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# Microstructure and flow properties of lyophilized mango pulp with maltodextrin

Marcos R. A. Afonso[1], Brena K. M. Rodrigues[1], José M. C. da Costa[1], Ana C. P. Rybka[2] & Nedio J. Wurlitzer[3]

[1] Universidade Federal do Ceará/Centro de Ciências Agrárias/Departamento de Engenharia de Alimentos. Fortaleza, CE. E-mail: m.r.a.afonso@gmail.com (Corresponding author) - ORCID: 0000-0002-8149-6276; brena_kelle5@hotmail.com - ORCID: 0000-0001-8807-6891; correiacostaufc@gmail.com - ORCID: 0000-0002-6266-6778
[2] Embrapa Semiárido. Petrolina, PE. E-mail: ana.rybka@embrapa.br - ORCID: 0000-0002-5747-3664
[3] Embrapa Agroindústria Tropical. Fortaleza, CE. E-mail: nedio.jair@embrapa.br - ORCID: 0000-0003-4607-5254

**ABSTRACT:** The present study had as objective to determine the flow properties and behavior of lyophilized mango pulp powder as a function of different concentrations of maltodextrin. In the samples of the powders contain 5, 10 and 15% of maltodextrin the angle of effective internal friction, wall friction angle, flow index and bulk density were determined. The microstructure was evaluated by scanning electron microscopy. The freeze-dried samples are characterized as having an amorphous structure, and the drying aid used modified the surface of the particles. The flow index was 3.19, 4.28 and 4.53 for samples containing, respectively, 5, 10 and 15% maltodextrin. Increasing the concentration of maltodextrin in the mango pulp decreased the effective angles of internal friction and wall friction. The bulk density of the powders increased with increasing concentration of maltodextrin for the samples containing 5, 10 and 15% of the maltodextrin, being equal to 597.8, 689.8 and 691.3 kg m$^{-3}$, respectively. Thus, it was concluded that the addition of maltodextrin modified the shape of the particles, decreased segregation, affected the flow properties of the mango powders, facilitating flow and increasing their bulk density.

**Key words:** powdered fruit, microscopy, flow index, powder rheology

## Microestrutura e propriedades de escoamento da polpa liofilizada de manga com maltodextrina

**RESUMO:** Objetivou-se com o trabalho determinar as propriedades e o comportamento do escoamento do pó da polpa de manga liofilizada em função de diferentes concentrações de maltodextrina. Nas amostras dos pós contendo 5, 10 e 15% de maltodextrina foram determinados o efetivo ângulo de atrito interno, ângulo de atrito com a parede, índice de fluxo e densidade consolidada. A microestrutura foi avaliada através de microscopia eletrônica por varredura. As amostras liofilizadas se caracterizam como de estrutura amorfa, e o adjuvante de secagem utilizado modificou a superfície das partículas. Os índices de fluxo foram 3,19, 4,28 e 4,53 para as amostras contendo, respectivamente, 5, 10 e 15% de maltodextrina. O aumento da concentração de maltodextrina na polpa de manga diminuiu os ângulos de atrito interno e atrito com parede. Já para a densidade aparente dos pós houve uma elevação em seus valores com o aumento da concentração de maltodextrina, sendo observados valores de 597,8, 689,8 e 691,3 kg m$^{-3}$ para as amostras contendo 5, 10 e 15% de maltodextrina, respectivamente. Dessa forma, concluiu-se que a adição da maltodextrina modificou a forma das partículas, diminuiu a segregação, afetou as propriedades de fluxo da manga em pó, facilitando o fluxo e aumentando a densidade consolidada.

**Palavras-chave:** fruta em pó, microscopia, índice de fluxo, reologia de pós

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## Introduction

Mango (*Mangifera indica* L.) is one of the most produced fruits in the world, being highly appreciated for its taste, color and aroma, and has many nutrients and short period of storage. In Brazil, the Northeast region is the main area of production and exportation, and the variety Tommy Atkins is one of the most popular (Marques et al., 2010; Sivakumar et al., 2011). Since it is highly perishable, technologies of conservation, such as drying, become interesting.

Drying is a technique that allows the increase in food stability, avoiding certain reactions of deterioration. Drying by lyophilization, besides having these advantages, provides greater retention of chemical and sensory properties of foods compared to other methods of food drying. The produced powdered foods are adequate and safe, participating in the most varied formulations in the industries (Martins et al., 2011; Xu et al., 2015).

Drying of foods which contain large amount of sugars results in highly hygroscopic products. Therefore, it is fundamental to use drying aids to facilitate the dehydration and operations of transport and storage. There are many of these agents but maltodextrin is the most used, especially in products with sensitive flavor and pigment (Cai & Corke, 2000).

Knowing rheological properties of food powders is necessary when these products are processed and stored, because the forces of attraction existing among their particles may favor and in some cases increase their problems of flow (Lopes Neto et al., 2009).

It is difficult to estimate the stability of food powders in storage when information on the physical, chemical and morphological properties of the studied material is not available, because each food has different characteristics. There are few scientific studies on the rheological properties of fruit powders, most of which in feed for animals, powdered milk and non-food powders, such as those of Fitzpatrick et al. (2004), Lopes Neto et al. (2009) and Campos & Ferreira (2013), respectively.

In this context to know the types of flow of this product and aspects of its microstructure, this study aimed to determine the flow properties of lyophilized mango pulp powder, as well as its microstructure, as a function of different concentrations ($m\ m^{-1}$) of maltodextrin.

## Material and Methods

The mango (*Mangifera indica L.*) variety selected for the study was Tommy Atkins, 2017 season, cultivated in Petrolina, PE, Brazil. It was transported by truck to Embrapa Tropical Agroindustry in Fortaleza, CE, Brazil. Fruits were sanitized with chlorinated solution (100 $mg\ L^{-1}$), then pulped in a Bonina 0.25 df pulper machine from ITAMETAL. The experiment used the drying aid maltodextrin DE20 from Cargill Brasil, purchased at the local market of Fortaleza, CE.

Maltodextrin was added in mango pulp at three concentrations, 5, 10 and 15%, thus obtaining three formulations. Maltodextrin and mango pulp were mixed in a solution agitator (TE - 120 TURATEC) for 3.30 min at 5 rpm. Then, 120 g of each sample were placed on a metal tray, with thickness of 1.5 cm and frozen to -38 °C in ultra-freezer from the company Terroni, model CL90 - 40V for 24 h.

After that, the samples were dehydrated for 24 h in a lyophilizer Terroni, model LS 3000, with final pressures between 20 and 26.7 Pa and sample temperature of 25 °C. Dehydrated mango pulp was removed from the trays and ground using the benchtop grinder MA 048, from the company Marconi, to obtain the powdered product. Then, the powders were placed in airtight laminated package composed of PET, aluminum and polyamide.

To evaluate the microstructure of the powders, the samples were deposited on double-sided adhesive tape, fixed on a metal frame and coated with platinum and gold in a metallizer, model Quorum Q 1550T ES. Micrographs with resolutions of 1000 and 2000x were obtained using a scanning electron microscope (SEM), model Quanta FEG 450. Samples of mango pulp powders containing 5, 10 and 15% of maltodextrin DE20 were evaluated.

In the rheological evaluation of the powders, the following parameters were determined: principal consolidation stress and unconfined failure strength, bulk densities, effective angles of internal friction and wall friction, through the device Powder Flow Test (PFT) from Brookfield Engineering Laboratories. The samples, in duplicates, with 20 g of mango pulp powders containing 5, 10 and 15% of maltodextrin DE20 were placed on circular stainless-steel trays and transferred to the device, which applied varied stresses on the surface of the powders through a circular stainless-steel disc to measure the rheological parameters.

The flow behavior of the powders was evaluated using the flow index (FI) as shown in Eq. 1 and Table 1, according to Lopes Neto et al. (2009).

$$FI = \frac{\sigma_1}{\sigma} \qquad (1)$$

where:

FI - flow index;

$\sigma_1$ - average principal consolidation stress, kPa; and,

$\sigma_c$ - average unconfined failure strength, kPa.

**Table 1.** Classification of the type of flowability of storable solid products

| Type of flow | Flow index (FI) |
|---|---|
| Non-flowing | FI < 1 |
| Very cohesive | 1 < FI < 2 |
| Cohesive | 2 < FI < 4 |
| Easy flowing | 4 < FI < 10 |
| Free flowing | FI > 10 |

## Results and Discussion

Figure 1 presents the microstructures of the powders obtained with different concentrations of maltodextrin.

In general, the particles exhibited varied and irregular shapes, besides presence of pores, indicated by the arrows in Figure 1, which are typical of lyophilized products. Conceição et al. (2016) claim that powders obtained by lyophilization have a porous structure due to the solid state of water during the

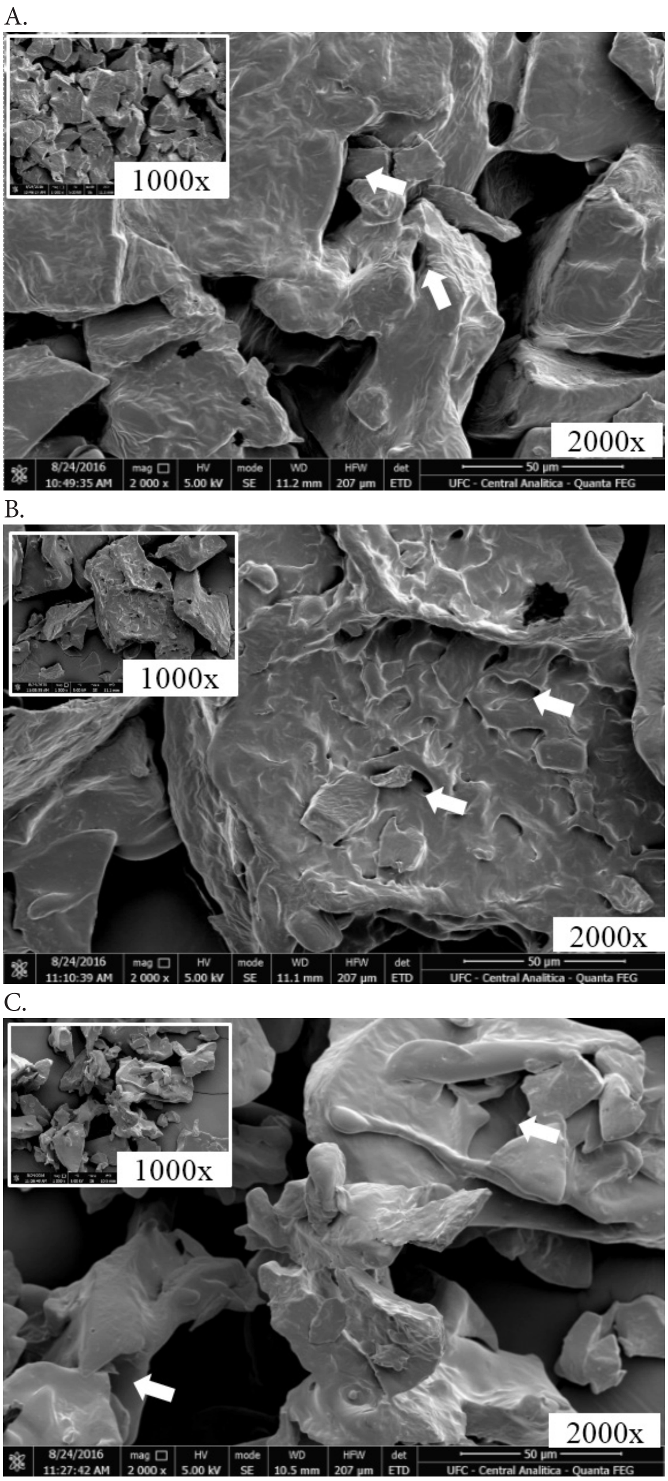


**Figure 1.** Electron scanning micrographs (1000 and 2000x) of mango pulp powder containing (m m$^{-1}$) 5 (A), 10 (B) and 15% (C) of maltodextrin 20DE

lyophilization process, which protects the primary structure of the food.

Particle surfaces were predominantly rough and with evidence of segregation, particularly among powders containing 5% of maltodextrin (Figure 1A). Fazaeli et al. (2012) studied the microstructure of foods obtained by different drying methods and observed that particle agglomeration could be caused by the low concentration of drying agents used, which is consistent with the results of the present study. This claim can be explained by the structural modifications caused by these agents, such as rounding of particle edges, reducing the segregation of the particles of the powders.

According to Figure 1, the increase in maltodextrin concentration in the formulation of the samples caused changes in the particles' state of segregation and surface, which showed more curved edges as the concentration of this drying aid increased (Figures 1A, B and C) and was less rough with maltodextrin concentration of 15% (Figure 1C). This behavior according to Tonon et al. (2009) can improve the flow characteristics of the powder.

In Table 2, it is possible to note that the values found, regarding the unconfined failure strength ($\sigma_c$), were higher for samples which received 5% of maltodextrin and lower for those containing 10 and 15%. Thus, as maltodextrin concentration increased there was a reduction in the flow strengths of the powders. Such decrease occurs due to structural changes in the particles caused by maltodextrin, such as reduction of roughness and more rounded edges. Rocha et al. (2017) observed the same behavior analyzing the flow strengths of mango pulp powders containing different concentrations of maltodextrin. Szulc & Lenart (2010) also found changes of flow strength as a function of size and type of particles in the study of flowability of baby food powders.

The principal consolidation stress applied to the powders (Figure 2) results from the force applied on the samples. As these stresses on the powders increased, there was a proportional increment in the bulk density of the studied samples (Figure 2). This behavior is explained by the compaction of the powder, which occurs when it is subjected to stress (Campos & Ferreira, 2013).

**Table 2.** Results of the flow strength of mango pulp powders containing 5, 10 and 15% of maltodextrin

| Maltodextrin concentration | | | | | |
|---|---|---|---|---|---|
| 5% | | 10% | | 15% | |
| (m m$^{-1}$) | | | | | |
| $\sigma_c$ | $\sigma_1$ | $\sigma_c$ | $\sigma_1$ | $\sigma_c$ | $\sigma_1$ |
| (kPa) | | | | | |
| 1.39 | 2.33 | 0.81 | 2.13 | 0.68 | 2.09 |
| 1.74 | 4.80 | 1.22 | 4.61 | 1.05 | 4.46 |
| 2.67 | 9.29 | 2.03 | 9.02 | 2.07 | 8.93 |
| 5.27 | 18.87 | 3.75 | 17.73 | 3.54 | 17.73 |

* $\sigma_1$ – Principal consolidation stress; ** $\sigma_c$ – Unconfined failure strength

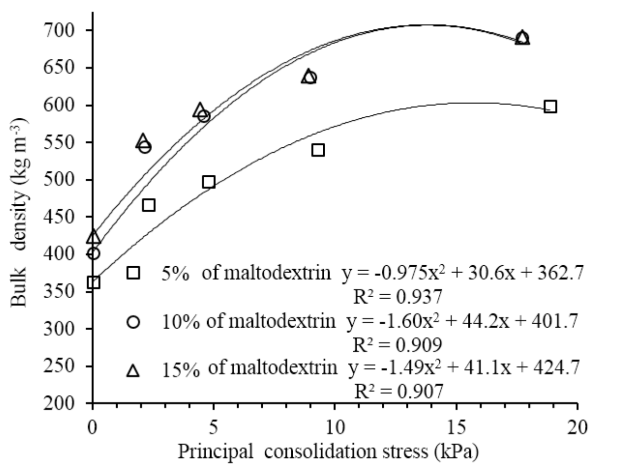


**Figure 2.** Bulk density of lyophilized mango pulp powders containing 5, 10 and 15% of maltodextrin

The density increased with the increment in maltodextrin concentration (Figure 2) and this behavior may be attributed to the shape of the particles and their surface characteristics. Rocha et al. (2017) observed the same behavior analyzing mango pulp powders containing maltodextrin obtained by drying in a spray dryer. This behavior can be explained by the changes in the size, contact among particles and amount of air entrapped between them. The micrographs (Figure 1) revealed an increase in the size of the particles of the powders containing 10 and 15% of maltodextrin, in relation to 5%, which results in lower amount of air entrapped between particles. In addition, according to Abdullah & Geldart (1999), the increase in particle size leads to powders with higher density and higher flowability. According to Mallol et al. (2008) and Mohammed et al. (2011), the shape of the particle, roughness, cohesion and agglomeration influenced the bulk density of the powders.

Campos & Ferreira (2013) state that powders with highest differences between initial and final densities of compaction resulted in more cohesive powders. The mango powders (Figure 2) showed initial bulk densities of 362.7, 401.7 and 424.7 kg $m^{-3}$ in the samples containing 5, 10 and 15% maltodextrin, respectively, and the sample containing 15% showed smaller difference between initial and final densities of compaction. Similar results were found by Rocha et al. (2017) for mango pulp powders containing 10 and 20% of maltodextrin, where the highest concentration of the drying aid resulted in smaller difference between initial and final densities in the powder.

Based on the results obtained for the effective angles of internal friction (δ) (Table 3), the values decreased with the increase of maltodextrin concentration in the formulation of the mango powders. This behavior was possibly caused by the alteration caused by maltodextrin in the samples, making them smoother and larger, which favor their flowability (Abdullah & Geldart, 1999).

Oliveira et al. (2014) found effective angles of internal friction (δ) of 31.0-41.2° and 27.8-34.2° for powders of *Coffea arabica* and *Coffea canephora*, respectively, and attributed such reduction to the water content (increases cohesion forces) and to the points of contact between particles (the greater the contact, the higher the resistance to flowing).

Regarding the angles of friction with the wall obtained for the samples, it was observed that the increase in maltodextrin concentration in the formulation resulted in lower angles of friction with the wall. Thus, the lower the angle, the lower the inclination needed by a wall to ensure the flow of the powders.

As in the present study (Table 3), Rocha et al. (2017) analyzed mango pulp powders containing 10 and 20% of maltodextrin obtained in spray dryer and reported lower and upper values of 17.4 and 22.5° and 15.6 and 19.3°, respectively.

**Table 3.** Effective angle of internal friction δ (°) and angle of friction with the smooth steel wall φ (°) for mango pulp powders containing 5, 10 and 15% of maltodextrin

| Samples (%) | Effective angle of internal friction, δ (°) | | Angle of friction with smooth steel wall, ϕ (°) | |
|---|---|---|---|---|
| | Lower | Upper | Lower | Upper |
| 5 | 48.7 | 58.0 | 19.8 | 23.9 |
| 10 | 45.6 | 50.1 | 16.0 | 21.3 |
| 15 | 45.3 | 48.2 | 14.9 | 18.9 |

Lopes Neto et al. (2009) obtained lower and upper values of 10.4 and 13.2° for wheat flour and 8.7 and 11.5° for corn flour.

According to Fitzpatrick et al. (2004), the angle of wall friction represents the adhesive resistance between the powder and the material of the wall of the storage environment, and the higher it is, the more difficult for the powder to move along the wall.

Thus, as observed in the micrographs of the powders, smoother surfaces of the particles with higher concentrations of maltodextrin have less friction with the material of the wall, facilitating their flow.

The values obtained for the strengths (Table 2) were used to determine the flow indices (FI) of the powders (Eq. 1). According to Lopes Neto at al. (2009) and based on Table 1, the results indicated that the powder containing 5% of maltodextrin is cohesive (3.19) and those mixed with 10 and 15% are easy flowing, with flow indices of 4.29 and 4.52, respectively.

The explanations for the results found may be associated with the shape of the particles and surface of the powders. According to the micrographs (Figure 1), the sample containing 5% of maltodextrin has less rounded edges and, along with the one containing 10%, the greatest roughness, increasing the cohesion among particles and compromising the flow.

Mohammed et al. (2011) observed that the irregularities on particle surface result in greater interconnection among particles, increasing the resistance to flowing. Campos & Ferreira (2013) observed in alumina and ceramic powders that the former is considered as cohesive and the latter as easy flowing, attributing this result to the average diameters and roughness of the surfaces of these powders.

## Conclusions

1. The increase of maltodextrin concentration added to the pulp changes the shape of the particles, leading to more rounded edges.

2. Flowing of mango pulp powder is facilitated with the increase in maltodextrin addition, varying from easy flowing to cohesive.

3. The increase of maltodextrin concentration in mango pulp results in a powder with lower angles of internal friction and friction with the smooth steel wall, besides leading to powders with higher bulk densities.

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