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# Effect of drying on the physical properties of adzuki bean

# Efeito da secagem nas propriedades físicas dos grãos de feijão adzuki

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## Abstract

The goal of the present study was to assess the effect of drying on the physical properties of adzuki bean (*Vigna angularis* Willd.). Adzuki beans with moisture content of 47.9% were dried in a oven with forced air ventilation at temperatures of 40, 60 and 80 °C and relative humidity of 18.5, 8.6, and 3.8%, respectively, until the moisture content reached 12.9%. We used 15 adzuki beans individualised in aluminium capsules. The orthogonal axes of the beans (length, width, and thickness) were measured at intervals of five percentage points during the reduction of moisture content. The parameters determined were: sphericity; circularity; volume of beans; volumetric contraction index; volume contraction percentage; surface area; projected area; and surface-volume ratio. The drying conditions altered the physical properties of adzuki bean. As a result of moisture content reduction, there was increased sphericity and surface-volume ratio, and decreased volume, unitary volumetric contraction, surface area, and projected area. Circularity was not influenced by the drying temperatures within the range of moisture content analysed.
**Key words**: *Vigna angularis* Willd. Shape. Size. Volume.

## Resumo

O objetivo neste trabalho foi avaliar o efeito da secagem dos grãos de feijão adzuki (*Vigna angularis* Willd.) nas propriedades físicas, ao longo do processo de secagem. Grãos de feijão adzuki com teor de água de 47,9% (b.u.) foram submetidos à secagem, em estufa com ventilação de ar forçado, nas temperaturas 40, 60 e 80 °C e umidades relativas de 18,5; 8,6 e 3,8%, respectivamente, até o teor de água, até atingir 12,9% (b.u.). Foram utilizados 15 grãos, individualizados em cápsulas de alumínio. Os eixos ortogonais dos grãos (comprimento, largura e espessura) foram mensurados em intervalos de cinco pontos percentuais durante a redução do teor de água. Determinaram-se os parâmetros esfericidade, circularidade, volume do grão, índice de contração volumétrica, porcentagem de contração volumétrica, área superficial, área projetada e a relação superfície-volume. As condições de secagem alteram as propriedades físicas dos grãos de feijão adzuki. Com a redução no teor de água há um aumento da esfericidade e da relação superfície-volume, e a diminuição do volume, da contração volumétrica unitária, e das áreas superficial e projetada. A circularidade não foi influenciada pelas temperaturas de secagem na faixa de teor de água analisada.
**Palavras-chave:** *Vigna angularis* Willd. Forma. Tamanho. Volume.

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## Introduction

Adzuki bean (*Vigna angularis* Willd.) possibly originated in China, which is the world's largest producer. Japan and South Korea are also major producers. In Brazil, adzuki bean is more expensive than common bean (*Phaseolus vulgaris* L.). Even though its production is still small, it has been increasing in recent years and the product is easily found in supermarkets (VIEIRA, 2002; ALMEIDA et al., 2013). According to Yousif et al. (2003), in Asian countries like Japan, China and Korea, this adzuki bean is consumed in the form of paste, cooked and sweetened, as desserts and snacks. In Brazil, it is mainly consumed in Japanese colonies, especially as sweets and many eastern delicacies. In south-western Goiás, Brazil, adzuki bean is well adapted in the first crop (sown in October or November) and reaches the productivity of 1,638.41 kg ha$^{-1}$ (GUARESCHI et al., 2009).

For safe storage of adzuki beans, it is necessary to reduce the moisture content to recommended levels. Therefore, it becomes essential to use the drying process, which is one of the stages of the pre-processing of agricultural products that allows storage for longer periods of time, without the risk of product deterioration. This process inhibits the development of micro-organisms and reduces the rates of enzymatic and non-enzymatic reactions (CORRÊA et al., 2011). According to Goneli et al. (2011), information about the size and volume-among other physical characteristics of agricultural products-are considered of great importance for studies involving heat and mass transfer and air movement in granular masses.

Knowledge of physical properties is also important for the development of equipment used for post-harvest operations of agricultural products (VARNAMKHASTI et al., 2008; GONELI et al., 2011), or the adaptation of existing equipment targeting higher income (GONELI, 2008).

In this regard, numerous authors have investigated the variations of physical properties relating to moisture content and drying temperature in various products, namely: castor bean (GONELI, 2008); physic nut fruits (SIQUEIRA et al., 2012), physic nut seeds (SIQUEIRA et al., 2013); and soya beans (OLIVEIRA et al., 2013).

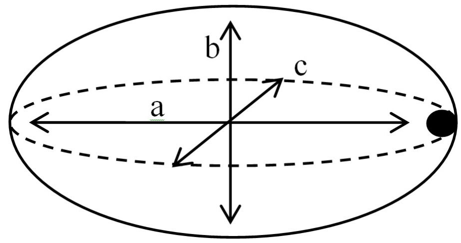
Since beans are an important source of protein in the diet and considering the importance of the drying process and the effects of this post-harvest step on the physical properties of the beans, the goal of the present study was to assess the effect of drying temperatures on the physical properties of adzuki bean throughout the drying process.

## Material and Method

The experiment was conducted in the Laboratory of Post-Harvest Plant Products of the Goiano Federal Institute of Education, Science and Technology – Rio Verde Campus (Goiano FI – Rio Verde Campus). Adzuki beans (*Vigna angularis* Willd.) with 47.9% of moisture content (wet basis [wb]) were dried in a oven with forced air ventilation at temperatures of 40, 60 and 80 °C and relative humidity of 18.5, 8.6, and 3.8%, respectively, until the moisture content reached 12.9% (wb).

We placed 15 adzuki beans individualised in aluminium capsules, with 60.12 mm diameter and 41.0 mm high, as proposed by Siqueira et al. (2012). The length, width and thickness of the beans were measured using a digital calliper with 0.01-mm resolution, at intervals of five percentage points during the reduction of moisture content (Figure 1). The reduction of moisture content was assessed by weighing a tray with 100 g of the product held in the same drying conditions to which the 15 grains were submitted.

**Figure 1.** Schematic drawing of adzuki bean (*Vigna angularis* Willd.) with orthogonal dimensions.




in which
a: largest axis of the beans, m;
b: medium axis of the beans, m;
c: smallest axis of the beans, m.

The shape of the adzuki beans, considered spheroid, in natural resting position, was obtained through the sphericity and circularity according to the expressions 1 and 2, respectively, proposed by Mohsenin (1986). The volume of each bean ($B_v$) was obtained throughout the drying process according to the expression 3 proposed by Mohsenin (1986). The unitary volumetric contraction ($\Psi_u$) was determined by the relationship between $B_v$ for each moisture content and initial volume using the expression 4. The volumetric contraction index (Ïψ) was obtained by means of the expression 5, and the surface area (S) was calculated by analogy to a sphere of the same medium geometric diameter using the expression 6 (TUNDE-AKINNTUNDE; AKINTUNDE, 2004). For this calculation, it was necessary to determine the geometric diameter ($G_d$) according to the expression 7 (MOHSENIN, 1986). The projected area ($P_a$) was calculated in accordance with Goneli (2008) using the expression 8, and the surface-volume ratio (SV) using the expression 9.

$$S_p = \left[ \frac{\{a.b.c\}^{1/3}}{a} \right].100 \quad (1)$$

$$C = \frac{b}{a}.100 \quad (2)$$

$$Bv = \frac{\pi \cdot a \cdot b \cdot c}{6} \quad (3)$$

$$\Psi u = \frac{V_g}{V_{g0}} \quad (4)$$

$$I_{\Psi_u} = (\Psi_{u0} - \Psi_{ut}).100 \quad (5)$$

$$S = \pi \cdot G_d \quad (6)$$

$$G_d = (a.b.c)^{1/3} \quad (7)$$

$$P_a = \frac{\pi ab}{4} \quad (8)$$

$$SV = \frac{S}{G_d} \quad (9)$$

in which: $B_v$ = bean volume, at time t, m³; $B_v0$ = initial volume of beans, m³; $S_p$ = sphericity; C = circularity; $\Psi_u$ = unitary volumetric contraction, decimal; $G_v$ = bean volume, at time t, m³; $G_v0$ = initial volume of beans, m³; $Ï\psi_u$ = volumetric contraction index, %; $\psi_{u0}$ = initial unitary volumetric contraction, decimal; $\psi_{ut}$ = unitary volumetric contraction, at time t, decimal; $G_d$ = medium geometric diameter, m; $P_a$ = projected area, m²; and SV = surface-volume ratio.

The experimental design used was completely randomized using a 3 x 8 factorial scheme, three drying temperatures (40, 60, and 80 °C) and eight moisture contents (47.9; 42.9; 37.9; 32.9; 27.9; 22.9; 17.9; and 12.9% [wb]) with fifteen repetitions.

The data were subjected to analysis of variance. The averages were compared using the F-test at 5% significance and polynomial regression analysis using the SISVAR® statistical software (FERREIRA, 2011).

The average relative error (P) was calculated according to the following expression:

$$P = \frac{100}{n}\sum\frac{\left|Y - \hat{Y}\right|}{Y} \quad (10)$$

in which:

Y: experimentally observed value;

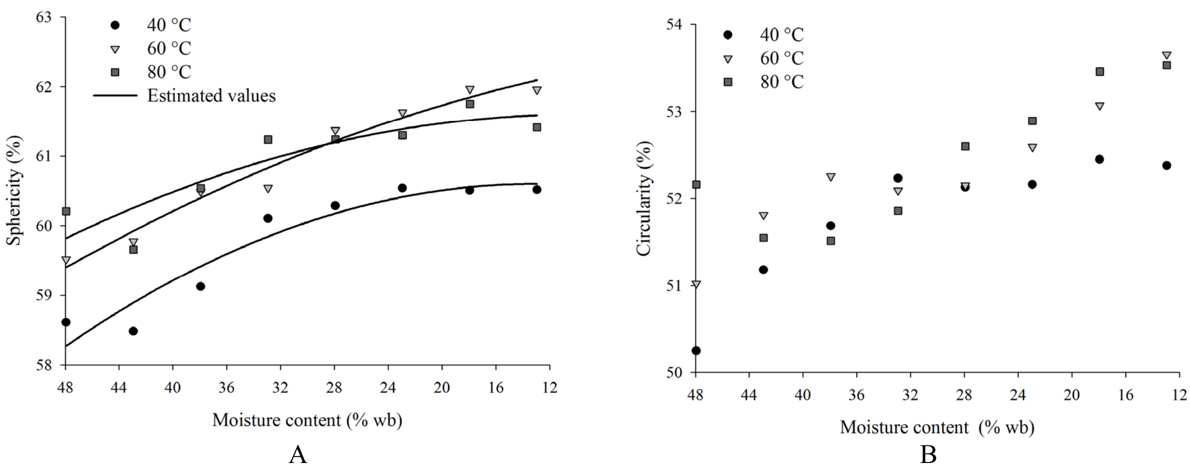
$\hat{Y}$: value calculated by the model;

n: number of experimental observations;

## Results and Discussion

Figure 2 illustrates the sphericity and circularity relating to the moisture content of adzuki beans dried at temperatures of 40, 60, and 80 °C. Figure 2A shows that the sphericity of the beans increased as a result of moisture content reduction at all temperatures. This increase was more significant at the temperature of 60 °C, indicating that, at the end of the drying process, the shapes of the beans were more spherical.

**Figure 2.** Sphericity (A) and circularity (B) of the adzuki beans (*Vigna angularis* Willd.) relating to moisture content, with drying conditions at temperatures of 40, 60, and 80 °C.




**Source:** Sigma Plot Programme.

Corrêa et al. (2006) assessed the sphericity of wheat grains during the drying process and also observed increased sphericity as a result of moisture content reduction. However, the sphericity of the grains submitted to 36 °C had decreased, possibly due to the low water removal rate under that condition. This result was not observed in our work at drying temperatures close to 40 °C. Al mahasneh and Rababah (2007) and Siqueira et al. (2012) found that the sphericity had decreased when the moisture content was lower.

The values of circularity did not differ in the three drying temperatures and the different levels of moisture content. The average values obtained were 51.80, 52.33, and 52.44% for temperatures of 40, 60, and 80 °C, respectively. Various agricultural products did not exhibit this behaviour, such as cotton seeds (OZARSLAN, 2002), millet (BARYEH; MANGOPE, 2002), flax (SACILIK et al., 2003), cocoa (BART-PLANGE; BARYEH, 2003), and physic nuts (SIQUEIRA et al., 2013), whose values of circularity increased when the moisture content was reduced.

Siqueira et al. (2012) observed a reduction in circularity in physic nuts subjected to drying at 60, 75, 90, and 105 °C; however, at lower temperature the nuts behaved differently. The authors explain that these differences can be attributed to width and length contractions, which occur differently depending on the temperature. Adzuki beans may also have behaved differently from other agricultural products with respect to the contraction of their dimensions during the drying process. Figure 3 illustrates the volume values (A), surface area (B), projected area (C), and surface-volume ratio (D) of adzuki beans during the drying process.

It can be observed that the volume of adzuki beans decreased when the moisture content was lower at all temperatures studied. Araujo et al. (2014) assessed the physical properties of peanut grains at different moisture contents and observed a reduction in the volume of the grains. This reduction in the volume of grains is related to volume contraction during the drying process due to the removal of water.

The volume of adzuki beans was greater at the highest temperature at all levels of moisture content. Siqueira et al. (2012) also observed the same behaviour in physic nuts when subjected to drying at higher temperatures. The authors explain that, under these conditions, the water removal rate was higher and caused the hardening of the tegument, which may have hampered the contraction of the grains and, consequently, reduced their volume with less intensity.

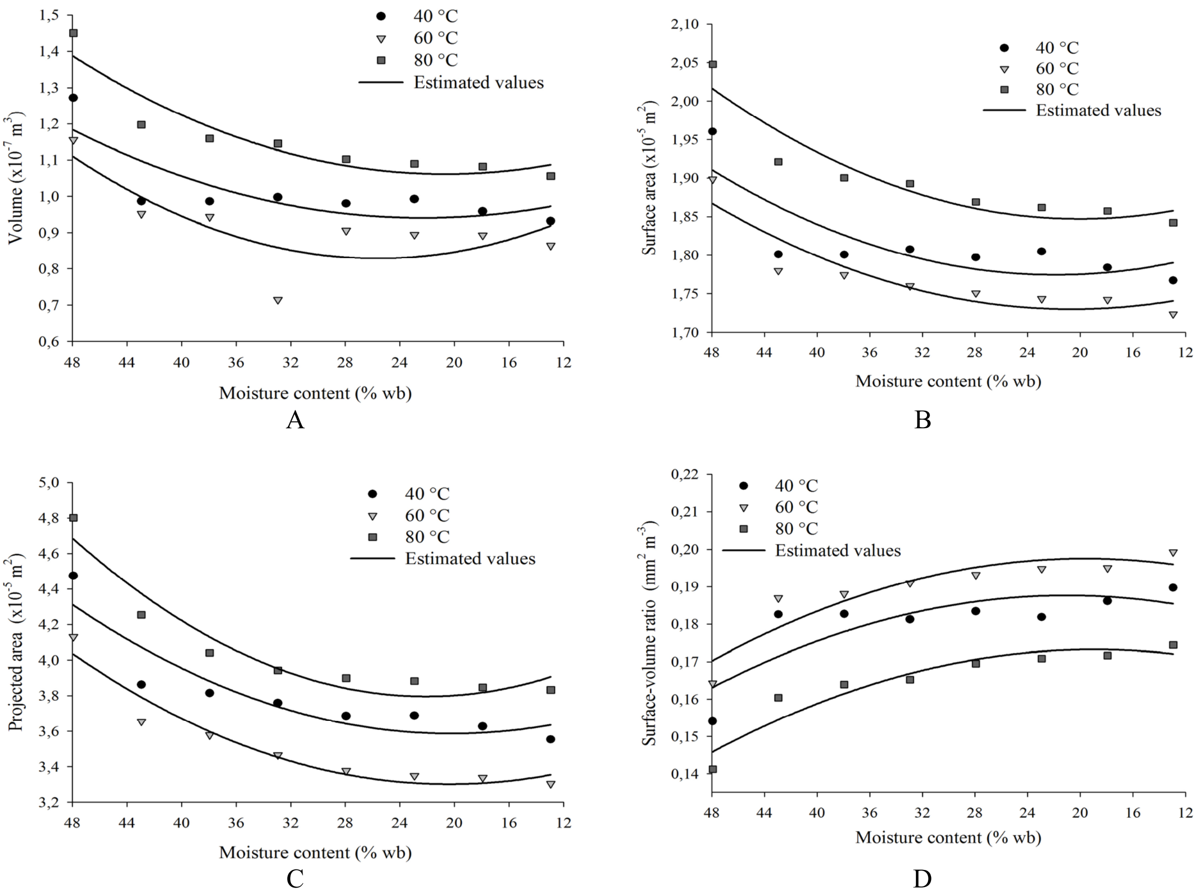
The surface area of the adzuki beans exhibited similar behaviour than that of the bean volume, i.e., it decreased with the reduction of moisture content in all drying conditions (Figure 3B). The values of the surface area were between $2.047 \times 10^{-5}$ and $1.767 \times 10^{-5}$ $m^2$. Bande et al. (2012) assessed the surface area of melon seeds with different moisture contents and observed a similar behaviour.

The projected area decreased with the reduction of moisture content at the temperature of 60 °C (Figure 3C), which was a similar behaviour than that obtained by Siqueira et al. (2012) and Goneli (2008). Araujo et al. (2014) affirmed that this phenomenon occurs due to the reduction of the characteristic dimensions of the product during the desorption process, which contributes to the shrinking of the beans and, consequently, to the reduction of the projected area.

The surface-area ratio of the adzuki beans increased with the reduction of moisture content. This increase was greater at the temperature of 60 °C and lower at 80 °C (Figure 3D). Similar results were obtained by Siqueira et al. (2012) when they assessed physic nuts.

According to Al Mahasneh and Rababah (2007), the surface-area ratio is used for determining the projected area of particles that move with turbulence in the air current, which can be useful in the construction of grain cleaning machines, separators, and pneumatic conveyors. When the surface-volume ratio increases, there is increase in the rate of heat transfer and mass, which affects several unitary operations, such as drying and cooling.

**Figure 3.** Volume (A), surface area (B), projected area (C), and surface-volume ratio (D) of the adzuki beans (*Vigna angularis* Willd.) relating to moisture content, with drying conditions at 40, 60, and 80 °C.




**Source:** Sigma Plot Programme.

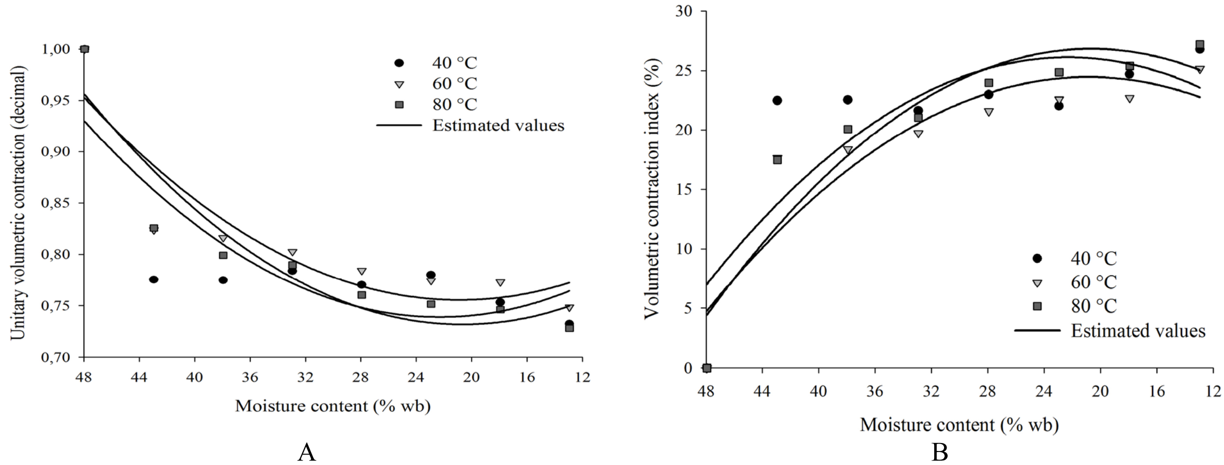
Figure 4 illustrates the values of volumetric contraction (A) and the unitary volumetric contraction (B) of adzuki beans. The drying process caused the contraction of the adzuki beans (Figure 4A), which was in line with the results obtained by Goneli et al. (2011). Afonso Júnior et al. (2003) and Santos et al. (2014) assessed the drying of coffee and maize grains and found that the volumetric contraction should not be neglected during the modelling of the drying process.

Figure 4B shows that the contraction of the product was the same at all drying temperatures and that it increased from 26 to 28% depending on the reduction of the moisture content. Goneli et al. (2011) assessed the unitary volumetric contraction of fruits of castor bean and found a volume reduction of 46% with respect to the initial volume, with moisture content ranging from 71.4 to 11.5% (wb).

Khraisheh et al. (2004) observed that the volumetric contraction of agricultural products during drying occurs heterogeneously. Apparently, at the beginning of drying, the products remain with the intact structure and retain their original shape. However, with the removal of water, the particles shrink.

Table 1 illustrates the models adjusted to the experimental data of sphericity, circularity, volume, unitary volumetric contraction, surface area, projected area, and surface-volume ratio of adzuki beans relating to the moisture content.

**Figure 4.** Unitary volumetric contraction (A) and volumetric contraction index (B) of the adzuki beans (*Vigna angularis* Willd.) relating to moisture content, with drying conditions at 40, 60, and 80 °C.




**Source:** Sigma Plot programme.

**Table 1.** Equations adjusted to the values of sphericity (Sp), volume ($B_v$), surface area (S), projected area ($P_a$), surface-volume ratio (SV), unitary volumetric contraction ($\psi_u$), and volumetric contraction index ($I\psi_u$) of the adzuki beans (*Vigna angularis* Willd.) relating to moisture content, with drying conditions at 40, 60, and 80 °C.

| Sphericity (%) | | | | Volume ($m^3$) | | | |
|---|---|---|---|---|---|---|---|
| T (°C) | Model | R² (%) | P (%) | T (°C) | Model | R² (%) | P (%) |
| 40 | Sph = –0.002 $x^2$ + 0.051 x + 60.266 | 91.4 | 0.35 | 40 | $B_v$ = 0.041 $x^2$ – 1.856 x + 114.25 | 65.2 | 4.75 |
| 60 | Sph = –0.001 $x^2$ – 0.021 x + 62.524 | 97.0 | 0.23 | 60 | $B_v$ = 0.032 $x^2$ – 1.349 x + 101.46 | 62.2 | 7.12 |
| 80 | Sph = –0.001 $x^2$ + 0.024 x + 61.481 | 80.2 | 0.39 | 80 | $B_v$ = 0.044 $x^2$ – 1.805 x + 124.76 | 87.1 | 3.03 |
| Surface area ($m^2$) | | | | Projected area ($m^2$) | | | |
| T (°C) | Model | R² (%) | P (%) | T (°C) | Model | R² (%) | P (%) |
| 40 | S = 0.002 $x^2$ – 0.087 x + 18.69 | 65.2 | 1.51 | 40 | $P_a$ = 0.010 x – 0.3797 x + 39.701 | 83.5 | 2.31 |
| 60 | S = 0.001 $x^2$ – 0.076 x + 18.08 | 82.9 | 0.96 | 60 | $P_a$ = 0.010 $x^2$ – 0.393 x + 37.014 | 93.5 | 1.42 |
| 80 | S = 0.002 $x^2$ – 0.087 x + 19.34 | 88.2 | 0.94 | 80 | $P_a$ = 0.013 $x^2$ – 0.585 x + 44.414 | 92.9 | 1.76 |
| Surface-volume ratio ($mm^2\ m^{-3}$) | | | | Unitary volumetric contraction (decimal) | | | |
| T (°C) | Model | R² (%) | P (%) | T (°C) | Model | R² (%) | P (%) |
| 40 | SV = –3E-05 $x^2$ + 0.001 x + 0.1727 | 65.2 | 2.86 | 40 | $\psi_u$ = 0.0003 $x^2$ – 0.013 x + 0.883 | 65.2 | 4.75 |
| 60 | SV = –3E-05 $x^2$ + 0.001 x + 0.1844 | 84.3 | 1.78 | 60 | $\psi_u$ = 0.0003 $x^2$ – 0.011 x + 0.872 | 81.7 | 3.11 |
| 80 | SV = –3E-05 $x^2$ + 0.001 x + 0.1616 | 89.8 | 1.69 | 80 | $\psi_u$ = 0.0003 $x^2$ – 0.012 x + 0.860 | 87.1 | 3.03 |

| Volumetric contraction index (%) | | |
|---|---|---|
| T (°C) | Model | R² (%) |
| 40 | $Iy_u$ = –0.0290 $x^2$ + 1.2961 x + 11.656 | 65.2 |
| 60 | $Iy_u$ = –0.0269 $x^2$ + 1.1227 x + 12.734 | 81.7 |
| 80 | $Iy_u$ = –0.0301 $x^2$ + 1.2448 x + 13.971 | 87.1 |

*Note.* x = moisture content of the beans, % wb.

It is worth noting that in all the variables analysed, the second-order polynomial models exhibited a coefficient of determination ($R^2$) of more than 80%, with the exception of the temperature of 40 °C for volume, surface area, surface-volume ratio, unitary volumetric contraction, and volumetric contraction index, and 60 °C for volume. With respect to the average relative error (P), the values were less than 10%. According to Mohapatra e Rao (2005), a value of the average relative error lower than 10% indicates good fit of the model to the experimental data. It should be noted that it is not possible to determine the average relative error for the index of volumetric contraction, because the value is zero with the highest moisture content. In this way, the models represented adequately the behaviour relating to the reduction of the moisture content.

## Conclusion

Drying conditions altered the physical properties of adzuki beans. With the reduction in moisture content, there was increase in sphericity and surface-volume ratio, and decrease in volume, unitary volumetric contraction, surface area, and projected area. The circularity was not influenced by the drying temperatures within the range of moisture content assessed.

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