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Shape and size of soybean grains under different moisture contents

Forma e tamanho de grãos de soja para diversos teores de água

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Abstract

Physical properties of soybean grains present differences as a function of cultivars and moisture content, with the correlation between physical properties. This study aimed to determine the characteristics related to the physical properties of grains with different moisture contents of three soybean cultivars. The experimental design was completely randomized design in a 3 × 6 factorial scheme with three replications, consisting of three soybean cultivars (6266 RSF IPRO, BMX Potência RR, and 14403Z6001) and six grain moisture contents (11, 13, 15, 17, 19, and 21% wb). Soybean grains presented an initial moisture content of 11.0, 11.0, and 10.8% wb, respectively for 6266 RSF IPRO, BMX Potência RR, and 14403Z6001. The other moisture contents were obtained by soaking in a BOD chamber maintained at 25 °C and 93% of relative humidity. We assessed volume, roundness, sphericity, surface area, volumetric shrinkage, and volumetric shrinkage rate. The data were submitted to the analysis of variance by the F-test ($p<0.05$) and when significant, regression analysis was performed for grain moisture contents and the means of cultivars were compared by the Tukey's test. Pearson's correlation analysis was also carried out to represent the linearity between grain physical properties. The cultivar BMX Potência RR obtained the highest results for volume, roundness, sphericity, and surface area. Volume and surface area increased as the moisture content of soybean grains increased; the opposite was observed for roundness and sphericity. A linear increase in volumetric shrinkage was observed as moisture content increased. The values of the correlation coefficients of the linear regression models can be used to describe the relationships between physical properties.
Key words: Surface area. Roundness. Volumetric shrinkage. Sphericity. *Glycine max* L. Volume.

Resumo

As propriedades físicas dos grãos de soja apresentam diferenças em função de cultivares e teores de água existindo correlação entre as propriedades físicas. Objetivou-se determinar características relacionadas as propriedades físicas dos grãos de soja de três cultivares em diferentes teores de água. O delineamento

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experimental foi inteiramente casualizado, em esquema fatorial 3 x 6, em triplicata, sendo três cultivares de soja (6266RSFIPRO, BMX Potência RR e 14403Z6001) e seis teores de água nos grãos (11, 13, 15, 17, 19 e 21% b.u). Os grãos de soja apresentavam o teor de água inicial de 11,0; 11,0 e 10,8% b.u., respectivamente para 6266 RSF IPRO, BMX POTÊNCIA RR e 14403Z6001.Os demais teores de água foram obtidos por adsorção em câmara tipo BOD mantida na temperatura de 25 °C e 93% de umidade relativa. Foram avaliados volume, circularidade, esfericidade, área superficial, contração volumétrica e índice de contração volumétrica. Os dados foram submetidos à análise de variância pelo teste F ($p<0,05$), quando significativo, realizou-se análise de regressão para os níveis de teor de água nos grãos e as médias das cultivares foram comparadas pelo teste de Tukey. Realizou-se também análise de correlação de Pearson intuito de representar a linearidade entre as propriedades físicas dos grãos. A cultivar BMX Potência RR obteve os maiores resultados para volume, circularidade, esfericidade e área superficial. O volume e a área superficial aumentaram com o incremento do teor de água dos grãos de soja ocorrendo o inverso para a circularidade e a esfericidade. Verificou-se aumento linear na contração volumétrica com a elevação dos teores de água. Os valores dos coeficientes de correlação dos modelos de regressão linear podem ser utilizados para descrever as relações entre as propriedades físicas.

Palavras-chave: Área superficial. Circularidade. Contração volumétrica. Esfericidade. *Glycine max* L. Volume.

In order to maintain quality and stability of grains, it is important to consider that altering the amount of water in the material leads to changes in their biological activity and chemical and physical properties during storage (ARAUJO et al., 2014), with different modifications as a function of genotype.

The determination of physical properties in grains has a relevance in several stages of preprocessing, such as the dimensioning of equipment and systems for harvesting, handling, transport, drying, and storage (GÜRSOY; GÜZEL, 2010; NIKOOBIN et al., 2009). In addition, shape and size of grains are of great interest for the control and automation of equipment, aiming at improving product quality, adding economic value and hence reducing costs with workforce and time in post-harvest operations (NUNES et al., 2014; PEREIRA et al., 2014). The reduction of grain moisture content causes variations in their mass, leading to considerable changes in their physical properties, which can also be influenced by grain geometry (RIBEIRO et al., 2005), both in the drying process and in case of grain rewetting.

According to Sirisomboon et al. (2007), size (surface area, projected area, and volume) and shape (roundness and sphericity) of grains are essential for determining the lower limit of the size of conveyors such as belt, bucket elevator, and screw conveyor. In addition, intergranular porosity and surface area affect the resistance to airflow through the material layer, being relevant the generation of information on such aspects for a better description of the drying process.

According to Araujo et al. (2014), grain volume is usually the physical characteristic that suffers most variation during drying, often providing a reduction in size or even in the geometric shape. These characteristics determine the size and shape of perforations of sieves used in the processing of grains and seeds.

For Siqueira et al. (2012), volumetric shrinkage allows predicting the volume occupied by the grain mass as a change in moisture content occurs, which is essential for developing new drying equipment.

Changes in physical and chemical properties of soybean grains occurring in a drying process or even during water soaking affect their potential as raw material for product manufacturing (KASHANINEJAD et al., 2008). Grain volumetric changes due to dehydration are reported as being the main causes of changes in the physical properties of agricultural products (RATTI, 1994; TOWNER, 1987).

Zogzas et al. (1994) observed that grain volumetric shrinkage of other crops during the drying process is not only a function of moisture content but also dependent on process conditions and grain geometry.

Considering the importance of the relationship between these physical properties, it is necessary to study the correlation between them in order to verify the likelihood of the behavior. In this context, grain physical properties present differences between cultivars and moisture contents, as well as the correlation between them. Therefore, this study aimed to determine the characteristics related to the physical properties of grains with different moisture contents of three soybean cultivars.

The analyses of grain physical properties of the three soybean cultivars were carried out at the Laboratory of Post-Harvest of Plant Products of the Federal Institute of Education, Science and Technology of Goiás, Campus of Rio Verde, GO, Brazil.

The experimental design was completely randomized design in a 3 × 6 factorial scheme with three replications, consisting of three soybean cultivars (6266 RSF IPRO, BMX Potência RR, and 14403Z6001) and six grain moisture contents (11, 13, 15, 17, 19, and 21% wb). The cultivar 6266 RSF IPRO has a cycle of 100 to 112 days, population of 250,000 to 320,000 plants per hectare, high fertility requirement, medium to large and heavy grains, and excellent productive potential. The cultivar BMX Potência RR has a cycle of 105 to 115 days, population of 350,000 to 450,000 plants per hectare, medium to high fertility requirement, medium to large and heavy grains, and excellent productive potential with a high number of pods with three grains. The cultivar 14403Z6001 has a medium to high fertility requirement, small grains, and excellent productive potential (BRASMAX, 2017).

Soybean grains were purchased from a seed production and processing unit and had moisture contents of 11.0, 11.0, and 10.8% wb for the cultivars 6266 RSF IPRO, BMX Potência RR, and 14403Z6001, respectively. Moisture contents were obtained by soaking in a controlled environment (B.O.D) maintained at 25 °C, with water availability for evaporation distributed in all compartments and an average relative air humidity of 93%.

Soybean grains were conditioned in plastic trays and moisture content was monitored by using an electric capacitance determining apparatus until the desired moisture content was reached, being validated by the oven method at 105 ± 3 °C for 24 hours (BRASIL, 2009).

Volume (Equation 1), roundness (Equation 2), sphericity (Equation 3), surface area (Equation 4), and volumetric shrinkage (Equation 5) were determined for each moisture content in the different soybean cultivars, with the measurements carried out by using a 0.01 mm precision digital caliper (MOHSENIN, 1986).

$$V = \frac{\pi(\mathrm{a} \times \mathrm{b} \times \mathrm{c})}{6} \tag{1}$$

$$\mathrm{Rdn} = \frac{\mathrm{b}}{\mathrm{a}} \times 100 \tag{2}$$

$$\mathrm{Sph} = \frac{(\mathrm{a} \times \mathrm{b} \times \mathrm{c})^{\frac{1}{8}}}{\mathrm{a}} \tag{3}$$

$$\mathrm{SA} = \frac{(\pi \times \mathrm{a} \times \mathrm{b})}{4} \tag{4}$$

$$\Psi\mathrm{m} = \left[1 - \left(\frac{V_g}{V_{go}}\right)\right] \times 100 \tag{5}$$

where V is the grain volume for each moisture content (m^3), V_{go} is the initial grain volume (m^3), V_g is the grain volume (m^3), Rnd is the roundness (%), Sph is the sphericity (%), SA is the surface area (m^2), Ψm is the volumetric shrinkage (%), a is the largest orthogonal axis of the grain (m), b is the average orthogonal axis of the grain (m), and c is the smallest orthogonal axis of the grain (m).

The experimental data were submitted to the analysis of variance by the F-test ($p<0.05$), followed by a regression analysis for grain moisture contents and the means of cultivars were compared by the Tukey's test using the SISVAR® statistical program (FERREIRA, 2011).

The Pearson correlation analysis (r) was performed in order to represent the linearity between grain physical properties. The database was composed of 72 pairs for analysis of six moisture contents (11, 13, 15, 17, 19, and 21% wb), three cultivars (6266 RSF IPRO, BMX Potência RR, and 14403Z6001), and four replications. When the tests were significant (P-*value*<0.05), the correlation coefficient (score) was classified according to Cohen (1988).

The cultivars BMX Potência RR and 14403Z6001 presented the highest and lowest grain volumes in the moisture contents of 13 to 21% wb, being the highest difference registered in the moisture content of 15% wb, with a value of 4.60 10^{-7}. The lowest difference was obtained in the moisture content of 21% wb, with a value of 3.40 10^{-7} (Table 1). When assessing soybean grains as a function of moisture content and cultivar, Kashaninejad et al. (2008) also observed volume differences in soybean cultivars. On the other hand, Nunes et al. (2014) did not observe differences among seven different cultivars when assessing the unit volume of wheat.

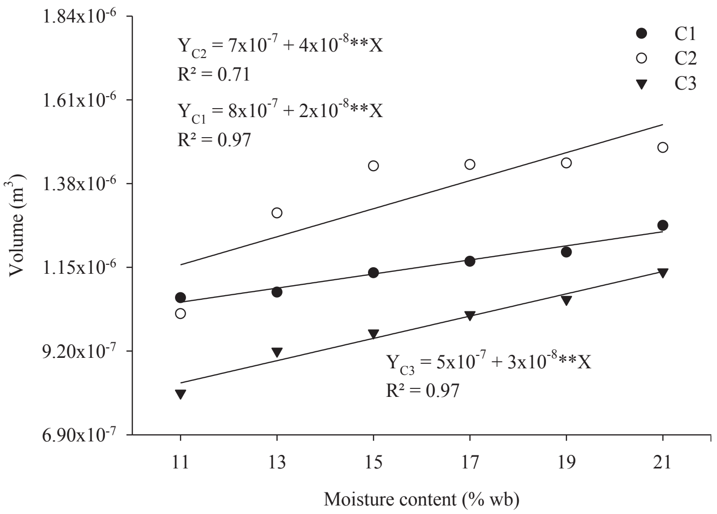
Table 1. Grain volume of the soybean cultivars 6266RSFIPRO, BMX Potência RR, and 14403Z6001 for different moisture contents (11, 13, 15, 17, 19, and 21% wb).

Cultivar[1]	Moisture content (% wb)					
	11	13	15	17	19	21
	Volume (m^3)					
C1	1.07×10^{-6}a	1.08×10^{-6}b	1.13×10^{-6}b	1.17×10^{-6}b	1.19×10^{-6}b	1.26×10^{-6}b
C2	1.02×10^{-6}a	1.30×10^{-6}a	1.43×10^{-6}a	1.43×10^{-6}a	1.44×10^{-6}a	1.48×10^{-6}a
C3	8.04×10^{-7}b	9.20×10^{-7}c	9.70×10^{-7}c	1.02×10^{-6}c	1.06×10^{-6}c	1.14×10^{-6}c

*Means followed by the same letter in the columns do not differ from each other by the Tukey's test at 5% significance. [1]C1 - 6266 RSF IPRO, C2 - BMX Potência RR, and C3 - 14403Z6001.

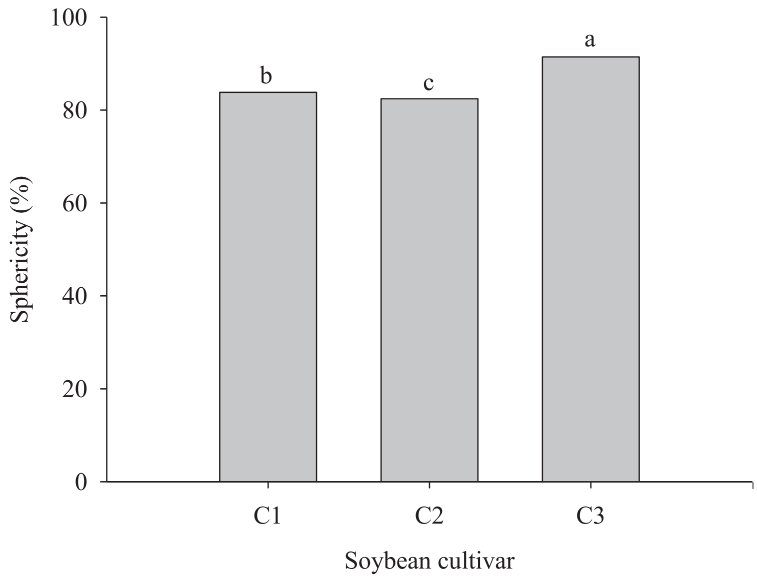
The cultivars 6266 RSF IPRO, BMX Potência RR, and 14403Z6001 presented a positive linear behavior for volume as a function of the increase in moisture content. In addition, the cultivars 6266 RSF IPRO and BMX Potência RR showed the lowest and highest increase in volume, respectively. An average increase of 4×10^{-8}, 8×10^{-8}, and 6×10^{-8} m^3 was observed for the cultivars 6266 RSF IPRO, BMX Potência RR, and 14403Z6001, respectively, at each increase of 2% wb (Figure 1). The highest volumes were observed for BMX Potência RR, 6266 RSF IPRO, and 14403Z6001, respectively. Soybean cultivars with larger grains, real and specific mass, generally have a larger diameter of grains, which results in a higher volume. Thus, the cultivars BMX Potência RR and 6266 RSF IPRO, which have larger grains, showed higher volumes when compared to the cultivar 14403Z6001, which has smaller grains. Guedes et al. (2011) assessed the volume of soybean grains as a function of moisture content for different measurement methods and observed a similar increasing linear behavior for the increase of grain volume as a function of the different moisture contents.

Figure 1. Grain volume of the soybean cultivars 6266 RSF IPRO (C1), BMX Potência RR (C2), and 14403Z6001 (C3) as a function of moisture contents.



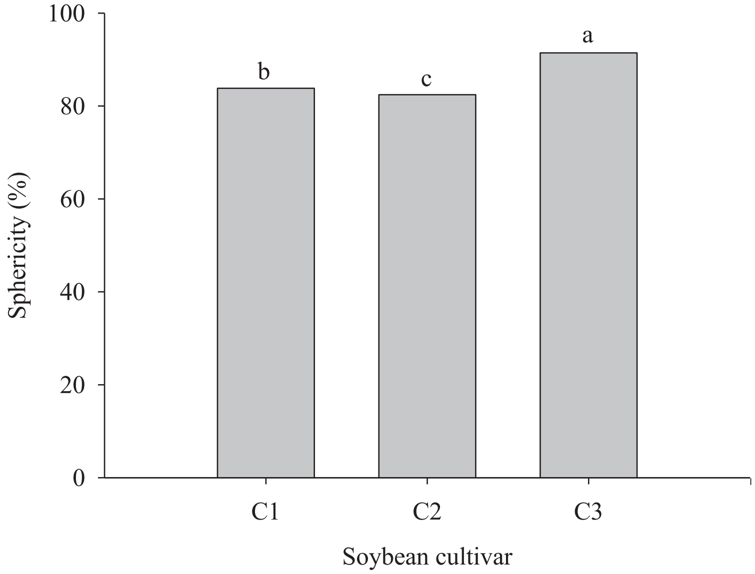
Regardless of the assessed moisture content, the grains of the cultivar 14403Z6001 presented a higher sphericity when compared to the grains of the cultivars BMX Potência RR and 6266 RSF IPRO (Figure 2). Kashaninejad et al. (2008) assessed soybean grains as a function of moisture contents and cultivars and also observed differences in the sphericity of soybean cultivars. This may be due to the genetic characteristics of this cultivar. Grain shape of the cultivar 14403Z6001 is closer to a real sphere when compared to the other cultivars, with a smaller grain size and more restricted depression in the sphere surface (SILVA, 2008).

Figure 2. Grain sphericity of the soybean cultivars 6266RSFIPRO (C1), BMX Potência RR (C2), and 14403Z6001 (C3).



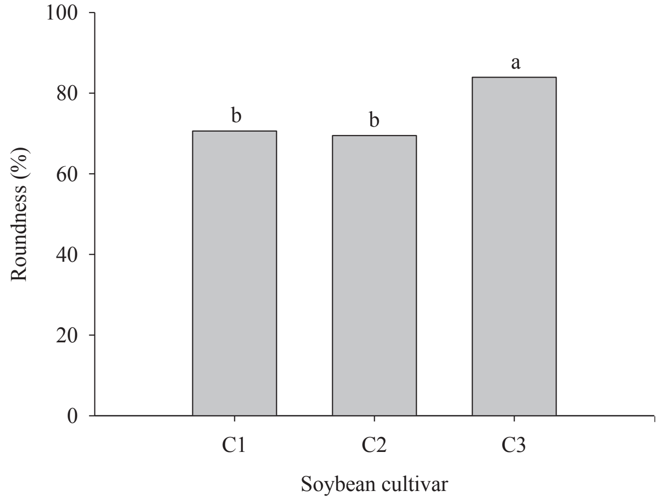
According to the behavior of grain sphericity as a function of moisture contents, an increase of 2% wb in moisture content provided a reduction of 0.92% in grain sphericity regardless of the cultivars (Figure 3). This reduction in grain sphericity is due to an increase in grain surface roughness, which is usually verified with an increase in moisture content (TAVAKOLI et al., 2009). Guedes et al. (2011) assessed the sphericity of soybean grains as a function of moisture contents for different measurement methods and observed a similar decreasing linear behavior. In a study with red bean during the drying process, Resende et al. (2005) observed a reduction in sphericity as a function of the increase in moisture content.

Figure 3. Sphericity of soybean grains as a function of moisture content.



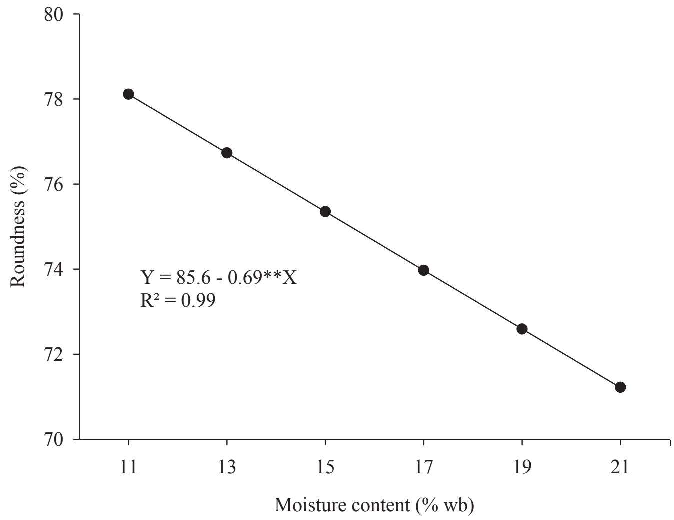
A significant difference was observed for grain roundness of the cultivar 14403Z6001 in relation to the cultivars 6266 RSF IPRO and BMX Potência RR. The percentage increase of the cultivar 14403Z6001 is 13.32% in relation to the cultivar 6266 RSF IPRO and 14.40% in relation to the cultivar BMX Potência RR. The grains of the cultivars 6266 RSF IPRO and BMX Potência RR did not differ for this variable (Figure 4). Kashaninejad et al. (2008) also verified differences of roundness for soybean cultivars when assessing grains as a function of moisture content and cultivars.

Figure 4. Grain roundness of the soybean cultivars 6266 RSF IPRO (C1), BMX Potência RR (C2), and 14403Z6001 (C3).



Regardless of the cultivars, an increase in two percentage points in moisture content provided a reduction of 1.38% of grain roundness in a linear behavior (Figure 5). As in sphericity, roundness is negatively influenced by the increased moisture content, which demonstrates that the increase of grain in size occurs in an unequal form, accentuating depressions and reducing roundness. Guedes et al. (2011) also verified a decreasing linear behavior for the roundness of soybean grains as a function of moisture content for different measurement methods when the moisture content is increased. Resende et al. (2005) also verified a reduction in the roundness of bean grains throughout the drying process as moisture content increased.

Figure 5. Roundness of soybean grains as a function of moisture content.



The cultivars BMX Potência RR and 14403Z6001 presented the highest and lowest surface area in the moisture contents of 13 to 21% wb, being the highest difference registered in the moisture content of 15% wb, with a value of 3.77×10^{-5}. The lowest difference was obtained in the moisture content of 13% wb, with a value of 3.02×10^{-5} (Table 2). No difference was observed between the cultivars 6266 RSF IPRO and BMX Potência RR for the moisture content at 11% wb, but both cultivars differed from the cultivar 14403Z6001. The cultivar 14403Z6001, which presents smaller grains, has lower orthogonal axes, which reflects in a smaller surface area (OLIVEIRA et al., 2014). Kashaninejad et al. (2008) also observed significant differences in the surface area when assessing different soybean cultivars.

Table 2. Surface area of different soybean cultivars for different moisture contents.

Cultivar[1]	Moisture content (% wb)				
	11	13	15	17	19
	Surface area (m^2)				
C1	7.34×10^{-5}a	7.46×10^{-5}b	7.81×10^{-5}b	8.17×10^{-5}b	8.27×10^{-5}b
C2	7.11×10^{-5}a	8.29×10^{-5}a	9.21×10^{-5}a	9.24×10^{-5}a	9.27×10^{-5}a
C3	4.9×10^{-5}b	5.27×10^{-5}c	5.44×10^{-5}c	5.53×10^{-5}c	5.64×10^{-5}c

*Means followed by the same letter do not differ from each other by the Tukey's test at 5% significance. [1]C1 - 6266 RSF IPRO, C2 - BMX Potência RR, and C3 - 14403Z6001.

A linear increase of the surface area was observed as moisture content increased. In addition, an average increase of 2.48, 6.09, and 4.06% was observed at each increase of 2% wb in the moisture content for the cultivars 6266 RSF IPRO, BMX Potência RR, and 14403Z6001, respectively (Figure 6). These cultivars present increases in diameter and volume of grains in relation to moisture content and changes in the orthogonal axes due to moisture content, leading to an increase in the surface area (SILVA, 2008). Guedes et al. (2011) also found similar results when studying the surface area of soybean grains as a function of moisture content. Oliveira et al. (2014) identified a linear increase of the surface area of corn as moisture content increased.

Figure 6. Surface area of soybean grains as a function of moisture content.

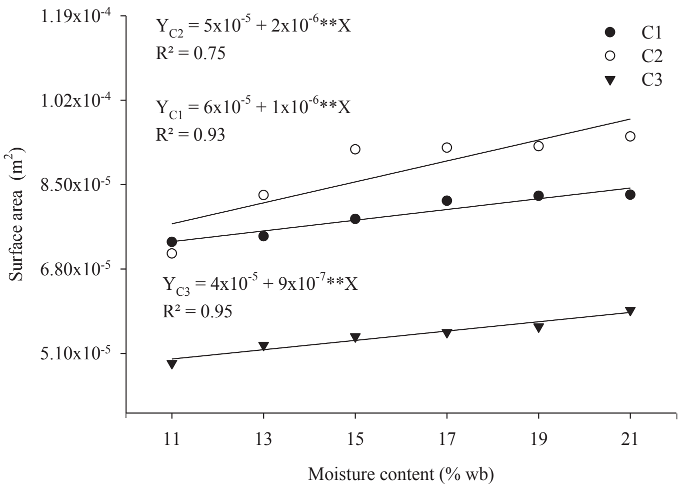
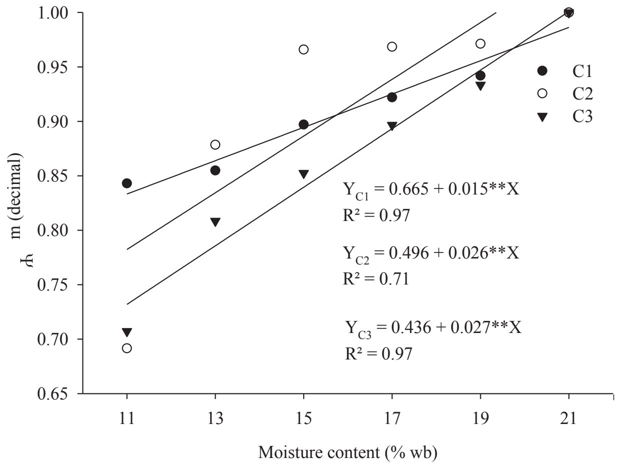


Figure 7 shows a linear increase in the volumetric shrinkage as moisture contents increased. An average increase of 3.49, 8.10, and 7.23 was observed at each increase of 2% wb for the cultivars 6266 RSF IPRO, BMX Potência RR, and 14403Z6001, respectively. Grain volume is influenced by moisture content since volume shrinkage is dependent on volume and tends to show increments with moisture content (GONELI et al., 2011). Corrêa et al. (2006) assessed wheat as a function of several moisture contents and also verified a linear increase in the volumetric shrinkage as moisture contents increased. Resende et al. (2005) observed similar results when analyzing bean grains throughout the drying process.

Figure 7. Volumetric shrinkage of grain mass of the soybean cultivars 6266 RSF IPRO (C1), BMX Potência RR (C2), and 14403Z6001 (C3) as a function of moisture content.

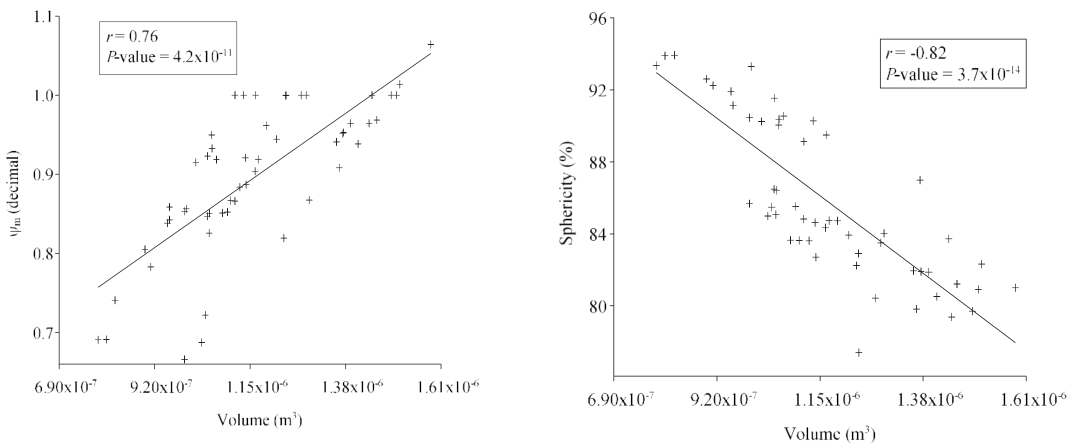


According to Figure 8, all scores presented high significance (P-value<0.05). The scores of volumetric shrinkage (Ψm) × sphericity (Sph) and Ψm × roundness (Rnd) presented a mean magnitude, while the others showed high magnitudes (Figures 8, 9, and 10).

Figure 8. Representation of the correlation of the scores volume × volumetric shrinkage (A), volume × sphericity (B), volume × roundness (C), and volume × angle of repose (D).

A

B



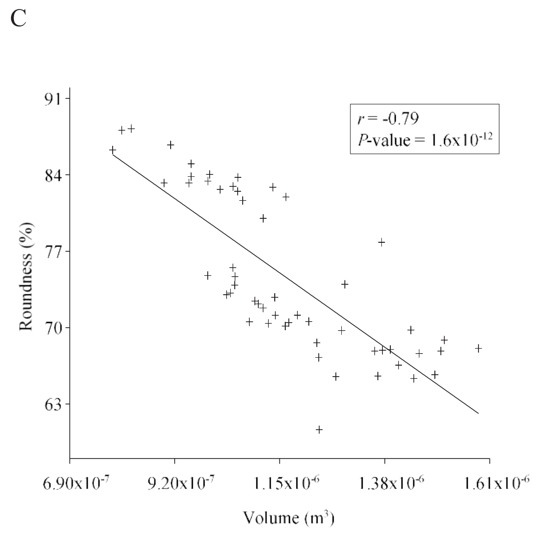
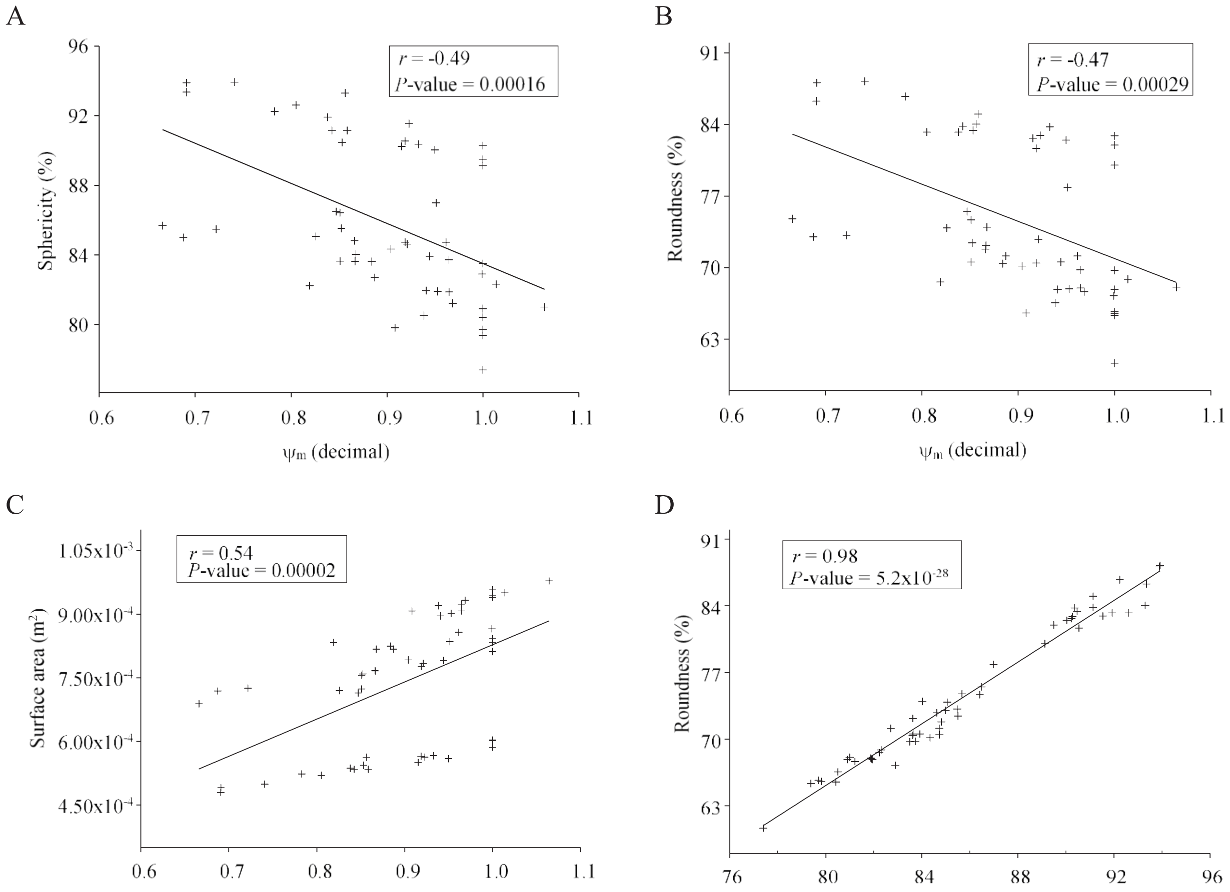


Figure 9. Representation of the correlation of the scores volumetric shrinkage × sphericity (A), volumetric shrinkage × roundness (B), volumetric shrinkage × surface area (C), and sphericity × roundness (D).

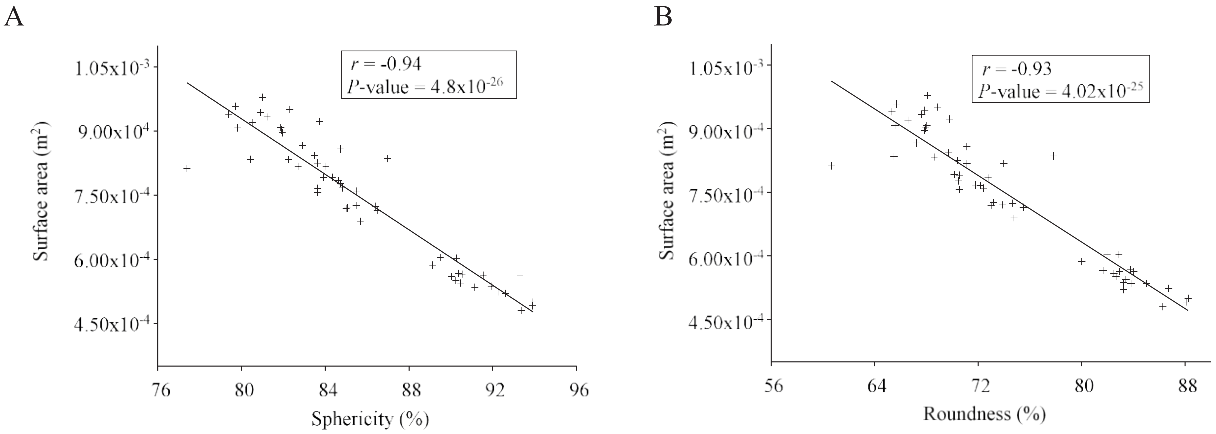


A positive correlation was observed between volume (v) × Ψm (Figure 8A) and v × SA (Figure 8D), in addition to a negative correlation between v × Sph (Figure 8B) and v × Rnd (Figure 8C). The strong correlation of volume with other variables was expected due to its close relationship and being generally influenced by grain size.

A positive correlation was also observed between Ψm × SA (Figure 9C) and Sph × Rnd (Figure 9D), in addition to a negative correlation between Ψm × Sph (Figure 9A) and Ψm × Rnd (Figure 9B).

The volumetric shrinkage presented a moderate correlation with sphericity, roundness, and surface area, indicating that both grain dimensions (a and c), or even when the three-dimensionality (a, b, and c) was considered, had an equal importance in the volumetric shrinkage. This fact was justified by the strong correlation with volume, but this correlation was not very strong, indicating an influence of other factors on the volumetric shrinkage. According to Corrêa et al. (2004), Ratti (1994), and Zogzas et al. (1994), the volumetric shrinkage of plant products during drying is not only a function of moisture content, but also dependent on the cultivar, environmental conditions of the process, geometry, and product composition.

Figure 10. Representation of the correlation of the scores sphericity × surface area (A) and roundness × surface area (B).



A negative correlation was observed between Sph × SA (Figure 10A) and Rnd × SA (Figure 10B), which was expected because, as it happens for volume, grain dimensions are also determinant for these physical properties.

Differences were observed for volume, roundness, sphericity, and surface area when the cultivars were compared, being the highest results obtained in the cultivar BMX Potência RR.

Volume and surface area increased as the moisture content of soybean grains increased. An opposite behavior was observed for roundness and sphericity. A linear increase was observed in the volumetric shrinkage as moisture contents increased. The values of the correlation coefficients of the linear regression models used to describe the relationships between the studied physical properties were satisfactory.

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