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Characterization of new hydrophilic polymers obtained from co-processed *Detarium microcarpum* seed gum with acacia, guar and tragacanth gums

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Abstract

This work was aimed at developing and characterizing new hydrophilic polymers obtained through co-processing of *Detarium microcarpum* seed gum (DMG) with acacia (ACG), guar (GGG) and tragacanth (TGG) gums respectively. The hydrophilic polymer obtained from the seed of *Detarium microcarpum* (DT) was co-processed with acacia, guar and tragacanth gums respectively in proportions of 5%DMG+95%ACG, 10%DMG+90%ACG, 15%DMG+85%ACG, and 20%DMG+80%ACG. Replicate co-processed powders of DMG+GGG and DMG+TGG were prepared. The co-processed powders were characterized for: densities (bulk density, tapped density and particle density), flow parameters (flow rate, angle of repose, Hausner's quotient, Carr's index and porosity), moisture properties (hydration capacity, swelling index, moisture content and moisture absorption), viscosity and pH respectively using standard methods. The results obtained showed that the densities of the polymers increased at all the concentrations they were co-processed. However, not all the co-processed polymers had a good flow. Moisture studies showed improved hydrophilic properties for all the co-processed polymers with regards to the swelling index and hydration capacities. The viscosities of the composite co-processed polymers also increased as the concentrations of the co-processed gums increased. Co-processing of acacia, guar and tragacanth gums with *D. microcarpum* seed gum enhanced the swelling index, hydration capacities and viscosities of these gums. This demonstrates that the new hydrophilic polymers obtained from the co-processing can be used as good suspending, disintegrating and binding agents when properly applied in drug formulations.

Keywords: *Detarium microcarpum*; Guar; Acacia; Tragacanth; Gum; Co-processing; Characterization

1. Introduction

The derivitization or sourcing of excipients (especially of pharmaceutical category) has traditionally been from plant (vegetable), animal and mineral sources, although synthetic sources also exist. According to the International Pharmaceutical Excipient Council (IPEC), an excipient bears the definition of any substance other than the active drug or pro-drug that is included in the manufacturing process or is contained in the finished pharmaceutical dosage forms. Excipients can also be classified on the basis of their origin, use in the dosage form, and functions they perform (1-4). Based on the roles they play, excipients usage could be considered as indispensable as long as medicinal products are concerned and in most of the formulations they are used in more quantity than the active pharmaceutical ingredient as it forms the bulk of the formulation. As a matter of necessity, the selection of an excipient is dependent on its properties *viz a viz* the ideal properties required of the excipient that can fit into the role desired.

Thus, excipient selection most often focuses on the desirable characteristics of the excipient such as its functionality, material consistency, regulatory acceptance, cost, availability, and its sources. Material properties such as the

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micromeritics, chemical, thermal, rheological, mechanical, etc. properties play an important role in the development of a drug formulation.

Excipients of natural origin remain preferable in the manufacturing of pharmaceutical dosage forms because of their low toxicity and cost, easy availability, non-irritant attribute, eco-friendliness, biocompatibility, improved patient tolerance, and public acceptance compared to synthetic excipients (5-7). The demand for improved or new excipients that conforms with the new technologies that is desirous of some Active Pharmaceutical Ingredients (APIs), particularly those that possess discrete APIs with multifunctional physicochemical properties as well as distinct elaborate approaches in their manufacture is on the rise (8).

Drug formulators must always bring into consideration the physicochemical properties, stability, compatibility between the excipients and API, pharmacokinetic properties, permeation characteristics, segmental absorption behaviour, drug delivery platform, intellectual property issues etc. while selecting an excipient for formulation development (9). This is important because excipients may not be completely inert as expected but may contain low quantities of pharmacological activity.

Each excipient added to a dosage form serves a specific purpose such as a binder, disintegrant, bulking agent, preservative or pH adjustment, determination of the rate at which the API is released from the dosage form, imparting enhanced dosage form performance in terms of rate of absorption upon application, improved therapeutic efficacy (7,8, 10, 11), reduction of viscosity (12, 13), enhancement of viscosity (13, 14) or improving solubility (14-16) effectively. The overall properties of the final dosage form such as its stability would be highly dependent on the excipients chosen, their concentrations and interaction with both the active compound and each other (14).

Excipients are added to perform certain functions in the dosage form in order to aid the API function optimally. The US Pharmacopoeia-National Formulary (USPNF) categorizes excipients according to the functions they perform in the formulations e.g. binders, disintegrants, bulking agents, emulsifiers, thickeners, etc. (16). There are various types of excipients in existence, with each having its peculiarities and requirements. Excipients may exist as single chemical entities as exemplified by some organic and inorganic acids, their salts, sugars, alcohols, etc.). Excipients may exist as modifications of existing substances which may have undergone physical treatments (like micronization), may have been chemically altered (like modified starch) or mixtures of chemically related components (like polyol esters) (14, 18,19). Mixed excipients are preparations that are ready-for-use, like ready-made coating materials. The concept of quality by design (QbD) helps in understanding excipients normal variability and its potential impact on the processes of formulation development that can be achieved. Excipient compatibility tests allows us to determine drug excipient interactions which can be either avoided or can be modified to utilize in an efficient manner which helps in minimizing the risk associated with the excipients. Excipient selection also depends on various routes of administrations. Excipient selection must be done on the basis of the characteristics an excipient offer (20).

A large percentage of excipients found in commercial circulation today are natural polymers derived from natural products such as plants (17) and have been used in the pharmaceutical sector in different capacities ranging from suspending, thickening, gelling agents as well as binders, and disintegrants. Examples of such polymers include tragacanth, guar gum, acacia, cellulose and its derivatives (21-23). Different parts of biological plants such as the stem, seed, root or tubers are richly endowed with polymers (gums and mucilages). The gum is seen as an exudate resulting from pathological damage cuts or incisions to the cell walls of the plant while the mucilage is basically a normal product formed inside the cell wall of the plant as a result of metabolic processes. The biomass has an abundance of polymers, its polymers are highly sought because of the obvious advantages it has over synthetic sources. Such advantages include high abundance, low cost, biodegradability and eco-friendliness. Although gums could be obtained as exudates from incisions or wounds made on the stems of plants, they are found in abundance in the seed or fruits of some plants such as locust bean, guar, tarra, cassia, detarium, breadfruit, etc. (24-26). Gums and mucilages appear alike and could generally be referred to as plant hydrocolloids or hydrophilic polymers. A major difference between gums and mucilages is that in the presence of water, gums are solubilized while mucilages form slimy masses.

In this study, four natural polymers obtained from *Detarium microcapum*, guar, acacia and tragacanth were considered. *Detarium microcarpum* (Family: Caesalpinaceae) is a dry savannah forest plant whose seed is used traditionally amongst the different ethnic groups in Nigeria as a soup thickener and delicacy (27). Investigations show that its seed gum can serve as a bioadhesive agent in the formulation of conventional release and sustained release tablets, and its oil as a matrix for depot injections, creams and emulsions (27).

Acacia is a natural gum that has wide pharmaceutical application as binder, suspending agent, or emulsifier. It is obtained from the air-hardened natural gummy exudate of the trunk and branches of *Acacia senegal* (L) Willdenow. It is easily soluble in cold water (up to 43–48 % v/v) but is precipitated in ethanol (28).

Guar gum, a non-ionic polysaccharide obtained from the seeds of *Cyamopsis tetragonolobus* of the Leguminosae family is found abundantly in nature. The gum is practically odourless and has a bland taste. Its physical appearance is off-white to very light yellow colour. Fine finished guar gum powder is available in different viscosities and granulomas depending on the desired viscosity development and applications. It finds extensive use in a variety of fields such as the food, textile, paper, cosmetic and pharmaceutical industries among many others where it is applied as thickener, stabilizer and binder (29). Its ability to form hydrogen bond upon hydration enables it to get easily hydrated in cold water (30).

Tragacanth gum is a viscous, odourless, tasteless, water-soluble mixture of polysaccharides obtained from sap that is drained from the root of some species of Middle Eastern legumes of the genus Astragalus. The gum seeps from the plant in twisted ribbons or flakes that can be powdered. It absorbs water to become a gel, which can be stirred into a paste. The major fractions are known as tragacanth, which is a highly water soluble mucilaginous colloid that swells in water to form a gel. It takes several days to achieve its maximum viscosity and the gel is most stable at pH range of 4-8. Its application in pharmaceutical dosage formulations are as a suspending agent, emulsifier, thickener and stabilizer (31).

Generally, the physical properties of a gum are manifestations of its chemical structure, the type and amount of solvent, concentration of ions and other substances dissolved in the solvent. Since gums are commonly composed of several different kinds of monomer units with many possible variations with regard to degree of branching, length of branches, and types of linkages, an almost infinite number of structures are possible. Forces act between molecules, and at different parts of the same molecules, and between polymer and solvent. These forces include: hydrogen bonding, ionic charges, dipole and induce dipole interactions and Van der Waals forces. All these forces affect such properties as gel-forming tendency, viscosity, and adhesiveness. The types of linkages are also important in determining physical properties due to their effects on chain flexibility. For example, it is known that linear molecules make more viscous solutions than long branched chain molecules of similar molecular weights but they have a tendency to precipitate because of association of the chains. If this association is prevented, stability can be achieved without much loss of viscosity. This can be done by introducing groups with ionic charges that repel one another, or by attaining many short side branches to prevent close approach of the chains. Commercial gums are often mixtures of two or more different polysaccharides (32).

Co-processing is a technological approach through which new excipients are developed and introduced into the market without undergoing the laborious safety checks and testing of a completely new chemical. It is achieved through the combination of two or more established excipients by an appropriate process that could give rise to a new excipient that has superior properties compared to the simple physical mixtures of their components. The main aim of this process is to obtain a product with added value related to the ratio of its price (33). In this study, the seed gum of *Detarium microcarpum* (DMG) was obtained and co-processed with acacia (ACG), guar (GGG) and tragacanth (TGG) gums to develop some novel polymers whose properties were evaluated and compared with the individual gums.

2. Materials and methods

2.1. Materials

The materials used include: Ethanol (BDH, UK), n-hexane (JHD, China), acacia gum (J.T Baker, USA) tragacanth gum (Lobachemie, India), guar gum (Qualikems, Germany).

2.2. Method

2.2.1. Procurement of sample

The seed of *Detarium microcarpum* was procured from the Main market, Enugu, Enugu State, Nigeria.

2.2.2. Identification of sample

The sample was identified as *Detarium microcarpum* seeds by Dr. Edwin Wosu of the department of Plant Science and Biotechnology, University of Port Harcourt, Nigeria and was assigned an e-herbarium identification number EH/ACM/067 and deposited in Ecoland herbarium EH, Diobu, Port Harcourt, Nigeria.

2.2.3. Processsing of Detarium microcarpum gum

The *D. microcarpum* seeds were sorted and 1.64 kg quantity of it was weighed, soaked in hot water for 24 h and the seed coats de-husked. The white pulps obtained were washed, sun- dried and milled to coarse powder, soaked in distilled water for 24 h and pressed in a muslin cloth to extract the mucilage. The mucilage was precipitated using 95 % v/v ethanol. The precipitate (gum) obtained was dried to constant weight in an oven (Memmert, England) at 40°C, pulverized (Binatone, Japan) and classified using a 250 µm sieve (Retsch®, Germany). The pulverized *D. microcarpum* gum was stored in air tight containers and kept away from light and heat for further use.

2.3. Preparation of co-processed hydrophilic polymers

Four batches each of co-processed hydrophilic polymers containing 5.0, 10.0, 15.0 or 20.0 % w/w of detarium gum (DMG) with 95.0, 90.0, 85.0 or 80.0 % w/w of either acacia gum (ACG) or guar gum (GGG) or tragacanth gum (TGG) were correctly weighed into Wedgewood mortars (Table 1). The constituent of each mortar was triturated to a homogeneous blend and 60 ml of distilled water poured into the mortar. Further trituration was done to obtain a fine slurry. Two hundred (200) ml of acetone was poured into the slurry to precipitate the polymer. The precipitated polymer was broken into small clumps, spread on a paper and dried to constant weight in a desiccator loaded with silica gel, after which it was pulverized and classified with 180 µm sieve (Retsch®, Germany).

Table 1 Formulation table of co-processed polymers containing various amounts of detarium, acacia, guar or tragacanth gums

Polymer	Batch 1 (% w/w)	Batch 2 (% w/w)	Batch 3 (% w/w)	Batch 4 (% w/w)
DMG +ACG	5% + 95%	10% + 90 %	15% + 85%	20% +80%
DMG + GGG	5% +95%	10%+90%	15%+85%	20%+80%
DMG +TGG	5%+95%	10%+90%	15%+85%	20%+80%

2.4. Evaluation of *D. microcarpum* gum

2.4.1. Physicochemical properties

The physicochemical properties of *Detarium microcarpum*, acacia, guar and tragacanth gums were determined alongside with the co-processed hydrophilic polymers obtained as shown in Table 1.

Percentage (%) yield

Both the weights of *Detarium microcarpum* seed (x) used for the extraction and the weight of the gum (y) extracted from it were determined and recorded. The percentage yield was calculated using equation 1

$$\% \text{ yield} = (y/x) \times 100 \quad \text{.....(1)}$$

Organoleptic properties

The taste, odour, colour, and texture of the *Detarium microcarpum*, acacia, guar and tragacanth gum powders were evaluated and noted. Similarly, the resultant co-processed powders from them were subjected to replicate evaluations. All determinations were done in triplicates.

pH measurement

The pH of 2.0% w/v aqueous dispersion of each of the powders was prepared and the pH determined with a pH meter (Hannah, USA).

Solubility profile

The solubility profile of the powdered samples was determined by visual observation with the naked eye of 50 ml of 2 % w/v dispersions of ethanol, acetone, diethyl ether and chloroform respectively.

Viscosity

The viscosity of a 2% w/v of DMG, ACG, GGG, TGG and the co-processed powdered hydrophilic polymers was determined with a model AV2T Brookfield viscometer (Brookfield Engineering Laboratories, Massachusetts, USA) using a spindle 61 for 30 sec at 27.4 °C .

Bulk and tapped densities

The bulk and tapped density each of DMG, ACG, GGG, TGG and the co-processed powdered hydrophilic polymers was determined by introducing 15 g of each powder in a Stampfvolumeter (STAV 2003JEF, Germany). Calculations for the densities were worked out using equations 2 and 3 respectively:

$$Bulk\ density\ (D_b) = M/V_b \quad \ldots\ldots 2$$

$$Tapped\ density\ (D_b) = M/V_t \quad \ldots\ldots 3$$

Where M is the mass of the powdered gum, V_b is the bulk volume and V_t is the tapped volume

Particle density

The determination of the particle density of DMG, ACG, GGG, TGG and the co-processed powdered hydrophilic polymers was determined by the liquid displacement method using n-hexane as the immersion fluid. A 25 ml volume capacity pycnometer was weighed empty (W), and later was filled with n-hexane. It was stoppered, wiped of any spilled n-hexane on its body and weighed (W1).The difference between the W1 and W was calculated as W2. A 0.5 g quantity of the co-processed gum powder was weighed into the pycnometer. The pycnometer was stoppered, wiped clean of excess n-hexane and reweighed. The particle density (Pd) was calculated using equation 4:

$$Particle\ density = W2 \times W3/V(W3-W4+W2+W) \quad \ldots\ldots 4.$$

Where V=25ml (volume of solvent)
W is the Weight of the empty pycnometer,
W2 is the weight of the solvent,
W3 is the weight of powdered gums,
W4 is the weight of the pycnometer + solvent + powder,

Triplicate determination was conducted for each powder sample (34).

Flow rate

A 15 g quantity each of DMG, ACG, GGG, TGG and the co-processed powdered hydrophilic polymers was poured into a clamped stoppered clean glass funnel whose orifice was 3 cm above a flat surface. The stopper was removed from the funnels orifice and the time taken for the powder to flow completely out from the funnel was measured and recorded. The diameter of the heap formed by the powder on the platform was measured and recorded. Using equation 5, the flow rate of the powder was calculated while the angle of repose was calculated from equation 6 (35, 36).

$$Flow\ rate = Mass\ of\ powder\ /\ time \quad \ldots\ldots 5$$

$$Angle\ of\ repose\ (\theta) = \tan^{-1}(2h/D) \quad \ldots\ldots 6$$

Where h is the height of the powder heap and D is the diameter of the base of the powder heap.

Determination of Hausner's Quotient and Carr's Index

The Hausner's quotient and Carr's index for DMG, ACG, GGG, TGG and the co-processed powdered hydrophilic polymers were calculated from equations 7 and 8 respectively (35, 36) ,

$$\text{Hausner's quotient } (H.Q.) = Dt/Db \quad \ldots\ldots 7$$

$$\text{Carr's Index } (C.I.) = 1 - (Dt/Db) \times 100 \quad \ldots\ldots 8$$

Where D_t is tapped densty, and D_b is bulk density

Powder porosity

The powder porosity, ϵ for the different powders was determined using Equation 9 (35, 36).

$$\epsilon = 1 - (Db/Pd) \times 100 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 9$$

where P_d is the particle density and D_b is the bulk density.

Moisture content

A 0.5 g quantity of DMG, ACG, GGG, TGG and the co-processed powdered hydrophilic polymers was placed in a tarred white porcelain crucible and dried in a hot air oven (Mermmet®, England) at 105˚C until a constant weight was obtained for each material. The percentage moisture content was determined using Equation 10 (37).

$$\text{Moisture content (M.C.)} = (W_i - W_f) / W_i \times 100 \quad \ldots\ldots\ldots\ldots 10$$

Where W_f is the final weight of powder after drying, and W_i is the initial weight of powder before drying.

Moisture sorption test

A 0.5 g quantity each of the powdered samples was weighed respectively into a tarred 7 mm Petri dish and placed in desiccators of relative humidity of 52, 75, 84 and 96 % respectively at room temperature of 29 ± 1˚C. The weight gained by each powder over a period of seven (7) days was calculated for each sample from Equation 11. Triplicate determinations were done.

$$\text{Moisture gained (M.G.)} = (W2 - W1) / W1 \times 100 \quad \ldots\ldots\ldots\ldots 11$$

Where W1 is the weight before exposure and W2 weight gained after exposure.

Swelling index

The swelling capacity of the powdered samples was determined by using the method of Bowen and Vadino with slight modification (38). A quantity of 1 g of the sample was placed in a 50 ml graduated glass measuring cylinder and tapped to obtain the tapped volume, V_t. A 50 ml volume aqueous dispersion of the powdered sample was prepared using distilled water. The mixture was shaken thoroughly and was allowed to stand undisturbed for 24 h on a flat surface and the volume of the sediment formed, V_v noted. Triplicate determinations were done for each of the samples and the swelling capacity calculated as a percentage using Equation 12.

$$\text{Swelling index (S.I.)} (V_v - V_t) / V_t = x \times 100 \quad \ldots\ldots\ldots\ldots 12$$

Hydration capacity

One (1) g of each of the powders was weighed into a 15 ml plastic centrifuge tube and 10 ml of distilled water was added to it. Each tube was shaken intermittently over a period of 2 h and left to stand for 30 min. Centrifugation at 1000 revolutions per minute (rpm) was done for 10 min using a table top centrifuge model TX 150 (ThermoFisher Scientific, UK). The supernatant was carefully decanted and the wet sediment weighed. This procedure is a slight modification of Kornblum and Stoopaks method (39). Triplicate determinations were done. The hydration capacity was calculated from equation 13.

$$\text{Hydration capacity (H.C.)} = x/y \quad \ldots\ldots\ldots\ldots\ldots\ldots 13$$

Where x is the weight of the wet sample/ powder sediment and y is the weight of the dry sample/powder.

2.5. Statistical analysis

The data obtained was analyzed statistically using one way analysis of variance (ANOVA) with the aid of an IBM SPSS version 21 software (IBM, Chicago, USA). Values were considered significant at 95 % confidence interval or $p < 0.05$.

3. Results and discussion

3.1. Percentage yield

The percentage yield of the gum extracted from the matured dry seed of *Detarium microcarpum* was 12.2% w/w. This amount is considered good.

3.1.1. Organoleptic properties

The gum obtained from *D. microcarpum* was fine pale brown in colour, and the smell was similar to the detarum seed odour.

3.1.2. Bulk, Tapped and Particle Densities

The result of the densities of the individual gums (DMG, ACG, GGG and TCG) and their co-processed derivatives (DMG and ACG or GGG or TCG) is presented in Table 2. The bulk and tapped densities of the co-processed polymers derivatives were higher than the individual polymers ($p<0.05$). Thus the DMG, ACG, GGG and TCG were bulkier than their co-processed derivative polymers. Increase in density would imply that the surface area was increased by the smaller size and diameter of the co-processed particles. This also suggests that a smaller space would be occupied inferring that co-processing aided the reduction of inter and intra particulate pores/voids and aiding greater intimacy between the individual particles of the co-processed product. Some other researchers had earlier reported that the interactions that exist within the particles in a bulk powder or any powder bed determines the main properties exhibited by the powder more so the flow behavior and densification or the settling of the particles of the powder in the bed on agitation or application of a quantified pressure (40, 41). Particle density refers to the density of the solid phase of the particles and is devoid of both inter and intra particulate space or voids that such particles may have. Thus, the particle density of a powder is independent of powder porosity, compaction, and pre-treatment given to the sample. The particle density of DMG was smaller than the other polymers used before co-processing. After co-processing the particle density of the new co-processed polymer was higher than the individual value of each of the polymers that was used for co-processing (Table 2). This shows that co-processing improved the level of intimacy and subsequently bonds that exist in the new polymer. Improved binding of powdered particles would result when the co-processed composites are used in preparing granules for tableting purposes as well as higher viscosity and suspending properties in suspension formulations when used as suspending agent. When significant differences exist in particle density, the powders tend to segregate during processing.

Generally, knowledge of the density of powders and granules play an important role in pharmaceutical processing such as mixing of the Active Pharmaceutical Ingredient with the excipients used in the formulation. The API and excipient are expected to have similar densities for proper mixing to occur leading to a uniform amount of drug between the different dosage units.

Table 2 Bulk densities, tapped densities and particle densities of the natural gums and their co-processed derivatives

Gums/Co-processed gums	Bulk density (g/ml)	Tapped density (g/ml)	Particle density (g/ml)
DMG	0.49 ± 0.01	0.66 ± 0.02	0.61 ± 0.06
ACG	0.63 ± 0.05	0.80 ± 0.03	2.04 ± 0.06
GGG	0.50 ± 0.01	0.64 ± 0.03	1.45 ± 0.02
TGG	0.66 ± 0.02	0.82 ± 0.02	1.60 ± 0.01
DMG5% + ACG95%	0.67 ± 0.00	0.98 ± 0.03	1.50 ± 0.61
DMG10% + ACG90%	0.58 ±0.02	0.90 ±0.02	2.02 ±0.40
DMG15% + ACG85%	0.57 ± 0.02	0.88 ± 0.02	1.94 ± 0.07
DMG20% + ACG80%	0.54 ± 0.02	0.84 ± 0.02	2.07 ± 0.47
DMG5% + GGG95%	0.58 ± 0.02	0.82 ± 0.02	1.53 ± 0.17
DMG10% + GGG90%	0.55 ± 0.02	0.80 ± 0.03	2.16 ± 1.40
DMG15% + GGG85%	0.53 ± 0.03	0.86 ± 0.06	2.44 ± 0.86

DMG20% + GGG80%	0.53 ± 0.03	0.86 ± 0.02	3.36 ± 0.40
DMG5% + TGG95%	0.63 ± 0.00	0.90 ± 0.00	1.20 ± 0.04
DMG10% + TGG90%	0.63 ± 0.00	0.84 ± 0.02	2.59 ± 1.15
DMG15% + TGG85%	0.57 ± 0.02	0.81 ± 0.02	4.36 ± 3.75
DMG20% + TGG80%	0.55 ± 0.01	0.82 ± 0.02	7.70 ± 1.27

3.1.3. Flow parameters

The flow properties (flow rate, angle of repose, Carr's index, Hausner's ratio and porosity) of the gums are presented in Table 3. The standard gums (ACG, GGG and TGG) had a poor flow rate while DMG had interrupted flow (categorized as no flow). The derived parameters for evaluating flow in powders such as the angle of repose (A.O.R.), Carr's index (C.I.) and Hausner's ratio (H.R.) showed that the powders had a poor or very poor flow. Amongst the polymers before co-processing, DMG had the highest A.O.R. and is followed by TGG. They could be classified based on Carr's scale of flow of particulate solids (37) as good flowing except DMG that had a fair flow. Most of the co-processed composite polymers had fair to passable A.O.R. An A.O.R value of 31-35° is described as good flowing, 36-40° as fair flowing and 41-45° as passable. Powders with CI of 16-20%, 21-25%, 26-31%, 32-37% and > 38% have been categorized as having fair, passable, poor, very poor and very very poor flow respectively. On the Hausner's parameter for flow, values of 1.19-1.25, 1.26-1.34, 1.35-1.45, 1.46-1.59 and > 1.60 have also been categorized as fair, passable, poor, very poor and very very poor flow respectively (16, 36, 37, 42).

Most of the co-processed polymer composites had CI in the range of 29.27 ± 0.64 - 38.37 ± 2.10 % and HR of 1.38 ± 0.03 - 1.62 ± 0.04 which falls into the category of poor to very poor flow. For the powders that flowed (DMG+GGG), the rate of flow was found to decrease as the mass or quantity of DMG in the co-processed polymer composite increased.

Table 3 Some micromeritic properties of DMG, ACG, GGG and TGG natural gums and their derivatives

Gums/Co-processed gums	**Flow rate**	**Angle of repose (⁰)**	**Carr's index (%)**	**Hausner's quotient**	**Porosity (%)**
DMG	-	36.10 ± 1.84	24.85 ± 0.90	1.33 ± 0.02	19.67 ± 1.92
ACG	0.64 ± 0.15	31.87 ± 0.37	21.30 ± 4.87	1.27 ± 0.08	78.57 ± 1.99
GGG	0.81 ± 0.24	32.55 ± 0.35	20.82 ± 3.98	1.25 ± 0.03	65.52 ± 1.00
TGG	0.78 ± 0.39	34.20 ± 1.03	19.04 ± 4.58	1.24 ± 0.07	58.75 ± 2.14
DMG5% + ACG95%	-	30.95 ± 0.64	31.63 ± 2.04	1.54 ± 0.04	53.33 ± 19.73
DMG10%+ ACG90%	-	31.70 ± 1.56	35.56 ± 0.27	1.55 ± 0.02	71.29 ± 6.67
DMG15% + ACG85%	-	31.70 ± 1.13	35.23 ± 0.22	1.55 ± 0.01	70.62 ± 1.05
DMG20% + ACG80%	-	39.65 ± 1.20	35.71 ± 0.29	1.56 ± 0.01	73.91 ± 5.92
DMG5%+ GGG95%	7.38 ± 0.54	33.95 ± 0.35	29.27 ± 0.64	1.41 ± 0.01	62.09 ± 2.80
DMG10%+ GGG90%	5.30 ± 1.70	33.05 ± 0.35	31.25 ± 0.72	1.45 ± 0.02	74.54 ± 1.46
DMG15% + GGG85%	3.05 ± 0.71	31.80 ± 0.00	38.37 ± 1.44	1.62 ± 0.04	78.28 ± 3.42
DMG20%+ GGG80%	1.79 ± 0.47	32.05 ± 0.35	38.37 ± 2.10	1.62 ± 0.06	84.23 ± 2.72
DMG5% + TGG95%	-	38.40 ± 0.00	30.00 ± 0.00	1.43 ± 0.00	47.50 ± 1.56
DMG10% + TGG90%	-	37.95 ± 0.64	27.67 ± 1.20	1.38 ± 0.03	75.67 ± 10.88
DMG15% + TGG85%	-	37.70 ± 0.28	29.63 ± 0.67	1.42 ± 0.02	86.92 ± 1.54
DMG20% + TGG80%	-	36.25 ± 0.92	32.93 ± 0.00	1.49 ± 0.00	92.86 ± 1.01

Key: (-) signifies no flow

3.1.4. pH measurement

The pH of the individual polymers showed acidity for acacia (ACG), TGG and DMG while GGG was alkaline (Table 4). The co-processed polymers had a pH inclined towards the polymer that constituted the greater percentage/proportion of the composite polymer. Thus co-processing did not cause much variation in the pH ($p>0.05$).

3.1.5. Solubility profile

The results of the solubility profile of DMG, ACG, GGG, TGG and the co-processed powdered hydrophilic polymers showed formation of gels in the presence of water but were precipitated out by ethanol, acetone, chloroform, diethylether etc.

3.1.6. Viscosity

The viscosities of the polymers are shown in Table 4. The order of viscosities in decreasing pattern was DMG > TGG > GGG > ACG. The same order was followed by the co-processed powders. However, co-processing with DMG greatly enhanced the viscosities of the composite polymers obtained with TGG, GGG and ACG ($p< 0.05$). Thus, the co-processed polymers when used as binders in granulations would produce harder tablets when compressed due to greater bonding of the granules as well as more stable suspensions when used as suspending agents than the individual polymers.

3.1.7. Moisture content, hydration capacity and swelling index

The moisture parameters (moisture content, hydration capacity and swelling index) of the natural gums and their co-processed polymers are presented in Table 4. The moisture parameters of the individual polymers were altered after being co-processed with DMG. The moisture content of DMG increased significantly ($p<0.05$) after being co-processed with ACG, GGG and TGG while that of ACG and GGG decreased ($p<0.05$). The moisture content of the co-processed polymers also showed significant increases ($p<0.05$) when the polymers were compared except for DMG20%+ACG80%, DMG15%+GGG85%, DMG20%+TCG80%, DMG5%+TCG95% where there were no significant differences ($p>0.05$).

Table 4 pH, viscosity, moisture content, swelling index and hydration capacity of DMG, ACG, GGG and TGG and their derivatives

Gums/Co-processed gums	pH	Viscosity (cP)	Moisture content (%)	Swelling index (%)	Hydration capacity (%)
DMG	6.40 ± 0.14	950 ± 0.00	11.90 ± 0.99	475.00 ± 3.56	10.62 ± 0.03
ACG	4.50 ± 0.00	3.00 ± 1.41	18.51 ± 0.98	132.20 ± 1.25	1.19 ± 0.15
GGG	9.67 ± 0.06	14.50 ± 4.95	18.94 ± 1.27	437.75 ± 2.98	5.40 ± 0.35
TGG	4.50 ± 0.14	28.75 ± 1.77	18.45 ± 0.01	1431.50 ± 1.32	16.17 ± 2.06
DMG5% + ACG95%	5.10 ± 0.00	43.50 ± 0.71	15.95 ± 1.20	183.50 ± 2.33	1.39 ± 0.54
DMG10% + ACG90%	4.70 ± 0.00	35.00 ± 0.00	13.08 ± 1.03	208.00 ± 3.56	1.37 ± 0.48
DMG15% + ACG85%	4.75 ± 0.07	46.50 ± 0.71	13.55 ± 0.07	250.00 ± 0.00	2.22 ± 1.07
DMG20% + ACG80%	4.80 ± 0.00	43.00 ± 0.00	15.55 ± 2.33	286.00 ± 0.00	5.50 ± 1.07
DMG5% + GGG95%	9.65 ± 0.07	34.00 ± 0.00	25.90 ± 0.00	767.50 ± 5.66	7.13 ± 2.36
DMG10%+ GGG90%	9.70 ± 0.00	43.50 ± 0.71	21.90 ± 0.99	1143.00 ± 2.33	7.29 ± 0.04
DMG15% + GGG85%	9.75 ± 0.07	52.00 ± 0.00	15.40 ± 3.68	1016.00 ± 2.24	10.24 ± 0.44
DMG20% + GGG80%	9.85 ± 0.07	54.50 ± 0.71	10.86 ± 0.51	869.00 ± 3.18	8.77 ± 1.42
DMG5% + TGG95%	4.60 ± 0.00	60.00 ± 0.00	21.30 ± 0.21	1455.47 ± 5.97	7.93 ±2.01
DMG10% + TGG90%	4.75 ± 0.07	147.50 ± 0.00	18.30 ± 3.96	1393.00 ± 5.55	6.66 ± 4.62
DMG15% + TGG85%	4.75 ± 0.07	175.00 ± 0.00	27.00 ± 6.08	1687.50 ± 8.39	9.98 ± 0.60
DMG20% + TGG80%	4.65 ± 0.07	282.2 0± 0.00	16.21 ± 0.56	1583.00 ± 9.58	10.15 ± 0.44

The swelling index of the three polymers DMG, ACG, GGG and TGG, were significantly different ($p<0.05$) from each other. Co-processing significantly reduced both the swelling index and hydration capacities of DMG+ACG at all percentage combinations ($p<0.05$) while both parameters were also greatly increased in co-processed composites of DMG+ GGG and DMG+TGG ($p < 0.05$). The co-processed polymer composites also were increased ($p<0.05$) when compared with the individual polymers as well as when their percentages of swelling were compared with each other. A similar trend was observed in the hydration capacities. These shows the polymers could serve as good binders in tablet formulations as well as good suspending agents in suspension formulations. However, both the binding and suspending properties shall be greatly enhanced ($p<0.05$) through co-processing at all polymer ratio or combinations.

Generally, the crystallinity of the polymers (both individual and co-processed) used in the study could be categorized as amorphous. This is because of their ability to take up moisture even in amounts that far exceed their weight and volume. This feature has been described as characteristic of amorphous materials in a report by Stamm after undertaking some studies on cellulosics and polymers (43).

4. Conclusion

A natural hydrophilic gum (DMG) was extracted from the matured seed of *D. microcarpum.* The natural polymers DMG, ACG, GGG and TCG used for this study have been used over the years by different scientists alone or in combination as admixtures or through co-processing to achieve different pharmaceutical purposes in drug delivery as either binders or disintegrants in solid dosage forms or as suspending agents and emulsifiers in disperse systems. However, the co-processing of DMG with ACG, GGG or TCG in different proportions resulted in new polymers (DMG+ACG, DMG+GGG and DMG+TCG) with stable pH, improved binding, disintegrant and suspending properties which can enable their use in enhancing drug delivery where such properties they possess are required.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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