Chapter 236

Variations in the physical properties of soybeans during the drying process and changes in the classification of soybeans stored with different temperatures and evaluation methodologies

https://doi.org/10.56238/devopinterscie-236

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ABSTRACT
The objective of this study was to evaluate the effect of drying at different temperatures on the physical properties of the grains; water content, volumetric contraction, the weight of thousand grains, apparent specific mass, length, width, thickness, circularity, sphericity, and comparison of methodologies of soybeans. To evaluate the physical properties, the soybean grain samples with an initial water content of 19.06% b.u. were subjected to the effects of drying air temperatures heated to 40ºC, 55ºC, 70ºC, and 85ºC. The samples were dried in a conventional natural convection oven until reaching 19% water contents, 17%, 15%, 13%, and 11% b.u. Subsequently, the drying curve of soybeans dried under different temperatures was characterized and the physical properties of an apparent specific mass, the weight of one thousand grains, and volumetric contraction were analyzed. It was noted that the increase in temperature affected the three-dimensional axes of the grains, causing them to lose water to the drying air. However, when these grains are dried at high temperatures spending less time, their characteristics are modified. The weight of the grains and the apparent specific mass decreased with increasing temperature during drying. The circularity, sphericity, and unit volume decreased with the increase in temperature during drying, therefore, it is not possible to use the new proposal of digital methodology instead of manual measurement, since the correlation between the two methodologies is close to zero. For the conditions under which the experiment was carried out, it can be concluded that with the increase in the temperature of the drying air, the grains dry faster, and yet the physical dimensions are more preserved, not being intensely reduced throughout the process.

Keywords: *Glycine max* (L.), Physical Characteristics of Soy, Apparent specific mass, Drying, Water content.

1 INTRODUCTION

Soybeans are one of the most important grains of agribusiness and great internal and external negotiations of the country. Brazil is the second largest producer of soybeans in the world and in the 2021/22 harvest, an average of 124 million tons of this grain were produced in the country, less than 10% of the previous 20/21 harvest, in an area of approximately 40 million hectares, taking into account the previous harvest, where there was an increase of 4.5% (CONAB, 2022).

It is of paramount importance the agribusiness sector soybean production is one of the most intensified, where the post-harvest is one of the main focuses, to ensure the physiological and chemical properties. Where studies never stop, seeking improvements for producers and shipowners. According to (COSTA et al., 2015), over time, changes in the properties of grains using technologies in agricultural genetic improvement have been constantly changing. Therefore, one should be aware of changes, seeking to be up to date with comparisons of previous physical properties.

The knowledge of the physical properties of the grains, such as surface area, projected area, volume, circularity, sphericity, the mass of one thousand grains, and specific mass, is used in the sizing of machinery and equipment during the drying process. Therefore, this is important for the design and sizing of transport equipment, such as conveyors, mug elevator, and helical conveyors (ARAUJO et al., 2014). On the other hand, to obtain better quality grains and homogeneous lots, proper drying should be conducted (Couto et al., 1999).

The drying of agricultural products was developed by the volumetric contraction of the product during the dehydration process (LANG 1993). The volumetric contraction of the grains occurs during drying, the result of the modification of the three-dimensional dimensions. However, with the volumetric contraction that occurs during the drying process, the grains lose water to their air, and dehydration occurs. Thus, it is necessary to monitor the transformations in the physical characteristics of agricultural products, because this requires adjustments in agricultural machinery (CORRÊA et al., 2006).

Drying is of paramount importance in post-harvest processing, where they go through several stages of drying that allow safe and effective storage. During drying, water content is one of the most affected factors, as it influences the physical and chemical properties of the grains. This loss of water is nothing more than the volumetric contraction of the grains, that is, changes in the sizing characteristic of the same.

The physical properties of agricultural products have their unrestricted use in harvesting and post-harvest operations, and the use of equipment for these procedures, with studies made in the aerodynamics of grains, projects, and equipment (RESENDE et al., 2005). According to CORRÊA et al. 2002, during drying and storage operations, these grains obtain heat transfer between them, until they are in a state of equilibrium, then, when there is a movement of hot air occurs this transference.

Being the factor that most influence the physical properties of agricultural products, the main operations of knowledge of the proper sizing of the machines used in post-harvest processing, are that characterize the quality of the final product (MOHSENIN, 1986).

In the course of drying, the grains lose water from their interior to the outside, as for this, can affect the physical, chemical, and biological parts, so changes can occur in them. Referring to the drying of products with excess or temperature deficit can affect the raw material for the manufacture of products or export.

According to Siqueira et al. 2012, the temperature used in drying and storage, and the physiological characteristics of soybeans are modified, such as the dimensions of circularity and sphericity in jatropha grains. The temperature used in the drying and storage of grains modifies the morphophysiological characteristics, such as the dimensions of circularity and sphericity in jatropha grains (SIQUEIRA et al., 2012). The drying air temperature increases the porosity in soybeans. Therefore, it causes a decrease in the values of the apparent specific mass and weight of one thousand grains BOTELHO et al., 2015).

Considering the importance of the drying process and the reflection of this post-harvest stage on the physical properties of agricultural products, the objective of this work was to evaluate the shape and determine the size of the fruits of pine nuts using circularity, sphericity, volume, surface area, projected area, and surface-to-volume ratio throughout drying, under various air conditions, and verify the possibility of using a single model to describe the results.

Given the drying processes influence the physical properties, the objective of this work was to evaluate the effect of drying at different temperatures on the physical properties of soybeans (specific mass, weight of one thousand grains, and volumetric contraction) and perform correlation analysis (sphericity and circularity) by manual methodology and digital methodology to determine the shape and size of grains

2 METHODOLOGY

The work was carried out in the laboratory of post-harvest and processing of agricultural products and the computer laboratory of the State University of Goiás, Santa Helena de Goiás Unit.

The soybeans were collected at the Fronteira Armazéns unit, with a water content of 19.06% b.u., soon after, drying began in a conventional natural convection oven with temperatures of 40ºC, 55ºC, 70ºC and 85ºC and then the analyses of the physical properties were performed with the following 19% water contents, 17%, 15%, and 13% and 11% b.u. Thus, the experiment is a factorial scheme (4x5) with four replications, composed of 4 temperatures and 5 humidity.

The reduction of the water content in the grains was carried out in the conventional oven of natural convection, the introduction of four trays with holes of 4 mm, where the weight of the mass of the grains was verified using weighing in an analytical balance with a precision of 0.001g, where each with 350 g of grains kept in the same drying conditions.

Analysis

Water content

The water content of the grains was determined through the greenhouse method at 105 ± 1 °C, for 24 hours, considering three replications, (BRASIL, 2009).

Volumetric contraction

For the volumetric contraction, the unit volume of soybeans was measured with a caliper. The dimensions of grain width, thickness, and length were measured (Mohsenin, 1986) for each water content sampled, according to the following expression.

$$V = \frac{(a * b * c)}{a} * 6$$

Where:
V = volumetric contraction;
a = shaft grain length, mm;
b = grain width axis, mm;
c = axis grain thickness, mm.

Weight of a thousand grains

The mass of one thousand grains was determined randomly, following the Rule for Seed Analysis (Brasil, 2009). Soon after, the weighing was performed on an analytical balance with an accuracy of 0.01g

Apparent specific mass

The specific mass of soybeans was determined using the methodology of (SIQUEIRA, RESENDE, CHAVES, 2012). Some adaptations were made for the development of the experiment, use of a container with its known volume in cubic centimeters and the mass of the grains. To perform the calculations, the following formula will be used:

$$\rho = \frac{m}{v}$$

Where:
ρ: apparent specific mass (g cm^{-3});
m: grain mass (g);
v: container volume (cm^3).

Soybean size

To identify shape and size, 4 replicates with 15 grains were followed, where their dimensions (length, width, and thickness) were measured with the aid of a digital caliper with 0.01mm accuracy. This method first follows the traditional methodology proposed by Resende et al., 2005, where a caliper is used and the measurements of 15 grains are measured manually, calculating their values by the following formulas.

Sphericity and circularity by the MOHSENIN method, 1986.

The sphericity (Es), given as a percentage, of the soybeans in the resting position was obtained utilizing the following equations; A: largest grain axis in mm; B: average grain axis in mm; and C: smallest grain axis in mm (CORRÊA, 2008).

$$ES = (\frac{(a * b \ * c)^1/3}{a}) * 100$$

Where:
Es = sphericity,%;
a = largest grain axis, mm;
b = average grain axis, mm;
c = smallest grain axis, mm.

Circularity (Cr), given as a percentage, was determined to pardy the grains in a natural resting position, was determined by the following expression prescribed by CORRÊA, 2008:

$$Cr = (\frac{di}{dc}) * 100$$

Where:
Cr = circularity, %;
di = diameter of the largest inscribed circle, mm;
dc = diameter of the smallest circumscribed circle, mm.

Sphericity and circularity by the AUTOCAD method

Then, the second form of measurement was performed through a 15-grain digital photograph shot in the resting position, then transferred the images were to the Autocad (student-free version) to take the measurements and then performed the calculations of sphericity and circularity through the projected area. Thus, using the following formulas proposed by Mohsenin, 1986:

Sphericity (E) was calculated from photographs of soybeans at rest and AutoCAD measurements, using the following expression proposed by Mohsenin 1986:

$$ES = (\frac{(a * b \ * c)^1/3}{a}) * 100$$

Where:
E = sphericity;
of = diameter of the largest circle in the projection;
dc = diameter of the smallest circumscritp circle in the projection.

Circularity (C), grains were calculated through photographs and AutoCAD, using the following expression prescribed by Mohsenin, 1986:

$$Cr = (\frac{di}{dc}) * 100$$

Where:
C = circularity;
Aρ = circle area inscribed in the projection of the object at rest, mm2;
Ac = airwise circumscrite circle in the projection of the object, mm².

The comparison of the methodologies of sphericity and circularity analyses was made through a correlation analysis, using the Excel software (Microsoft ®).

3 RESULTS AND DISCUSSION

Drying Curve

Figure 1 shows the variation in the water content of soybeans as a function of drying time under different temperatures.

Figure 1. Experimental values of the moisture contents of the grains were found as a function of the drying time.

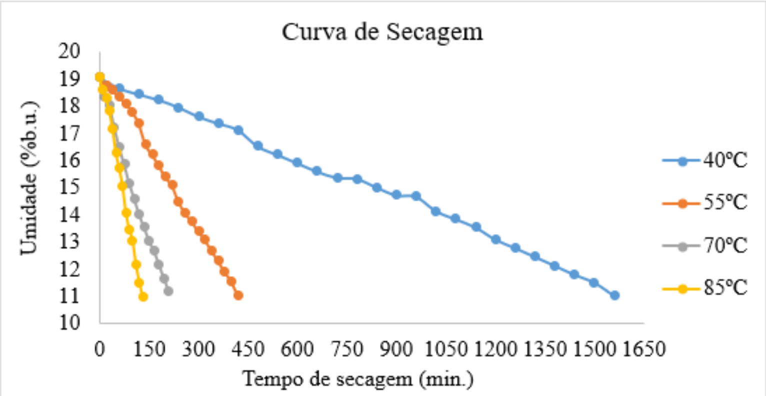


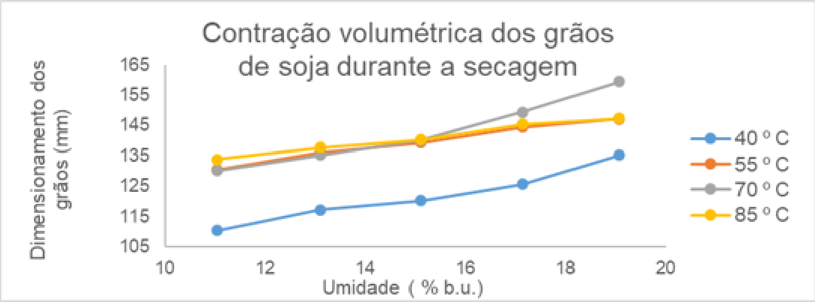
Figure 1 shows that the initial humidity was around 19% b.u. for all drying temperatures. Specifically, the temperature of 85ºC, which is commonly used for drying grains, provided the drying of the product in a time of 2 hours. An approximate period was observed for the temperature of 70ºC, around 3 hours. Facts observed by the sharp decline in the drying curves of the two temperatures. Although high drying temperatures can affect the structure of grains, such as cracks, and cracks among others (CABRAL, 2022), they are necessary to give constant operational cadence and agility to the processes of a storage unit.

The drying at a temperature of 55ºC lasted on average 7 hours, which implies a longer time of exposure of the grains to the drying air and, consequently, greater energy expenditure and availability of labor.

The temperature of 40ºC took around 26 hours to dry the grains, providing a slow drying. According to Alves et al. (2015), the most durable drying process carried out with low temperatures, shakes the integrity of the grains less. This temperature is traditionally used for seed drying, as it preserves the quality and vigor of the product (CARDOSO et al., 2015).

Figure 2 shows the results of the variation of the unit volume of the grains during the drying process, which can be defined as the volumetric contraction of the grains.

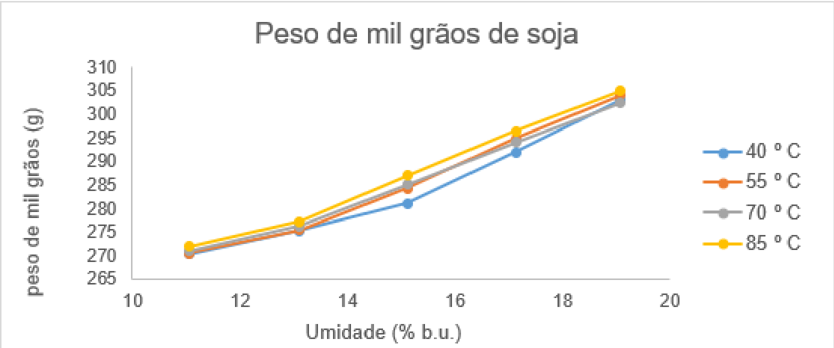
Figure 2. Volumetric contraction of soybeans concerning different drying temperatures.



It is observed, in Figure 2, that at higher temperatures with the volumetric contraction, the grains do not undergo major modifications, differing from the lower temperature, specifically the temperature of 40º C. With the dehydration of the grains, there is the contraction of all volumetric dimensions, where this dehydration is the reduction of the water content in the mass of the soybeans. Thus, reducing the projected area of the grain under resting conditions (LANG et al., 1994). A relevant observation concerning this experiment was that the grains have already started the drying process with a water content of 19%, that is, with the volume already reduced. Therefore, no large variations in volumetric contraction can be observed during drying.

The weight of one thousand grains is represented in Figure 3, in which they were dried at different temperatures until reaching the storage humidity (11 % b.s.).

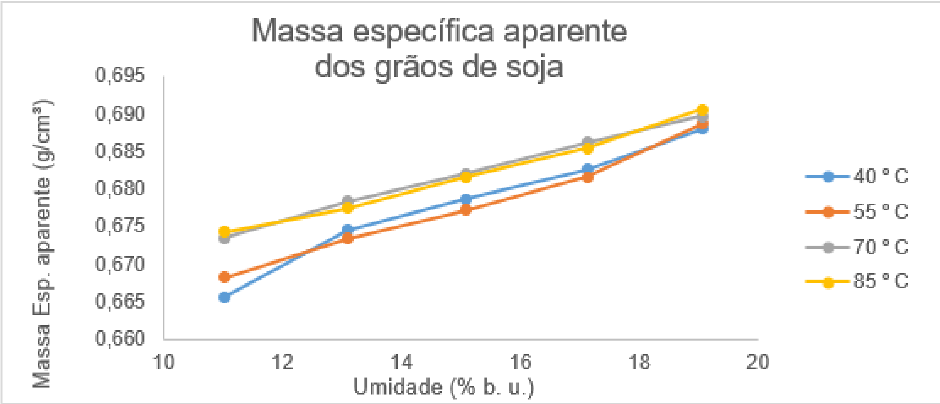
Figure 3. It represents the experimental values of the weight of one thousand soybeans during drying temperatures.



It is observed that by the figure above, the values of the weight of one thousand grains at the temperature of 40 ºC were lower than that of the temperature of 85 ºC. It is observed the increase of the drying temperature, from 40ºc to 80ºC in which both temperatures lost on average 30 g of water, such that they did not suffer a great reduction in the weight of one thousand grains. Therefore, studies carried out obtained different results, in which the weight of a thousand grains shows a difference as a function of the drying temperature (BOTELHO et al., 2015).

Figure 4 shows the result of the specific mass of soybeans, as a function of different drying temperatures. It is noted that the specific mass of the temperature of 70 and 85 ºC obtained similar results, in which the initial humidity its mass is around 0.690 g.cm-¹, and when dried up to 11ºC the specific mass reduces to 0.674 on average. At a temperature of 40 ºC, through a slow drying process, the specific mass of the grains was reduced by around 0.666 g.cm-¹, that is, the specific mass of the temperatures was lower because of the stayed a longer period inside the drying oven.

Figure 4. It represents the experimental values of the specific mass of soybeans as a function of different drying temperatures.



The reduction of the specific mass in soybeans as a function of drying temperatures is remarkable. When the grains are dried at high temperatures such as 85 ºC, an increase in their volume is not so noticeable when compared to drying at lower temperatures. Therefore, it is noted that at the temperature of 55 and 40 º C in a slower drying, the grains result in an adequate drying for seeds, in which, some thermal damage such as cracks and cracks cause gaps in the volume of the grains, presenting empty spaces, thus reducing the weight. Similar results were found by Scariot et al. (2017) when they studied the water content in the harvest and drying temperature in the quality of bean seeds.

Figures 5, Figure 6, and Figure 7 show the variations in the length, width, and thickness of soybeans during the drying process under different temperatures.

Figure 5. Calculated values of the length of the temperature of the drying air.

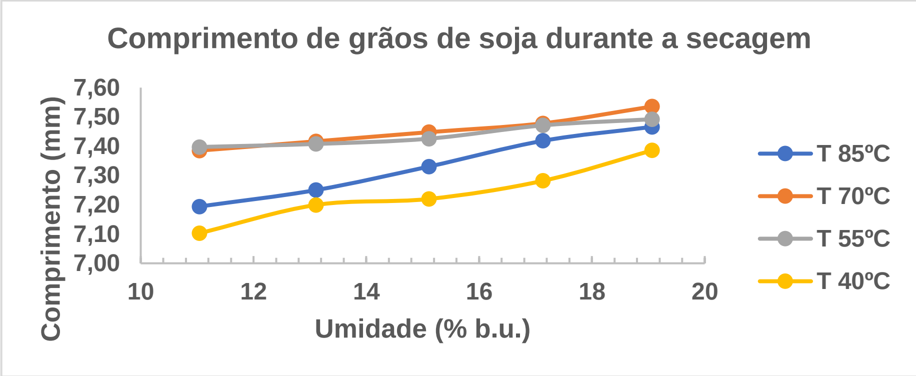


Figure 6. Results were obtained through the calculations of and width of the drying of soybeans.

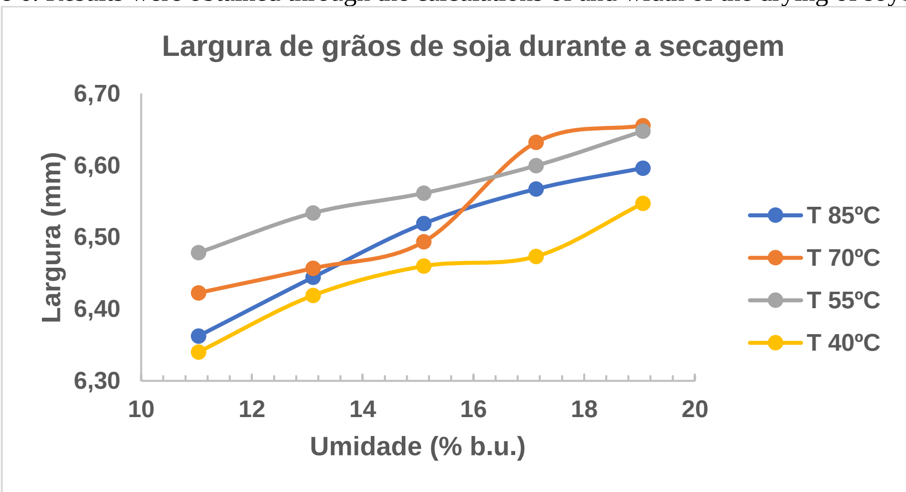
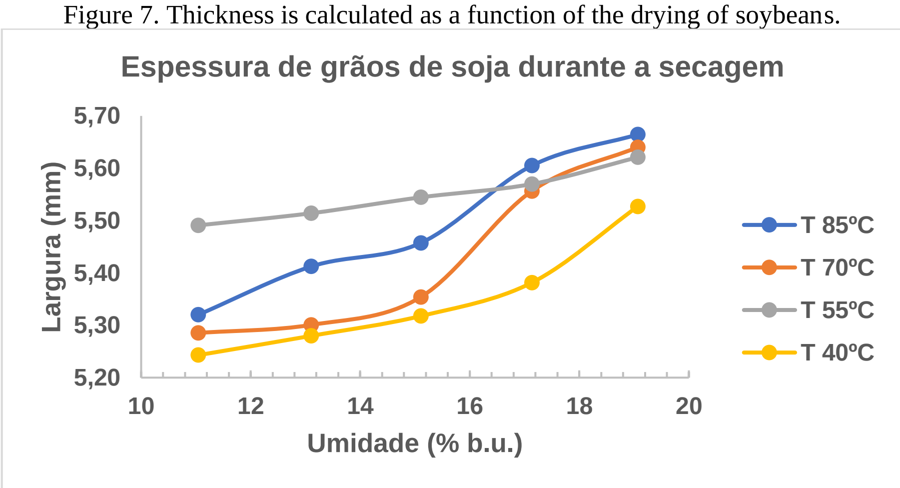


Figure 7. Thickness is calculated as a function of the drying of soybeans.



It was possible to observe that these three dimensions had different behavior during drying, in which they start from an average initial value and reduce drastically. However, it was noteworthy that at the temperature of 85ºC, the dimensions of the soybeans always did not keep higher than the dimensions of the grains dried at a temperature of 40ºC.

This phenomenon can occur in porous materials during drying. The drying at 85ºC was so fast that the internal structures contracted, causing the dimensions evaluated to undergo major changes or variations more quickly. On the other hand, drying at 40ºC can be considered a slow process, which allows the internal structures of the grains to contract more, causing a greater reduction in the dimensions evaluated.

Figure 8 and Figure 9 show the data on the sphericity and circularity of soybeans, respectively, as a function of different drying temperatures. It is noted that the sphericity and circularity of the grains did not decrease considerably according to the reduction of the water content, remaining constant from the beginning of the process. This contradicts what was concluded by Siqueira et al., 2012, who reported that according to the temperatures used in drying, the physiological characteristics of the grains were modified, that is, with higher temperatures and longer time, the grains lose greater water content, changing their physical properties compared to a sphere.

Figure 8. Sphericity of soybeans, as a function of different drying temperatures.

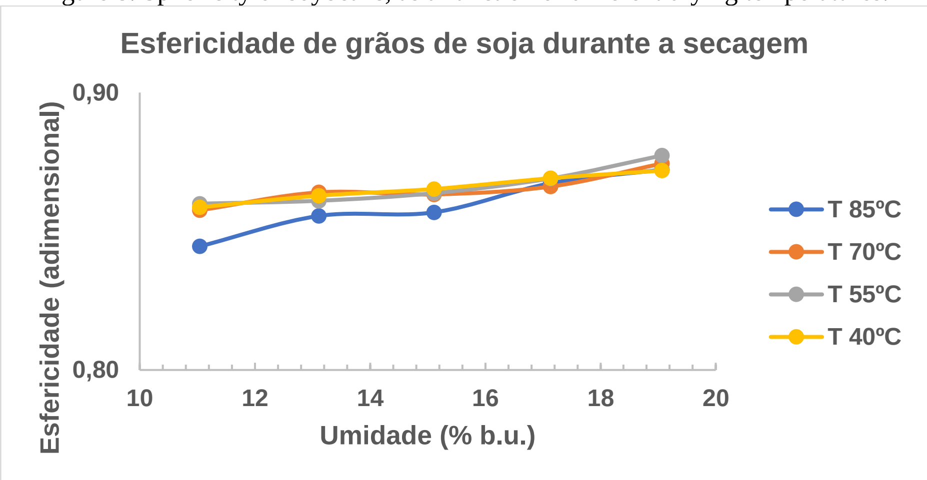
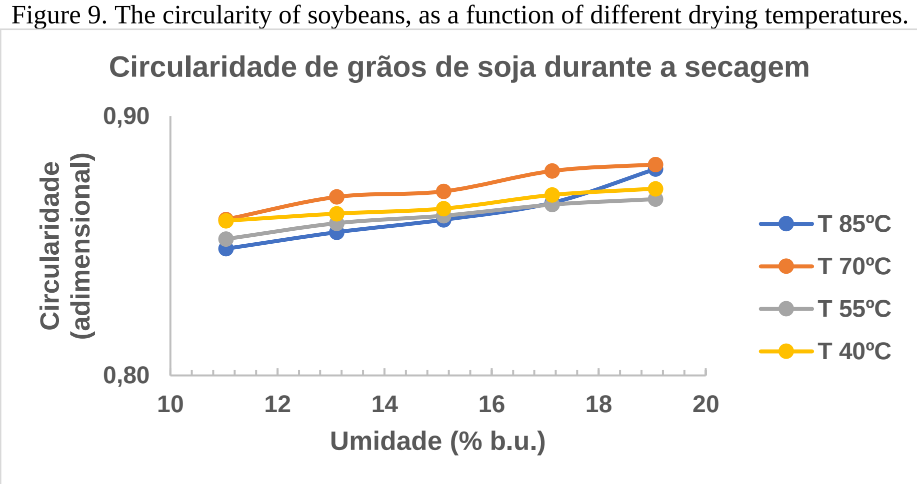


Figure 9. The circularity of soybeans, as a function of different drying temperatures.



When the grains are dried under high temperatures, they leave their original forms, and with the decrease in water content, their shape approaches a circle in the resting position (Corrêa et al., 2006). On the other hand, it should be noted that the drying process of the present experiment began with the grains with humidity at 19% b.u., that is, with dimensions already reduced. This consequently contributed to the observed great variations in physical properties.

Comparison of methodologies

Table 1 presents the correlation analysis between the characteristics evaluated by the traditional methodology proposed by Mohsenin, 1986, and the new methodology developed by this study.

Table 1. Analysis of the correlation between the factors analyzed and the shape characteristics of soybeans dried at different temperatures.

Factors	*Tempertoºc tura*	*Humidity % b.u.*	*CAD Sphericity*	*CAD Circularity*	*MOH Sphericity*	*MOHCircularity*
Temperature ºC	1.00					
Humidity % b.u.	-0.01	1.00				
CAD Sphericity	-0.07	0.03	1.00			
CAD Circularity	-0.04	0.02	-0.01	1.00		
MOH Sphericity	0.03	-0.14	0.24	0.01	1.00	
MOH Circularity	-0.12	-0.03	0.44	0.02	0.56	1.00

It was noted that the correlation values were around zero, not proving to be highly positive or negative, but neutral.

When the drying air temperature and the moisture of the grains were correlated with the characteristics of sphericity and circularity, it was observed that the correlation was close to zero. This indicates that these factors did not interfere with any of the methodologies used to characterize the grains.

On the other hand, the correlation between the methodology proposed by Mohsenin and the new methodology proposed by this work, being null or close to zero, indicates that one does not replace the other. This can also be explained by the difference between the models proposed for the calculations, in which the traditional model takes into account the three dimensions of the grains (length, width, and thickness), and, already in the new methodology, a model was used that considers only length and width, due to the impossibility of obtaining the thickness dimension in the resting position of the grains.

It is noteworthy that more in-depth and detailed studies should be conducted to improve the digital methodology and it can replace the traditional methodology more efficiently.

4 FINAL CONSIDERATIONS

The intensity of the drying air influences and modifies the physical characteristics of the grains. Although physical measurements of the grains have been carried out, it is believed that the internal structures of the soybeans are strongly altered by the drying process, whether these processes are slow or fast.

Therefore, it can be considered that the equipment designs for the grains and seeds dried under different temperatures should include variations of the same, especially about sieve sieves, vibration, and inclination of densimetric tables, etc.

The increase in temperature, being 40, 55, 70, and 85ºC, provides a significant change in the physical properties of the grains, especially when the initial humidity is higher, having a greater loss of water from the grains, within the levels indicated for the harvest (13 to 19% b.u).

The proposed new methodology, using CAD software, does not replace the traditional methodology. However, further studies and the elaboration of appropriate models are needed for the characterization of the shape of the grains.

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