mean yield pressure, $P_y$, is inversely related to the ability of a material to deform plastically under pressure. It has been shown to be the reciprocal of the slope of the second compression phase of the Heckel plot. It gives an impression of the ease of plastic deformation and softness of a material. The CA and X had low values of $P_y$ compared with CW and SCMC with high values. This implies that acetone extract of cissus gum and X had a quicker onset of plastic deformation. The rank order of $P_y$ value was X<CA<CW<SCMC as shown in Table 2.

The $P_k$ value is a pressure constant obtained from Kawakita plot and it is an inverse of the total amount of plastic deformation occurring during the compression process. The lower the $P_k$ value, the more the total amount of plastic deformation occurring during compression. It was observed from this study that X had the lowest $P_k$ value and thus exhibited the highest degree of plastic deformation followed by CA, CW and SCMC (Table 3).

While $P_y$ relates essentially to the onset of plastic deformation during compression, $P_k$ relates to the amount of plastic deformation occurring during compression process [13]. Thus, it could be seen that xanthan gum and acetone extract of cissus gum had faster onset of plastic deformation and at the same time exhibited higher amount of plastic deformation during compression than aqueous extract of Cissus gum and sodium carboxymethycellulose.

*Mechanical properties*

The mechanical strength of tablets provides measure of the bonding potential and can be evaluated in terms of certain parameters such as crushing strength or friability. Tablets with inadequate mechanical strength may be characterized by excessive friability and variations in crushing and tensile strength values which may be either too high or too low. The value of crushing strength and friability provide measures of tablet strength and weakness respectively. The crushing strength for compacts increased as compression pressure increases (Figure 3). Xanthan gum compact had higher crushing strength than CW, CA, and SCMC, this difference was significant ($p < 0.001$). This could be due to the fact that there are more particle-particle contact points with the particles of the polymer which help to create more solid bonds and results in higher crushing strength values.[24] It was also observed that the difference between the crushing strengths of CA and CW was significant ($P < 0.001$). The crushing strength value was found to have a direct relationship with the $P_y$. Xanthan gum with the fastest on-set of plastic deformation had the strongest crushing strength while SCMC with a longest time of on-set of plastic deformation had weakest crushing strength. Thus lower values of Py usually indicate harder tablets. Such information could be used as means for binder selection when designing tablet formulations.[1]

Friability was found to decrease with increase in relative density (Figure 4). The friability values for all the compacts were below 1%. Convectional tablets which loose less than 1% of their weight during the friability test are generally considered acceptable.[25]

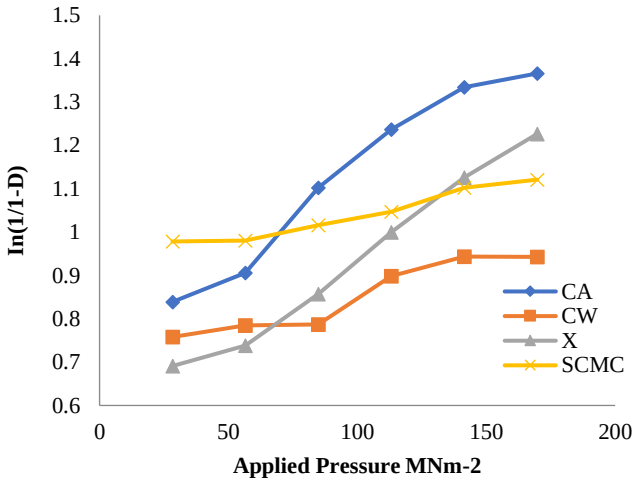


**Figure 1:** Heckel plots for the polymer compacts. CA = cissus gum (water extract), CW = cissus gum (acetone extract), X = xanthan, SCMC = sodium carboxymethylcellulose.

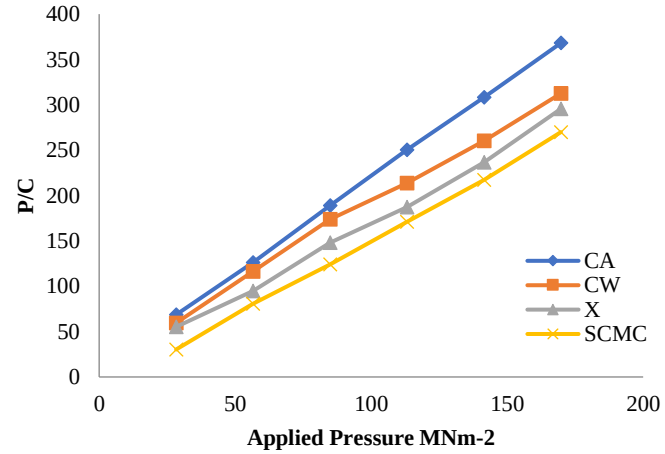


**Figure 2:** Kawakita plots for the polymer compacts. CA= cissus gum (water extract), CW = cissus gum (acetone extract), X = xanthan, SCMC = sodium carboxymethylcellulose.

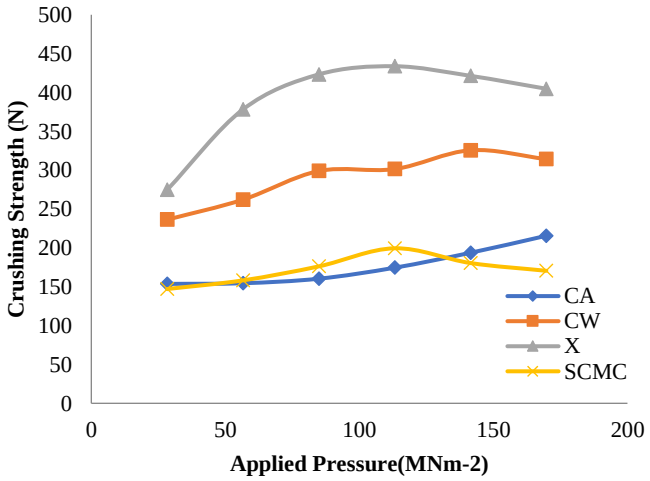


**Figure 3:** Effect of Applied Pressure on Crushing strength of polymer compacts. CA= cissus gum (water extract), CW = cissus gum (acetone extract), X = xanthan, SCMC = sodium carboxymethylcellulose.

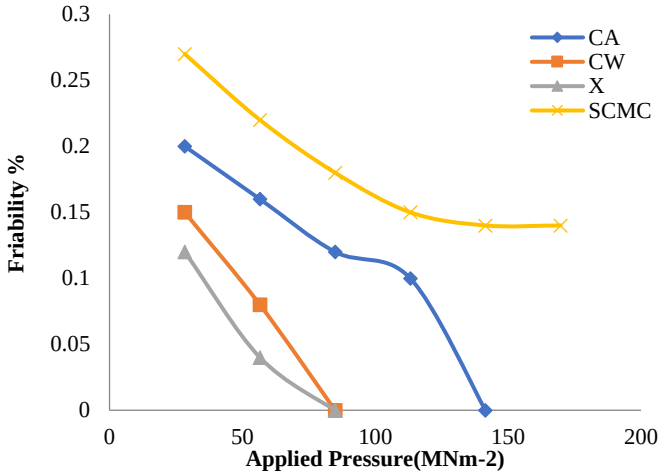


**Figure 4:** Effect of Applied Pressure on Friability of polymer compacts. CA= cissus gum (water extract), CW = cissus gum (acetone extract), X = xanthan, SCMC = sodium carboxymethylcellulose.

## Conclusion

Both water and acetone extracts of cissus gum had fast onset of plastic deformation and also exhibited high level of plastic deformation forming a cohesive compact which compared favourably with xanthan, a natural standard gum and better than sodium carboxymethyl cellulose a semi-synthetic gum. Hence, the gums could be used as binders in tablet formulations.

## Conflict of interest

The authors declare no conflict of interest.

## Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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