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Effect of Drying Methods on the Powder and Compaction Properties of Microcrystalline Cellulose Derived from *Cocos nucifera*

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Authors' contributions

This work was carried out in collaboration between both authors. Author OSI designed the study. Author NN performed the bench work, statistical analysis, wrote the protocol and the first draft of the manuscript. Author NN managed the analyses of the study and the literature searches. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: This work aims at investigating the effect of drying methods on the powder and compaction properties of microcrystalline cellulose (MCC) obtained from the matured fruit husk of *Cocos nucifera* (CN).
Study Design: Experimental design.
Place and Duration of Study: University of Nigeria, Nsukka from March 2014 to September, 2016.
Methods: Dried CN husk chips were treated with sodium hydroxide to obtain α-cellulose which on further treatment with dilute hydrochloric acid gave MCC. One portion was lyophilized at - 45 ± 2°C for 3 h (coded *MCCL-Cocos*) while a second portion was fluidized dried at 60 ± 1°C for 2 h (coded *MCCF-Cocos*). The MCCs were characterized using standard methods. Avicel PH 102 was used as comparing standard.

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Results: Physicochemical properties of the derived MCC such as degrees of polymerization DP and crystallinity, molecular weight, morphology and micromeritic properties were determined. The compaction properties were assessed using Kawakita and Heckel equation models. The MCCs had crystallinity index ranging from 81.25 to 82.12%, DP of 222. *MCCF-Cocos* had better flow indices than *MCCL-Cocos*. The powders exhibited good densification behaviors based on the Kawakita model assessment. Compacts of *MCCL-Cocos* were significantly (P = 0.01) harder than *MCCF-Cocos* compacts. Heckel analysis showed plastic behavior. The compaction properties - hardness and tensile strength of the CN MCCs were lower than that of Avicel PH 102.
Conclusion: Fluid bed dried MCC had better flowability while lyophilized MCC had superior densification and compaction properties. Thus drying methods had an effect on the powder and compaction behavior of *C. nucifer*a MCC.

Keywords: Cocos nucifera; microcrystalline cellulose; powder; compaction.

1. INTRODUCTION

The cells of all green plants are known to contain cellulose and lignin abundantly in their cell walls and this is responsible for the structure and mechanical strength exhibited by such plants [1]. Cellulose has over the years been found to be very useful in many activities of mankind because of its possession of such attributes as strong tensile strength, low density and eco-friendliness. Microcrystalline cellulose for industrial purposes is mostly derived from purified cotton linter and wood pulp. The desire for cheaper eco-friendly processes as well as the need to slow down the fast global deforestation has stimulated renewed interest in agro-fiber plants waste [2]. As a result of this, the husk from the fruit of the coconut plant (*Cocos nucifera*), which occurs as a huge agricultural waste globally and especially along the coast line areas in Nigeria, was investigated as a source for the production of MCC.

Cocos nucifera is a large palm plant of the family *Arecaceae* that has pinnate leaves and bears numerous fruits in bunches at a time. Each fruit contains a nut (shell) with a large volume of water or milk inside and three indentations on the head. The fruit consists of three layers: the exocarp, mesocarp and endocarp. The husk is made up of the exocarp and mesocarp while the mesocarp consists mostly of a fibrous material. The coconut plant is cultivated in many tropical and sub-tropical regions where the plant thrives as a result of climatic reasons – abundant sunshine, regular rainfall and high humidity [3]. It thrives well on sandy soils and is highly tolerant of salinity. Different brands of microcrystalline cellulose are commercially available from different manufacturers in a quest to meet the various requirements of the different consumers. Many of these brands exist as a result of the various physical powder characteristics which each brand possesses. Such differences are imparted by variation of not only the pulp source but also the processing steps during manufacture [4]. One of the processing steps is drying. Commercially, most MCC is dried by the spray drying method which imparts a high inter particulate porous and aggregate nature to the dried powder [5,6]. Fluid bed drying method aids powders to dry as discrete particles with a low inter particulate void while lyophilization causes the iced portion of a frozen material to be sublimed directly into vapour at a low partial pressure of water [7]. On drying, this leaves a material with a high porous inter particle void [8]. All these different drying methods are expected to affect the particle morphology, size, porosity and aggregation which in turn would affect the characteristic of the material. Thus in this study, an investigation of the effect of drying procedure by lyophilization and fluidization on the powder and compact characteristics of the MCC derived from the fruit husk of CN was carried out.

2. MATERIALS AND METHODS

2.1 Materials

Sodium hydroxide (Merck, Germany), Hydrochloric acid, Magnesium nitrate (BDH, Poole England), sodium hypochlorite 3.5% w/v (JIK®, Reckitt and Colman Nig. Plc), Avicel® PH 102 (FMC Biopolymer, USA), Potassium sulphate, Sodium chloride (J. T. Baker, New Jersey, USA), Talc, Magnesium stearate (Sigma, USA) and distilled water (Pharm. Tech. Lab, Uniport). Dried chips of coconut fruit husk.

2.2 Methods

2.2.1 Isolation of alpha cellulose

Matured fruits of the coconut plant, *Cocos nucifera*, were harvested from different trees within Mgbuoba town, Port Harcourt, Rivers State, Nigeria. The fruits were de-husked and husk fibers/strands cut into small pieces of about 3 – 5 mm length and were air dried until completely dry and stored appropriately. The method of Ohwoavworhua et al. [9] with modification was adopted. An 800 g quantity of the dried brittle fibers/strands of the coconut husk were placed in a 15 L stainless steel container to which 10 L of 3.5% w/v solution of sodium hydroxide was added and digestion was effected for 4 h at a boiling temperature of 100°C on a sand bath to partially de-lignify the husk. The de-lignified mass was thoroughly washed with water until neutral to litmus. Excess water was squeezed out through a muslin cloth. First bleaching was done using 0.4% w/v of sodium hypochlorite solution heated to 100°C for 30 min. After washing thoroughly with water until neutral, the resultant pulp was further treated with 17.5% w/v solution of sodium hydroxide at 100°C for 1 h. The resultant pulp was bleached two more times with 0.4% w/v of sodium hypochlorite and followed by washing with distilled water until neutral to litmus.

2.2.2 Acid hydrolysis of alpha cellulose obtained from *Cocos nucifera* husk

A 60 g quantity of the alpha cellulose was put in a 2 L glass beaker (Pyrex®, England) and treated with 0.8 L of 2.5 N HCl at 105 ± 2°C in an oil bath. The hot acid mixture was poured into cold water and stirred vigorously until cold, and allowed to settle. The supernatant was decanted and the material obtained was washed until neutral to litmus and excess water squeezed out with a muslin cloth. The lumps of MCC obtained were divided into two portions. One portion was fluid bed dried using a Tornado model (Sherwood®, China) fluid bed dryer set at an inlet air temperature of 60 ± 1°C for 2 h. The second portion was lyophilized at - 45°C for 3 h using an LGT 18 freeze dryer (Gallenkamp®, England). Each of the material was milled using a domestic blender (Binatone®, Japan) and screened through a 250 µm stainless sieve (Retsch®, Germany). The microcrystalline cellulose obtained by the different drying processes was stored separately.

2.3 Physicochemical Evaluation

2.3.1 Identification

The color, odor, taste and texture of the MCC were observed and recorded. A 2 g portion of the MCC was soaked in iodine solution for 5 min and drained of excess reagent. Observations were made for change in colour. Also, 2 drops of 60% v/v of sulphuric acid solution were added to a fresh portion of the MCC and observations were also recorded [10].

2.3.2 pH determination

This was done by shaking for 5 min a dispersion of 2 g of *MCCF-Cocos, MCCL-Cocos* and Avicel PH 102 in 100 mL of distilled water. This was allowed to settle and the pH of the supernatants determined [10] using a pH meter (PHS® 25, India). Three replicate determinations were made.

2.3.3 Solubility

A few drops of excess of distilled water, acetone, 0.1 N hydrochloric acid (HCl) and ethanol were added to 1.0 g of *MCCF-Cocos, MCCL-Cocos* and Avicel PH 102. Observations were recorded.

2.3.4 Elemental / Heavy metal analysis

Analysis for the presence of heavy metals such as lead (Pb), iron (Fe), zinc (Zn) manganese (Mn) and Arsenium (As) was done using Atomic Absorption Spectroscopy, AAS (Model AA-7000, ROM version 1.01, S/N A30664700709 SHIMADZU, Japan).

2.3.5 Total ash content

The total ash content was determined by the measurement of the residue left after the independent combustion of 3 g of *MCCL-Cocos* in a furnace at 550°C for 5 h.

2.3.6 Scanning Electron Microscopy (SEM) test

The morphology and particle shape were investigated using a scanning electron microscope (Phenom Prox, Model no MVE016477830, Netherlands)

2.3.7 X-ray Diffraction (XRD)

An X-ray diffractometer (D/MAX-1200, Rigaku, Japan) powered by a 45 kv X-ray generator

(RINT 2000, Rigaku, Japan) at an input of 35mA and set at 0.020° and step time of 29.10 sec (Cu Kα radiation) and a scan speed of 2° per sec at a 2 theta (Θ) range of 3 - 80° was used. The degree of crystallinity of each sample was calculated from Equation 1 [11].

$$\text{Crystallinity index (C.I)} = [(I_{002} - I_{am} / I_{am})] \times 100 \quad (1)$$

Where I_{002} is the highest peak intensity of the crystalline fraction and I_{am} is the low intensity peak of the amorphous region.

2.3.8 Degree of polymerization and Molecular weight

A U tube viscometer (Technicu size C100, 1983) and an ammoniacal solution of copper was used. Stock solutions of 2% w/v of *MCCL-Cocos* and Avicel PH 102 were separately made. Serial dilutions of 1%, 0.5%, 0.25%, 0.125% w/v were made from each MCC stock solution. Flow time measurements were made for each MCC solution at the different dilutions available and the flow rate measurements determined. The dilutions were considered adequate when the viscometric time measurements for the MCC solutions were identical to that of the ammoniacal solution of copper. The experiments were conducted at ambient temperature (29 ±1°C). The densities of the different MCC solutions were determined using pycnometric method. From the relative viscosity, the reduced viscosity was measured. The intercept of y-axis of the plot of the reduced viscosity versus concentration is the intrinsic viscosity. From the value of the intrinsic viscosity, the degree of polymerization was calculated from Equation 2 [12].

$$(DP)^{0.85} = 1.1 \times \eta \quad (2)$$

where η is the intrinsic viscosity.

The molecular weight can be calculated from Equation 3

$$DP = M / Mo \quad (3)$$

Where M is the molecular weight of the material or polymer, and Mo is the molecular weight of glucose.

Calculations and plots to determine the intrinsic viscosity, relative viscosity, the molecular weight and degree of polymerization were done for each MCC sample.

2.3.9 Swelling capacity determination

The swelling capacity of the microcrystalline cellulose samples *MCCF-Cocos, MCCL-Cocos* and *AV-102* were determined by using the method of Bowen and Vadino [13] with slight modification. A 3 g quantity of *MCCF-Cocos, MCCL-Cocos* and *AV-102* was individually placed in a graduated glass measuring cylinder and tapped to obtain the tapped volume, V_t. A dispersion of each powdered sample was made in 85 mL of water with thorough shaking before making up the volume to 100 mL with more water. The mixture 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 and the swelling capacity calculated as a percentage using Equation 4 [14].

$$\text{Swelling capacity (S.C.)} = [(V_v - V_t)/ V_t] \times 100 \quad (4)$$

2.3.10 Hydration capacity

The hydration capacity was determined using the Kornblum and Stoopaks method [15] with slight modification. A 1 g quantity of each of the sample was put in a 15 mL plastic centrifuge tube and 10 mL of distilled water added to each. Each tube was shaken intermittently over a 2 h period and left to stand for 30 min. Centrifugation at 1000 revolutions per minute (rpm) was done for 10 min. The supernatant was carefully decanted and the wet sediment weighed. The hydration capacity was calculated as:

$$\text{Hydration capacity (H.C.)} = x/y \quad (5)$$

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

2.3.11 Moisture content

A 5 g quantity each of *MCCF-Cocos, MCCL-Cocos* and *AV-102* were placed individually in tarred white porcelain crucibles and dried in a hot air oven (Mermmet®, England) at 105°C until constant weights were obtained. The moisture content was determined as the percentage of the ratio of the weight of the sample after drying to the weight of the sample before drying [16]:

$$\text{Moisture content (M.C.)} = [(Wi-Wf) / Wi] \times 100 \quad (6)$$

Where Wf is the final weight of powder after drying, and Wi is the initial weight of powder before drying.

2.3.12 Moisture sorption test

A 2 g quantity each of the *MCCF-Cocos, MCCL-Cocos* and *AV-102* were placed on the surface of three different 7 mm tarred Petri dishes and kept in desiccators of relative humidities of 96, 84, 75 and 52% respectively at room temperature of 29 ± 1°C. The weight gained over a 5 day period was calculated for each sample from Equation 7. Determinations were done in triplicates.

$$\text{Moisture sorbed (M.S.)} = [(W_2 - W_1)/W_1] \text{ X } 100 \quad (7)$$

Where W_1 is the weight before exposure and W_2 is the weight after exposure

2.3.13 Particle size analysis

The method of nest of sieves was used. Stainless steel sieves (Retsch®, Germany) ranging from 1000 µm to 45 µm arranged in descending order with a collection pan underneath the sieves was placed on a sieves shaker (Retsch® Ltd, Germany). The sieves were weighed empty. A 15 g sample of each of *MCCF-Cocos, MCCL-Cocos* and *AV-102* were placed on the topmost sieve and was agitated for 5 min at an amplitude of 1.5 mm/g. The weight of material retained on each of the sieves was obtained by deducting the weight of the empty sieves from its weight with the powder sample retained. The percentage of samples retained was calculated. Triplicate determinations were done and the mean weight at each determination calculated as [17]:

$$\text{Average diameter} = [\Sigma (\% \text{ retained X mean aperture})] / 100 \quad (8)$$

2.3.14 Bulk and Tapped density

A 10 g quantity each of *MCCF-Cocos, MCCL-Cocos* and *AV-102* was poured freely under gravity into a 50 mL clean, dry, graduated measuring cylinder and the volume occupied by the sample noted as the bulk volume (Vb). The bulk density, Db was calculated from Equation 9 [17]:

$$Db = M / Vb \quad (9)$$

Where M is the mass of the MCC powder.

The cylinder was tapped on a flat wooden platform by dropping the cylinder from a height of about 2 – 3 cm at 2 – 3 sec intervals until there was no further reduction in the volume of the MCC powder. The tapped volume V_t was noted and the tapped density, D_t was calculated from Equation 10:

$$D_t = M / V_t \quad (10)$$

2.3.15 Particle density

The particle density of each of the MCC samples was determined by the liquid displacement method using xylene as the immersion fluid. A pycnometer of 25 mL volume was weighed empty, filled with xylene, stoppered and excess fluid wiped off the body of the pycnometer. This was weighed and denoted as, a. A 1 g quantity of each of the powdered samples was weighed, and noted as Wp. It was placed in the stoppered pycnometer, wiped clean of excess fluid and reweighed. The particle density was calculated from Equation 11 [18].

$$Pd = Wp/[(a + Wp) – b] \text{ x } S.G. \quad (11)$$

Where Pd is the particle density, S.G. is specific gravity of the xylene, a is the weight of pycnometer and xylene, Wp is the weight of powder and b is the weight of pycnometer + xylene + powder. Triplicate determinations were made for each powder sample.

2.3.16 Flow rate and angle of repose

A 10 g quantity of MCC powder was poured into a clamped stoppered clean glass funnel whose orifice was 5 cm above a flat surface. The powder was allowed to flow freely from the funnel unto the platform. The time of flow, the diameter and height of the powder heap formed were measured. The flow rate and tangent of the powder heap were calculated as:

$$F.R. = M / F.T. \quad (12)$$

Where F.R. is flow rate, F.T. is flow time and M is mass of powder used.

$$\text{Angle of repose } (\Theta) = \tan^{-1}(h / r) \quad (13)$$

2.3.17 Hausner's quotient (ratio) and Carr's index

The Hausner's quotient and Carr's index for each powder were calculated from Equations 14 and 15 [12].

Hausner's quotient (H.Q.) = Dt / Db (14)

Carr's Index (C.I.) = (1 – Db / Dt) x 100 (15)

2.3.18 Powder porosity

Powder porosity, ϵ is given as: [19].

ϵ = (1 – Db / Pd) x 100 (16)

where Pd is the particle density, and Db is the bulk density

2.3.19 Compactibility and powder cohesion

The Kawakita Equation describes the relationship between the volume reduction of a powder column and the applied pressure on tapping. A 10 g quantity of the MCC was poured freely into a 50 mL graduated, glass measuring cylinder. The bulk volume, Vo was noted and the cylinder was mechanically tapped at pre-determined incremental number of taps and the volumes occupied by the powder noted each time until there was no further decrease in volume, V. The degree of volume reduction, C was calculated from the values of V and Vo. The degree of cohesion and compactibility of the powder was calculated using the Kawakita Equation 17 [20].

N / C = N / a + 1 / ab (17)

C is derived from (Vo – V)/Vo. The cohesiveness of the powder sample is described by 1/b while 'a' is considered as the compactibility of the powder. When N/C is plotted against N in a graph, 1/a is the slope while 1/ab is the intercept. The procedure was carried out on *MCCF-Cocos, MCCL-Cocos* and *AV-102*.

2.4 Compaction of Microcrystalline Powders

The *MCCF-Cocos, MCCL-Cocos* and *AV-102* were compressed at a target compact weight of 300 mg at different compression loads ranging from 4.90 to 14.71 MPa (Megapascal) using a 10 mm diameter flat faced set of punches for 30 sec. The powder was manually fed into a single punch hydraulic tablet press (Model C, Carver Inc., Winscosin, USA). The punches and dies were lubricated with stearic acid powder before each compaction cycle.

2.4.1 Evaluation of microcrystalline cellulose compacts

The batches of the compacts were each allowed a 24 h post compression relaxation time before evaluation for weight uniformity, thickness, hardness, friability, disintegration time and tensile strengths.

2.4.2 Weight uniformity test

Twenty compacts randomly selected from each batch of *MCCF-Cocos, MCCL-Cocos* and *AV-102* were individually weighed. The mean, standard deviation and coefficient of variation were determined. Acceptance or rejection was based on British Pharmacopoeia tolerance limits for uncoated tablets of > 250 mg which is ± 5% [6].

2.4.3 Thickness/height and diameter test

With the aid of a micrometer screw gauge ten compacts randomly selected from each of the batches were measured for thickness and diameter. The mean and standard deviation was calculated for each batch.

2.4.4 Hardness test

The hardness of ten compacts randomly selected from each batch of MCC was determined using an Erweka® TBH 200 hardness tester (Erweka®, Germany). The mean, standard deviation, and coefficient of variations were determined.

2.4.5 Disintegration time test

Six tablets randomly selected from each batch were used for the test. The test was carried out using an Erweka®ZT-3 double basket disintegration tester (Erweka®, Germany) and each compact held in place with a glass disc inside each cylindrical hole. Each beaker was filled with 500 mL of 0.1 N HCl heated to a temperature of 37 ± 1°C. The time taken for each compact to completely break up and pass through the mesh was noted. Triplicate determinations were made.

2.4.6 Friability test

Ten tablets randomly selected from each batch of the compacts were de-dusted and collectively weighed into one of the drums of an Erweka model TAR 200 (Erweka®, Germany) twin drum electronic friabilator programmed to revolve at 25 revolutions per minute (rpm) for 4 min. At the end

of the exercise the tablets were collected and de-dusted and any broken tablets were rejected. The tablets were reweighed and the abrasion resistance (B) calculated from Equation 18 [21].

$$B = 100 (1 – W / Wo) \text{ or } 100 (Wo – W / Wo) \quad (18)$$

Where Wo is the initial weight and W is the final weight.

2.4.7 Tensile strength

The tensile strengths of the compacts were determined based on the hardness, thickness and tablet diameter using Equation 19 [22].

$$\text{Tensile strength (TS)} = 2P / \pi dt \quad (19)$$

Where P is the breaking force, d is the tablet diameter, t is the tablet thickness.

2.4.8 Heckel analysis

The Heckel Equation analyzes the relative density of a powder bed to the applied compression pressure during tableting. It describes the densification behavior of the powder bed from the point the die is filled to the time a quantified pressure is applied. It also describes the deformation mechanism of the powder in forming the compact. The Equation is stated as [23].

$$\ln (1 / 1-D) = KP + A \quad (19)$$

where D is the relative density of a powder compact at pressure P, K is a constant to measure the plasticity of the compressed material, A is the Y axis intercept, related to die filling and particle rearrangement before deformation and bonding of the separate particles.

2.4.9 Reworking potential of microcrystalline cellulose

Compacts of the microcrystalline cellulose compressed at the different compression loads were randomly selected, crushed to fine particles, screened through a 250 µm stainless sieve and recompressed at the same compression loads and target compact weights of 300 mg using 10 mm flat faced punches. Reworked compacts were evaluated 24 h post compression for uniformity of weight, thickness, hardness, and friability. Plots of hardness against compression pressure were made for the initial compacts and the reworked compacts. The area under the curve (AUC) of each plot was determined using Wolfram/Alpha Widget software. The re-workability was calculated as the percentage of AUC of reworked MCC (AUCr) against AUC of initial MCC (AUCi) compact.

$$\text{Reworking Potential (R.P.)} = (AUCr/AUCi) \times 100 \quad (20)$$

2.5 Statistical Evaluation

The data obtained were statistically analyzed using ANOVA and students t test (SPSS version 21). Values were considered significant at P = 0.00 or below or equal to 0.05.

3. RESULTS AND DISCUSSION

3.1 Physicochemical Properties

The yield of α-cellulose and microcrystalline cellulose obtained from CN were 29.22 and 13.88% respectively with reference to the dry starting material. Results of organoleptic and some physicochemical evaluation tests show the MCCs to be fine, odorless, tasteless and brownish in color. Except for the color, all the other characteristics were similar to Avicel PH 102.

The absence of a dark blue color on the treatment with iodine showed the absence of starch while the presence of a blue color when treated with sulphuric acid confirmed that the sample is MCC (Table 1). The insolubility of the MCCs in water and some organic solvents is a feature common with MCC and is attributable to their high crystallinity and structure. The samples were near neutral as shown by the pH values obtained (6.58 ± 0.19 to 6.49 ± 0.21). This quality makes them suitable for the formulation of both acidic and basic drugs. The low ash content (1.94) shows that the material was well processed and contains minimal organic matter. The moisture content ranged from 6.58 to 8.88 and falls within compendial set limits [10]. The DP of 222 obtained is typical of MCC and conforms to values of < 350 that is characteristic of MCC [10] (Table 1). The molecular weight of MCC derived from CN (39,994.61) is dependent on the number of polymer chains that are attached to it after polymerization and the value obtained is characteristic of processed cellulose such as Avicel PH 102 [24,25,26]. Diffractograms of the samples (Figs. 1 & 2) showed diffraction patterns that are similar to Avicel PH 102 (Fig. 3). Peaks were observed at 22.74° and 17.00° of 2

theta (θ) for the crystalline and amorphous regions respectively for *MCCF-Cocos* and at 22.86° and 17.50° of 2θ for *MCCL-Cocos*. These gave percentage crystallinity values of 82.25 and 80.15% for *MCCF-Cocos* and *MCCL-Cocos* respectively. These values were also comparable with that obtained for Avicel PH 102 which was 80.15% at 23.32° and 16.24° of 2θ. Crystallinity values of 60 – 80% have been reported for MCC [27,28]. The micrographs from SEM test (Fig. 4) for *MCCL-Cocos* showed strands whose morphology, texture and size resembled AV-102 (Fig. 5). Elemental analysis results show that the samples were safe as the value of heavy metals was within compendial and World Health Organization (WHO) safe limits [10,29].

The moisture hysteresis results show an increase in the amount of moisture adsorbed as the relative humidity increased. *MCCL-Cocos* significantly (P = 0.00) adsorbed more water than *MCCF-Cocos* at the different relative humidities tested except at 96%. Avicel PH 102 adsorbed more water than the MCCs from *CN* at the different relative humidities tested.

Hydration capacity has been described as the amount of water a material is able to absorb on hydration while swellablity indicates increase in volume of water taken up after absorption [30]. The hydration capacity of the *MCCF-Cocos* was 2.33 ± 0.11 (Table 1) and is lower than that obtained with the lyophilized

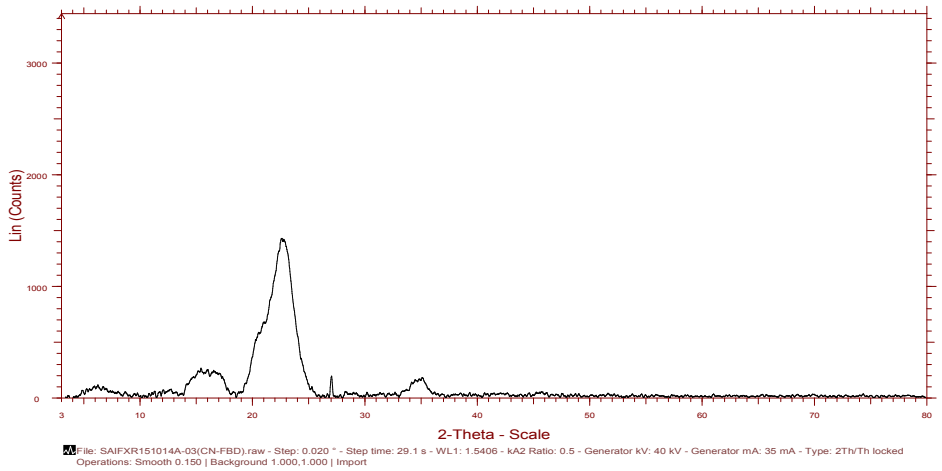

Fig. 1. X-ray diffractogram of *MCCF-Cocos*

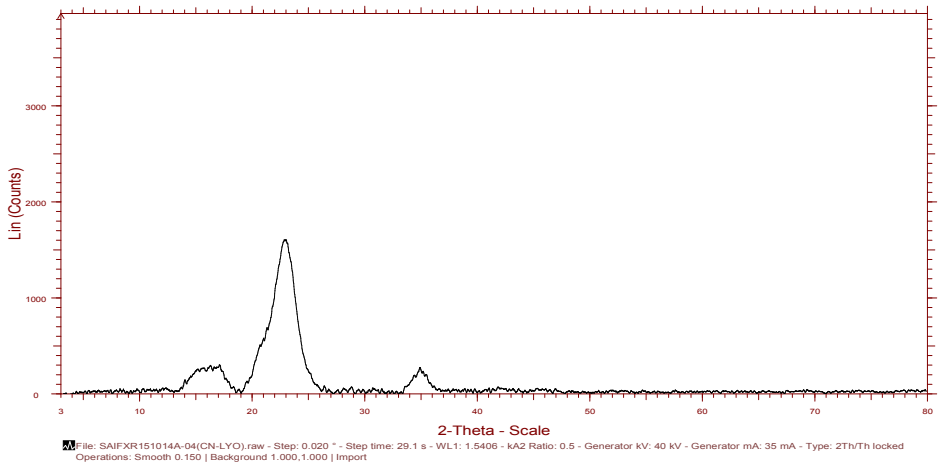

Fig. 2. X-ray diffractogram of *MCCL-Cocos*

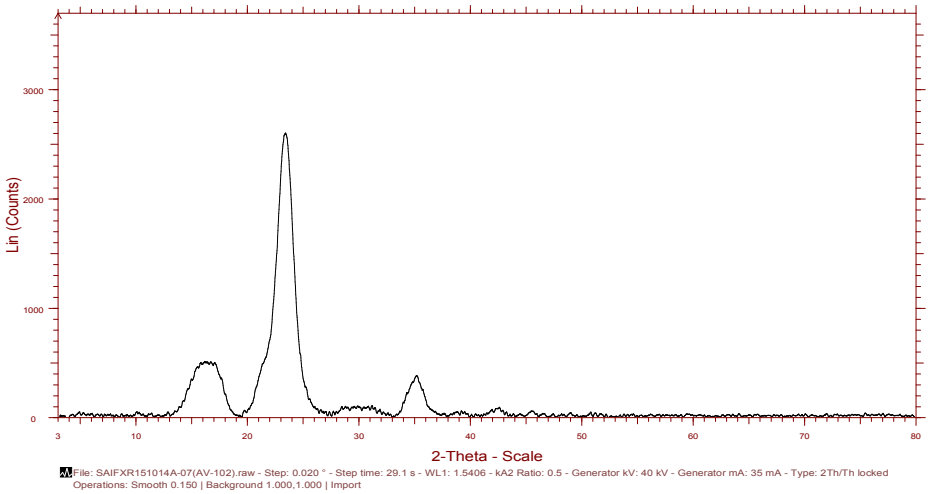

Fig. 3. X-ray diffractogram of AV-102

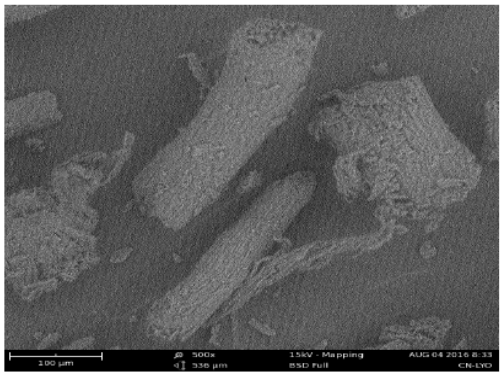

Fig. 4. SEM micrograph of *MCCL-Cocos*

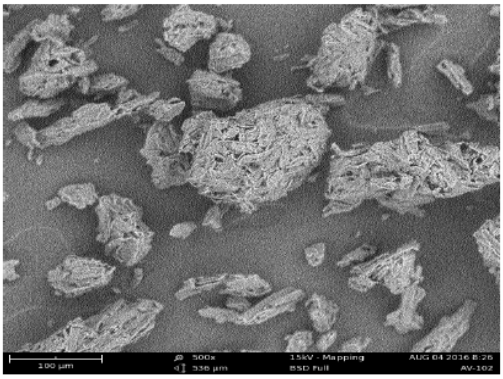

Fig. 5. Scanning electron micrograph of AV-102

powder (2.84 ± 0.09). Both values were lower than that of *AV-102* (3.55 ± 0.07). Swelling capacity values of the *MCCF-Cocos* was 33.63 ± 2.31 % and this represents about one-third of that for *AV-102* (111.57 ± 3.53). These moisture values impart positively in the disintegration characteristic of MCC in tablet formulations as water uptake could occur by two mechanisms: wicking and swelling.

3.2 Micromeritic Properties

Some of the powders properties are shown in Table 3. The bulk and tapped densities, flow rate, and packing fraction of *MCCF-Cocos* was higher than those of the lyophilized powder, *MCCL-Cocos*. Also angle of repose (26.63 ± 2.86°), Hausner's quotient (1.16 ± 0.01) possessed by the fluidized dried powder was lower than angle of repose (35.91 ± 1.29), Hausner's quotient (1.28 ± 0.01) and Carr's index (27.36 ± 5.25%) for *MCCL-Cocos.* This implies that the *MCCF-Cocos* has a greater tendency to flow than *MCCL-Cocos*. However, the porosity and particle density values obtained for the lyophilized powder were higher than the fluid bed dried powder. This would lead to better densification. Porosity of *MCCL-Cocos* was significantly (P = 0.01) higher than *MCCF-Cocos* but comparable with AV-102 implying higher voids/air spaces in the powder bed for *MCCL-Cocos*. The packing fraction of *MCCF-Cocos* (0.87 ± 0.01) was higher than that of *MCCL-Cocos* (0.79 ± 0.01) and shows a more densely packed and consolidated

powder bed (Table 2) which can translate to better flowability for *MCCF-Cocos* than *MCCL-Cocos*.

The Kawakita plot of the powders is shown in Fig. 6. Compactibility and cohesiveness values derived from the graph (Table 3) show higher

Table 1. Some physicochemical properties of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

Sample/Parameter		*MCCF-Cocos*	*MCCL-Cocos*	AV- 102
Iodine solution		Reddish brown color	Reddish brown colour	Reddish brown colour
Sulphuric acid(60% v/v)		Blue color	Blue colour	Blue colour
Solubility in water, alcohol, acetone, dilute mineral acid.		Insoluble	Insoluble	Insoluble
Solubility in ammoniacal solution of copper tetramine.		Completely soluble	Completely soluble	Completely soluble
pH ± SD		6.58 ± 0.19	6.49 ± 0.21	6.74 ± 0.31
Ash content		1.94	1.94	1.95
% crystallinity		82.14	81.25	80.15
Molecular weight		39,994.61	39,994.61	42,156.48
Degree of polymerization		222	222	234.40
Hydration capacity		2.33 ± 0.11	2.84 ± 0.09	3.55 ± 0.07
Moisture sorption (%)	RH 96 %	4.80 ± 0.01	4.80 ± 0.22	7.80 ± 0.05
	RH 84 %	1.10 ± 0.10	1.40 ± 0.15	1.60 ± 0.20
	RH 75 %	0.50 ± 0.02	0.70 ± 0.10	1.10 ± 0.01
	RH 52 %	0.20 ± 0.05	0.40 ± 0.01	0.60 ± 0.03
Elemental analysis (ppm)	Pb	0.00	0.00	0.00
	Mn	0.00	0.00	≤ 10
	Zn	0.12	0.12	≤ 10
	Fe	0.00	0.00	≤10
	Na	1.09	1.09	≤10
	As	0.01	0.01	≤10
Swelling capacity (%)		33.63 ± 2.31	23.38 ± 4.13	111.57 ± 3.53
Loss on drying (%)		8.88	7.96	6.58

Table 2. Some micromeritic properties of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

Sample /Parameter	*MCCF-Cocos*	*MCCL-Cocos*	*AV- 102*
Bulk density (g/mL)	0.40± 0.04	0.32 ± 0.01	0.31 ± 0.04
Tap density (g/mL)	0.47 ± 0.03	0.41 ± 0.03	0.38 ± 0.02
Angle of repose (˚)	26.63 ± 2.86	35.91 ± 1.29	30.52 ± 2.35
Flow rate (g/s)	5.46 ± 0.44	Poor flow	5.23 ± 0.22
Carr's index (%)	12.77 ± 1.36	5.25 ±3.85	18.96 ± 0.67
Packing Fraction	0.87 ± 0.01	0.79 ±0.01	0.81 ± 0.01
Hausner's quotient	1.16 ± 0.01	1.28 ± 0.01	1.23 ± 0.01
Porosity (%)	73.74 ± 0.53	79.86 ± 0.01	80.10 ± 0.27
Particle density	1.55 ± 0.02	1.60 ± 0.01	1.56 ± 0.07
Particle size (µm)	166.69	176.85	154.11

Table 3. Compactibility and cohesiveness of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

Sample	a	b	1/a	1/b(P_k)	1/ab (%)	R^2
MCCF-Cocos	0.22	0.11	4.60	9.09	22.40	0.998
MCCL-Cocos	0.27	0.14	4.56	7.14	19.37	0.992
AV-102	0.22	0.11	3.39	9.09	12.42	0.992

values for *MCCL-Cocos* than *MCCF-Cocos*. The compactibility values obtained suggests that the lyophilized powder bed would undergo greater densification on application of stress or agitation by tapping. Cohesiveness describes the ability of the powders to adhere to each other leading to aggregation and when values are high, flow would be impaired. The lyophilized MCC had a higher value than the fluid bed dried MCC and thus would have a poorer flow. Comparatively, *MCCL-Cocos* has a significantly (P = 0.02) higher compactibility than *MCCF-Cocos* but lesser than AV-102.

3.3 Compact Properties

The compacts formed weighed between 290.10 ± 2.75 to 301.60 mg ± 2.48%. These values fall within the BP set limits of ± 5% for tablets weighing above 250 mg. Increased compression load resulted in a decreased thickness of the compacts. The friability values were all below 1% and decreased as the compression pressure increased. *MCCL-Cocos* had values that were consistently lower than their corresponding *MCCF-Cocos* compacts at the same compression pressures. There was also a general increase in hardness as the compression load increased. The lyophilized compacts were significantly (P = 0.01) harder than the fluidized dried compacts. All values were above 40 N (Fig. 8) and could be considered strong enough to withstand rigors of handling and transportation. Tensile strength values (Fig. 9) were in the range of 1.73 – 4.73 MN/m^2 for the *MCCF-Cocos* compacts and 1.98 – 5.30 MN/m^2 for the

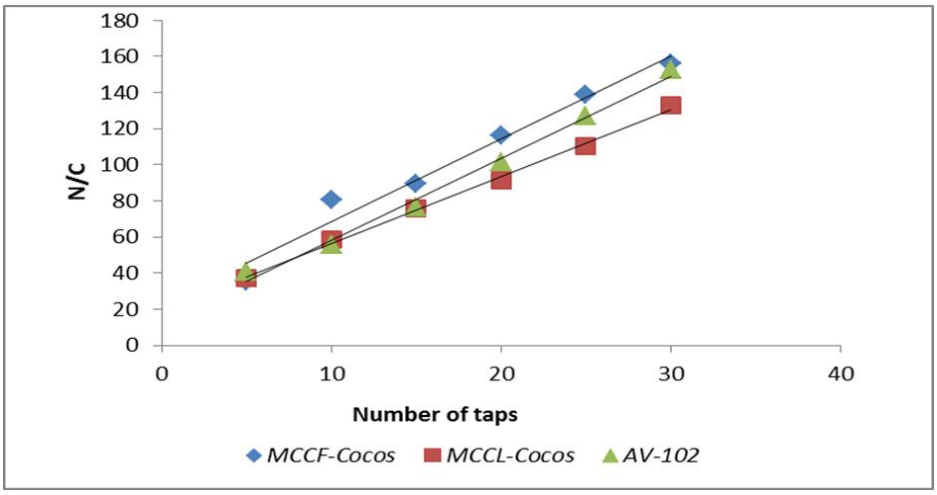

Fig. 6. Kawakita plots of *MCCF-Cocos, MCCL-* and *AV-102*

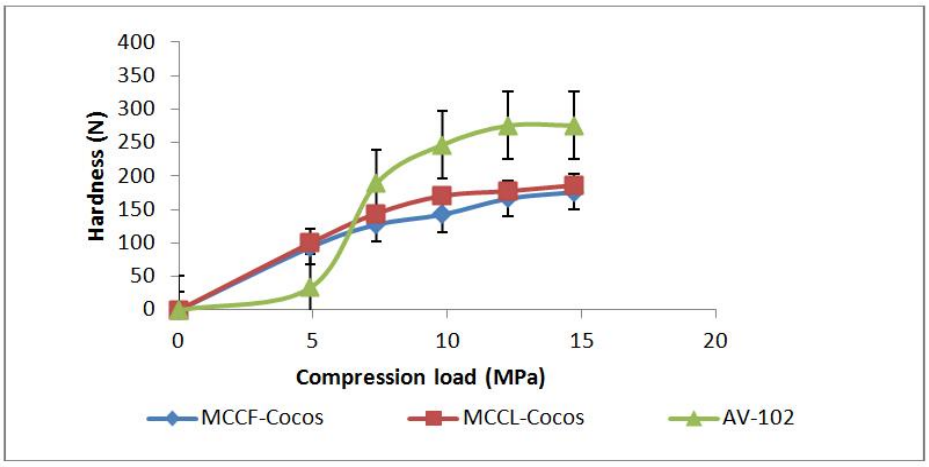

Fig. 7. Hardness plots of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

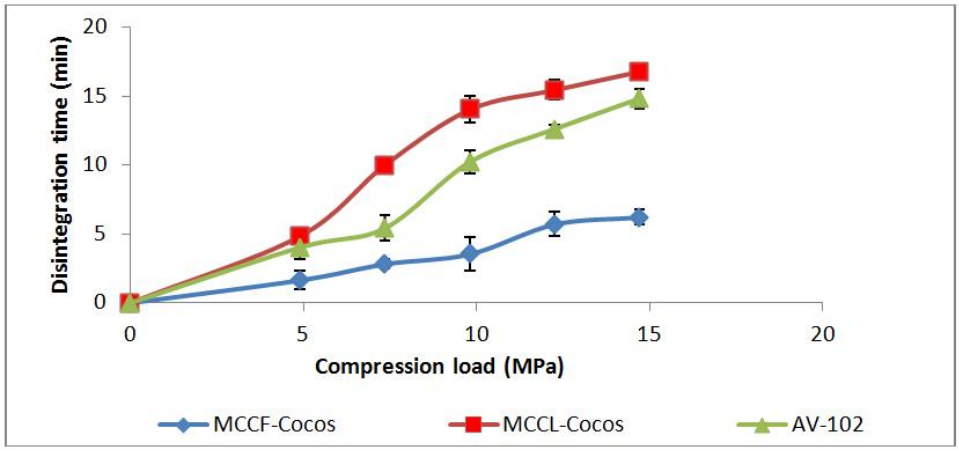

Fig. 8. Disintegration efficiency of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

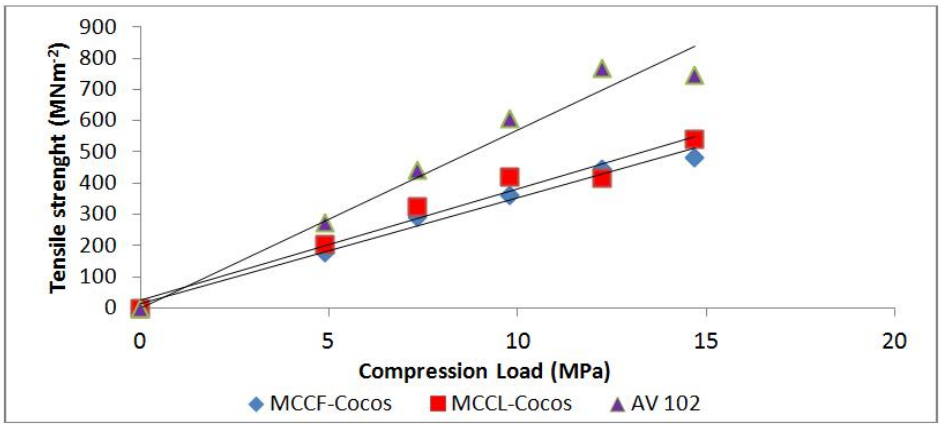

Fig. 9. Tensile strength of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

MCCL-Cocos. The lyophilized compacts were consistently and significantly (P = 0.01) stronger at all compression loads. Values for AV-102 ranged from 0.73 – 7.31 MN/m^2. The disintegration time of all the compacts was within 15 min except for *MCCL-Cocos* compacts compressed at 12.26 and 14.71 MPa. The *MCCL-Cocos* compacts had disintegration time values that were significantly (P = 0.02) higher than the *MCCF-Cocos* compacts (Fig. 7). The hardness, disintegration time and friability were within both BP 2012 and USP 2009 specifications and thus were adjudged good [10,31]. The Heckel parameters (Table 4) were derived from the straight line portion of the Heckel plot (Fig. 10). The yield pressure, Py describes the tendency of the material to plasticize or fragment under an applied pressure which can be related to its compressibility. *MCCF-Cocos* and *MCCL-Cocos* values were 0.14 and 0.18 respectively while *AV-102* was 0.22. This implies that *MCCF-Cocos* exhibited a faster plasticity or onset of deformation than *MCCL-Cocos* and *AV-102*. The lyophilized powder compacts had a plastic behavior equivalent to the commercial sample, *AV-102*. The D_o (initial packing in the die as a result of filling by powder) value of *MCCF-Cocos* was higher (0.26), than *MCCL-Cocos* and *AV-102*. This implies that *MCCF-Cocos* exhibited a higher degree of packing and re-arrangement on die filling than both the lyophilized and *AV-102*. In terms of degree of particle packing at zero and low pressure (D_A), particle re-arrangement and fragmentation (D_B), in the early phase of compression, *AV-102* had the highest value followed by *MCCF-Cocos and MCCL-Cocos.* Generally, all the MCC powders had good compactibility and plasticity, *MCCL-Cocos* was more compactible than *MCCF-Cocos*.

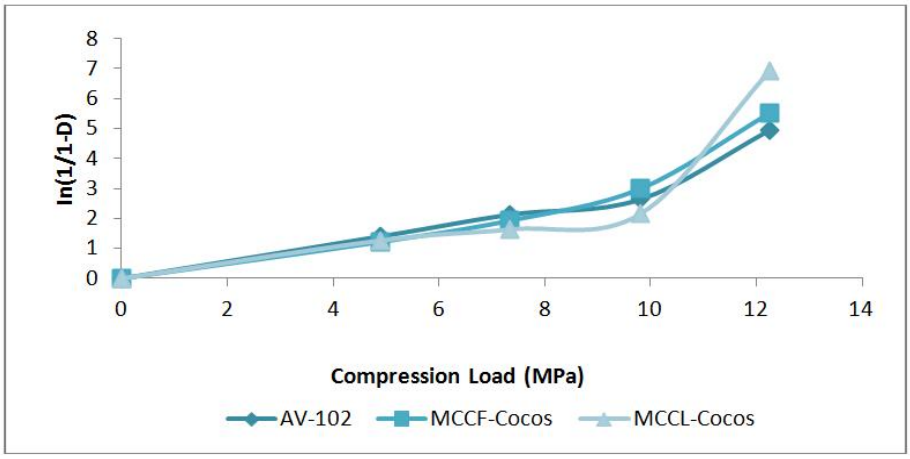

Fig. 10. Heckel plot of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

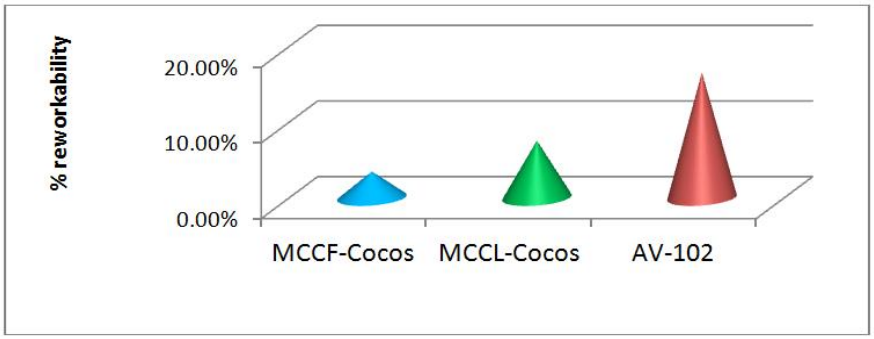

Fig. 11. Reworking potential of *MCCF-Cocos, MCCL-Cocos* and *AV-102*

Table 4. Parameters of Heckel plot

Sample	K	Py (MNm^{-2})	D_o	D_A	D_B	A	R^2
MCCF-Cocos	11.14	0.14	0.26	0.57	0.31	0.18	1.00
MCCL-Cocos	4.09	0.18	0.20	0.31	0.11	0.16	0.99
AV-102	4.46	0.22	0.19	0.91	0.00	0.21	0.98

The reworking potentials of the powders are shown in Fig. 11. All were re-workable implying that after compaction or exposure to similar stresses, the powders do not lose much of its compressibility and densification behavior. It could still be useful in the formulation of tablets that would have good mechanical properties.

4. CONCLUSION

The powder characterization test results show that variation in processing method such as drying procedure significantly affected the characteristics of the MCC derived from *Cocos nucifera* in terms of flowability and the indices associated with it. The bulk and tapped densities, flow rate, Carr's Index, and packing fraction of the *MCCF-Cocos* were higher than *MCCL-Cocos* while angle of repose, Hausner's quotient, porosity and particle density of *MCCL-Cocos* were higher than *MCCF-Cocos*. This obviously means that the *MCCF-Cocos* flowed better than the *MCCL-Cocos*. The flowability of *MCCF-Cocos* was similar to that of AV-102. The densification, volume reduction and compactibility as assessed by the Kawakita model show that *MCCF-Cocos* differed from the *MCCL-Cocos* but was similar to AV-102. In terms of mechanical strength and tabletability, compacts formed from *MCCL-Cocos* were

significantly (P = 0.01) stronger than the compacts formed from the *MCCF-Cocos*. Compacts of AV-102 were stronger than compacts of both *MCCF-Cocos* and *MCCL-Cocos*. Thus hardness, tensile strength, and disintegration of compacts formed from *MCCL-Cocos* and AV-102 were of higher value than those of *MCCF-Cocos* while the compact friability was in the order AV-102 < *MCCL-Cocos* < *MCCF-Cocos* respectively. The hardness, disintegration time and friability were adjudged good because they conformed to both BP 2012 and USP 2009 specifications for uncoated tablets. Heckel evaluation showed that the MCCs undergo plasticity and slippage even on the application of low pressure which explains their good mechanical properties. All the MCCs: AV-102, *MCCL-Cocos* and *MCCF-Cocos* were quite reworkable but AV-102 had the highest reworking potential.

CONSENT

It is not applicable.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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