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PHYSICAL PROPERTIES OF COWPEA GRAINS DURING DRYING

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ABSTRACT

The objective of this work was to evaluate the influence of moisture content on the physical properties of cowpeas (*Vigna unguiculata*) during drying. Samples of manually harvested and threshed cowpeas with an initial moisture content of 0.250 (b.s) were dried in a forced air oven at 40 °C until the final moisture content was 0.13 ± 1 (b.s). Drying was followed by determining the mass difference, with the initial moisture content being known. The following physical properties during drying were determined for the predetermined moisture content: the angle of repose, bulk density, real density, intergranular porosity, mass of thousand grainsand shape factors [sphericity, circularity (for the natural repose position), geometric diameter and the surface-volume ratio]. The main characteristic dimensions of the grains (largest, intermediate and smallest) were measured during drying in order to determine the shape factors. There was an increase in the bulk and realdensities and in the sphericity, circularity and surface-volume ratio factors during drying. The other physical properties (mass of a thousand grains, angle of repose and intergranular porosity), as well as the geometric diameter had a reduction in their values as the water content decreased during drying.

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INTRODUCTION

Cowpeas have been one of the main cultivation options for the second crop in some regions of the country as an alternative for filling areas after the end of the ideal corn sowing period (Menezes Júnior *et al*., 2019). As with other crops, cowpea grains must be pre-processed in order to enable safe storage while maintaining their physical and chemical attributes. Drying stands out from commonly used processes which guarantees reduced water content of products to maintain their quality. Drying is based on a complex process involving the transfer of heat and mass which occurs between the drying air and the grain. A high temperature causes an increase in the partial vapor pressure of the product, which results in a reduction in the water content (Santos *et al*., 2013; Goneli *et al*., 2014). However, despite being indispensable, drying usually causes significant changes in the physical properties of agricultural products due to the reduced water content. The water content is described as being the main factor causing changes in the physical characteristics of the grains, causing shrinkage and changes in shape and surface roughness, among others (Botelho *et al*., 2015; Sousa *et al*., 2016). Adequate determination and knowledge of the changes in the physical properties of the grains during their processing become necessary, as these are characteristics of fundamental importance for optimizing industrial processes, Given the above and emphasizing the importance of knowing the physical properties of agricultural products, we sought to evaluate the influence of water content on the angle of repose, the bulk density, the real density, the intergranular porosity and the mass of a thousand grains of cowpeas during the drying process.

MATERIAL AND METHODS

The experiment was developed in the Agricultural Products Quality and Post-harvest laboratory belonging to the Federal University of Mato Grosso in Sinop – MT, Brazil. Cowpeas (*Vigna unguiculata* (L.) Walp.) were harvested and manually threshed in irrigated plantations after reaching their physiological maturity point, with an average initial water content of 0.25 (b.s.). After being harvested, the samples were sent to the laboratory and submitted to a cleaning process to remove impurities, foreign material and broken or damaged grains. The initial water content was determined by the gravimetric method using an oven with forced air circulation with a temperature of 105 ± 1 °C for 24 h, with three samples of 40 g of grains (Brasil, 2009). The cowpea grains were dried in a greenhouse with forced air circulation at 40 °C until reaching a final water content of 0.13 (b.s.). The reduction in water content throughout the drying process was accompanied by a difference in mass using an analytical scale with a resolution of 0.01 g (this scale was also used in all mass determinations in this work). During drying, samples of the product were taken with previously determined water levels and sent tohave the physical properties of the grains evaluated. A device made of medium density fiber (MDF) was used to determine the angle of repose, which holds approximately 20 L of product and one of its sides is made of glass to allow visualization of the grains. The device also has a hatch which allows the grains to flow when opened, enabling the formation and measurement of its slope. For this index, three repetitions were performed for each water content and later calculated using Equation 1:

$$\hat{A} = arctg\frac{h}{t} \quad (1)$$

In which: Â: angle of repose, °;h: slope height, mm; andt: slope base, mm.

The bulk density (Equation 2) was determined by measuring the grain mass naturally accommodated in a container of known volume. The used container has a relation between the diameter and the height equal to one and a volume of 1 L. The use of a funnel with a discharge register fixed on a rod made it possible for the container to be completely filled under the same conditions. For this property three repetitions were made per water content.

$$\rho_{ap} = \frac{m_g}{V_t} \quad (2)$$

In which:ρ_{ap}: bulk density, kg m^{-3};m_g: mass of the grain sample, kg; and,V_t: total volume occupied by the grain sample, m^3.

To determine the real density (ρ_u), twenty grains were randomly sampled and dried separately in a metal container under the same drying conditions as the other samples, with the main characteristic dimensions (largest, intermediate and smallest) of each grain being measured, as shown in Figure 1. The characteristic dimensions were determined using a digital caliper with 0.01 mm resolution.

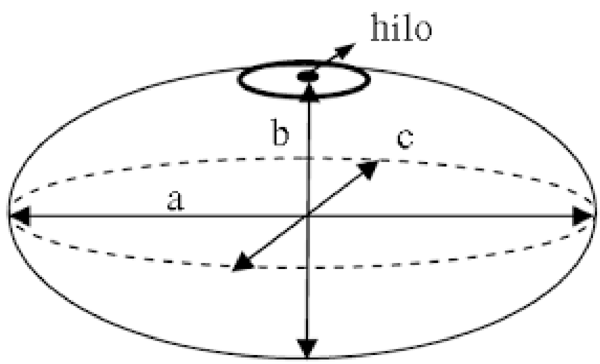


Figure 1. Schematic design of cowpea grains, in which: a, b and c are, respectively, the largest, the intermediate and the smallest characteristic dimensions of the BRS Imponente cowpea cultivar

After obtaining the main characteristic dimensions of cowpeas during drying and considering that they have a scalene spheroid shape, their real density was then calculated using Equation 3 (Mohsenin, 1986).

$$\rho_u = \frac{m_g}{V_g} = \frac{m_g}{\frac{\pi}{6}(abc)} = \frac{6}{\pi}\frac{m_g}{(abc)} \quad (3)$$

In which: ρ_u: real unit density, kg m^{-3};m_g: unit mass of grain, kg; V_g: Unit volume of grain, m^3;a: largest main characteristic dimension of the grain, m;b: intermediate main characteristic dimension of the grain, m; and,c: smallest main characteristic dimension of the grain, m.

Intergranular porosity was indirectly determined using Equation 4 (Mohsenin, 1986), considering its dependence on bulk density (ρ_{ap}) and the real unit density (ρ_u).

$$\varepsilon = 100\left[1 - \frac{\rho_{ap}}{\rho_u}\right] \quad (4)$$

In which: Ɛ: intergranular porosity, %.

For the variation in the mass of a thousand grains during drying, the mass and water content of two samples of a thousand grains were dried separately in a metal tray under the same conditions as the other samples. The main characteristic dimensions (Figure 1) obtained during drying were also used to determine the shape factors [sphericity, circularity (for the natural repose position of the beans), surface-volume ratio and geometric diameter] of the cowpeas in water content.

Equations 5 and 6 were used for determining sphericity, geometric diameter, and circularity (Cr) (Mohsenin, 1986).

$$\phi = \frac{D_g}{a} = \frac{(abc)^{1/3}}{a}x100 \quad (5)$$

$$C_r = \left(\frac{b}{a}\right)x100 \quad (6)$$

In which: ϕ: sphericity, percentage; D_g:geometric diameter, mm; and, C_r: circularity, percentage.

The calculation of the surface area used to determine the relationship between the surface area and the volume (RSV) was performed using Equation 7. This equation is known as the Knud Thomsen Equation and if used with the constant "z" equal to 1.6075, it results in a maximum error of 1.061% in estimating the surface area of a spheroid (Ersoy, 2010; Mele *et al*., 2011).

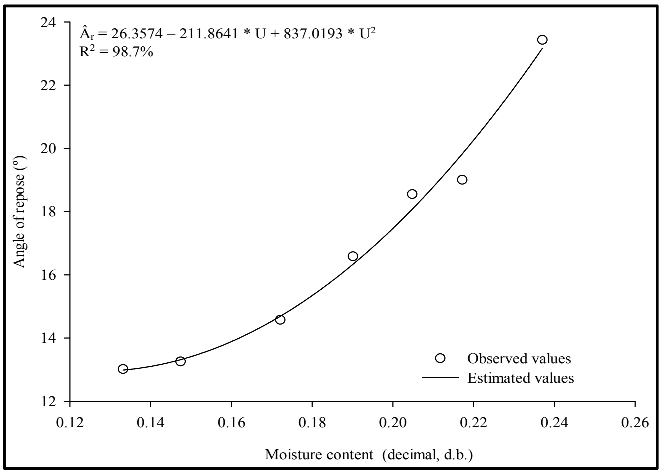
$$\hat{A}_s = 4\pi\left[\frac{\left(\frac{a}{2}\right)^z\left(\frac{b}{2}\right)^z + \left(\frac{a}{2}\right)^z\left(\frac{c}{2}\right)^z + \left(\frac{c}{2}\right)^z\left(\frac{b}{2}\right)^z}{3}\right]^{\frac{1}{z}} \quad (7)$$

In which:$\hat{A}_s$: superficial area, mm^2.

The dependence between the physical properties of the BRS Imponente cultivar cowpeas as a function of water content during the drying process was estimated through analysis of variance, followed by linear regression. The evaluation of the obtained estimates was made by the Student's t-test considering 5% probability.

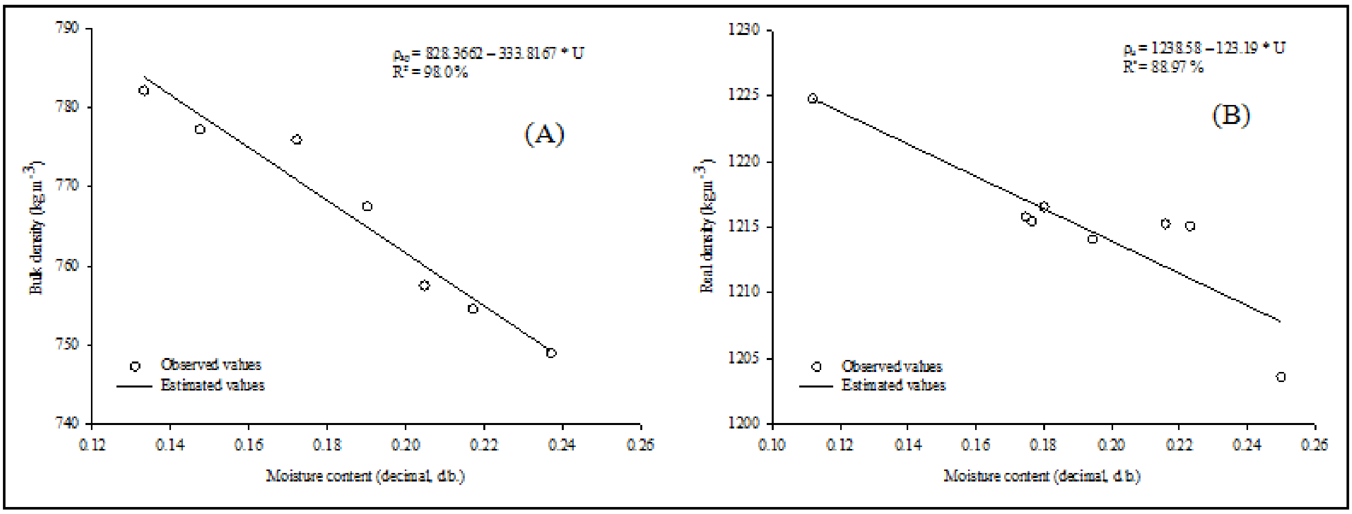
RESULTSAND DISCUSSION

It was observed that the angle of repose of the BRS Imponente cowpea cultivar grains (Figure 2) decreased with the reduction in the water content. The means of the angle of reposevaried between 23.4 to 13.0 ° for a range of water content from 0.25 to 0.13 (b.s.). The observed averages were lower than the averages observed in a study on the physical properties of cowpeas from the *Fradinho* commercial group, in which the angle of repose was 23 ° for water content of 13.5% (b.s.) (Lanaro *et al*., 2011). The dependence observed between the angle of repose and the water content for the BRS Imponente cowpea cultivar was also observed for other products such as moringa seeds (Aviara *et al*., 2013), coffee fruits (Botelho *et al*., 2016) and peanut grains (Araújo *et al*., 2014). The dependence between the angle of repose and the water content was also explained by means of a second degree polynomial equation, which showed a good fit to the experimental data ($R^2 = 0.99$) (Figure 2). Knowledge of this property is important, as it directly interferes with the storage of the product, so the smaller the angle of repose, the greater the bulk storage capacity of the grains with natural accommodation of the product (Nunes *et al*., 2014). It was noted that the bulk and real unit densities of the grains increased with the reduction in the water content during drying (Figure 3). The amplitude of the bulk density was 748.95 to 782.20 kg m^{-3} for water contents between 0.25 and 0.13 (d.b.), and 1203.6 to 1224.7 kg m^{-3} for real unit density when the water contents varied from 0.25 to 0.11 (d.b.). Linear models satisfactorily described the dependence between the bulk and real unit densities with the water content of the grains, presenting determination coefficients of 98.0 and 89.0%, respectively.



*Significant at 5% probability by the Student's t-test

Figure 2. Observed and estimated values of the angle of repose of the BRS Imponente cowpea cultivar grains as a function of water content

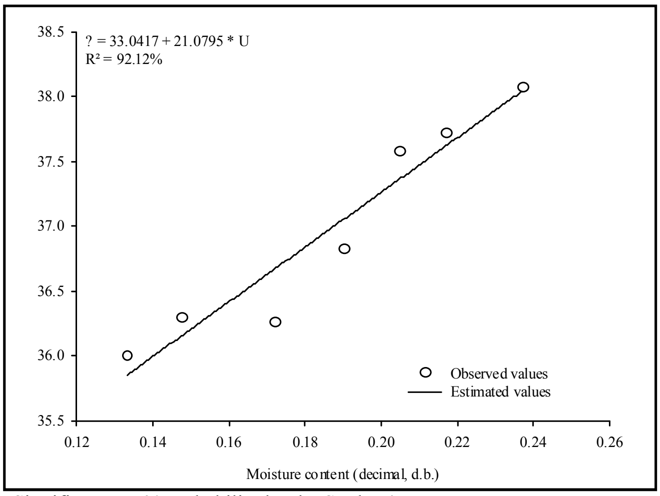


*Significant at 5% probability by the Student's t-test

Figure 3. Observed and estimated values of the (a) bulk and (b) real unit densities of the BRS Imponente cowpea cultivar grains, depending on the water content

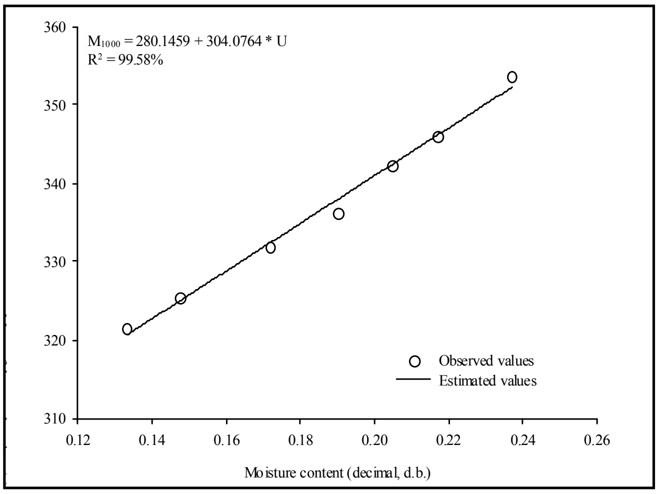
These results were consistent with those obtained in evaluating the physical properties of the Vermelho Coimbra common bean cultivar grains, in which the values varied between 761.0 to 893.0 kg m^{-3} for bulk density and 1361.0 to 1468.0 kg m^{-3} for real unit density for water contents between 0.42 to 0.11 (b.s.) (Resende*et al*., 2008). Similar trends were also observed in buckwheat grains (Quequeto *et al*., 2018), cowpeas from the *Fradinho* commercial group (Lanaro *et al*., 2011), soybeans (Wandkar *et al*., 2012; Hauth *et al*., 2018) and BRS Valente and BRS Pontalcommon bean cultivars (Jesus *et al*., 2013). The increase in bulk density was due to a more intense reduction in the volume of the grains (reduction of the characteristic dimensions a, b and c) than due to the water loss in the form of steam to the drying air. Therefore, the volumetric reduction of grains causes a reduction in intergranular voids, making more grains fit in the same space (Couto *et al*., 1999). The grain porosity decreased in proportion to the reduced water content of the cowpea grains (Figure 4). There was a reduction of approximately 2.07% in the grain porosity from the beginning to the end of the drying process. A linear model adequately described the relationship between porosity and water content (R^2 of 92.12%). A similar trend was reported in the works by Siqueira *et al*. (2012) in jatropha fruits; Jesus *et al*. (2013) in BRS Valente and BRS Pontal bean cultivars; and by Oba *et al*. (2019) in cowpea seeds.It is believed that this reduction of empty spaces in the intergranular mass is due to the joint effect of the volumetric contraction and the reduced mass of the product during drying, causing the grains to rearrange themselves better (Oba *et al*., 2019).

It is noteworthy that the decrease in porosity can favor resistance to air passage through the mass of the grains, compromising the uniformity and efficiency of pre-processing operations such as drying, aeration and cooling (Quequeto *et al*., 2018). For the mass of a thousand grains, it was noted that the reduced water content during the drying process also resulted in a reduction of the mass of a thousand grains (Figure 5). The water content decreased from 0.25 to 0.13 (b.s), while the grain mass decreased from 353.58 to 321.51 g. The grain loses part of its mass in the form of water vapor during drying due to the difference in partial steam pressure between the product to be dried and the drying air which surrounds it, which directly influences its mass. The dependence between the variables could also be satisfactorily described by a linear model that presented a determination coefficient of 99.0%. The reduction in the mass of a thousand grains is systematically reported during the drying of agricultural products such as cowpea seeds (Oba *et al*., 2019), black-eyed (Lanaro *et al*., 2011) and red bean grains (Resende *et al*., 2008), peanut grains (Araújo *et al*., 2014), and safflower grains (Martins *et al*., 2017), among others. It was found that the roundness and sphericity increased linearly with the reduction in the water content of the grains, presenting a range of values from 0.682 to 0.687 (decimal) and from 0.705 to 0.707 (decimal) for a water content range of 0.250 to 0.112 (decimal, b.s.), respectively (Figure 6). The dependence between variables and water content was also satisfactorily explained by a linear regression model with an adjustment of 91.99 and 84.57% for roundness and sphericity, respectively.



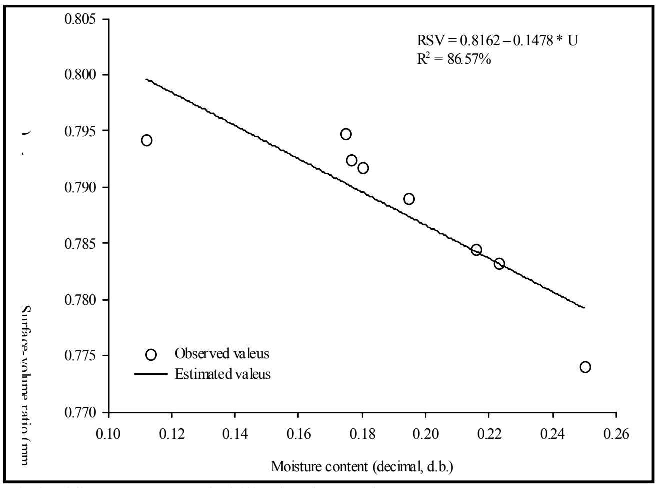
Significant at 5% probability by the Student's t-test

Figure 4. Observed and estimated values of intergranular porosity of BRS Imponente cowpea cultivar grains as a function of water content



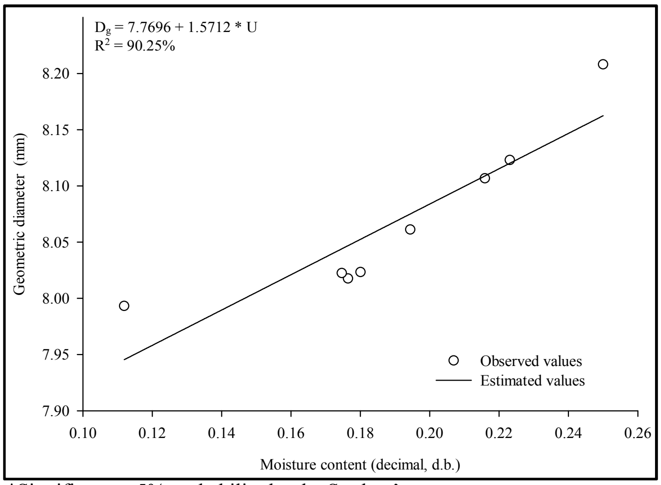
*Significant at 5% probability by the Student's t-test

Figure 5. Observed and estimated values of the mass of a thousand grains of the BRS Imponente cowpea cultivar as a function of water content



*Significant at 5% probability by the Student's t-test

Figure 7. Observed and estimated values of the surface-volume ratio of the BRS Imponente cowpea cultivar grains as a function of water content



*Significant at 5% probability by the Student's t-test

Figure 8. Observed and estimated values of the geometric diameter of cowpea grains as a function of water content

Similar results to this work for circularity in relation to water content were found by Araújo *et al*. (2014) for peanuts; Oba et. al. (2019) in cowpea seeds; and Resende *et al*. (2008) in cowpeas. The same for sphericity was reported by Mendes *et al*. (2016) in adzuki beans grains; Jesus *et al*. (2013) in common beans; Lanaro *et al*. (2011) in black-eyed beans; and Guedes *et al*. (2011) in soybeans. Knowledge of circularity and sphericity as well as other properties related to size and shape are important for the development of equipment projects for grading grains, improving the efficiency of the process, and reducing losses associated with product breakdown (Hauth *et al*., 2018). Like that observed for sphericity and circularity, the surface-volume ratio of cowpeas increased proportionally to the reduction in water content (Figure 7). This index ranged from 0.774 to 0.794 mm^{-1} for the water content range from 0.250 to 0.112 (decimal, b.s.), with the dependence between variables being satisfactorily described by a first-degree polynomial model that presented an adjustment determination coefficient of 86.57%. The same trend was reported during the drying of jatropha fruits (Siqueira *et al*., 2012), in grains of different soybean cultivars (Hauth *et al*., 2018) and in peanut grains (Araújo*et al*., 2014). Knowledge of this index is important for studies on drying and conservation of agricultural products, since the lower the surface-volume ratio, the easier the heat and mass transfers are, as well as the respiratory activity (Araújo *et al*., 2015; Botelho *et al*., 2016). It was also found that the geometric diameter reduced linearly with drying with the water removal from the BRS Imponente cowpea cultivar grains (Figure 8). The geometric diameter decreased from 8.21 mm for the water content from 0.25 (decimal, b.s) to 7.99 mm for the final water content of 0.112 (decimal, b.s). The dependence between these variables was also satisfactorily explained by a linear model (R^2 = 90.25%).

Similar values have been described by Oba *et al*. (2019) in evaluating cowpea seeds, and Jesus *et al*. (2013) in common BRS Pontal and BRS Valente cultivar bean seeds.

CONCLUSION

The water content influences the physical properties of cowpeas so that their reduction provides an increase in the bulk and real unit densities, and a reduction in the angle of repose, intergranular porosity and the mass of a thousand grains. For the shape factors, the reduction of the water content promotes an increase in circularity, sphericity and surface-volume ratio as well as a reduction in the geometric diameter.

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