Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 12 June 2022
https://doi.org/10.14295/CS.v13.3586

Mechanical properties of pumpkin seeds

Daniel Emanuel Cabral de Oliveira[1]*, Sarah Gabrielle Sousa Bueno[1], José Mauro Guimarães Carvalho[1], José Roberto da Costa Júnior[1], Osvaldo Resende[2], Vinícius Soares Costa[1]

[1]Federal Institute of Education, Science and Technology of Goiano, Iporá, Brasil
[2]Federal Institute of Education, Science and Technology of Goiano, Rio Verde, Brasil
*Corresponding author, e-mail: oliveira.d.e.c@gmail.com

Abstract

Due to the lack of information on the mechanical properties of pumpkin seeds and the need to develop equipment that can be used more efficiently for their processing, the objective of this project was to study the mechanical properties of commercial pumpkin seeds. Pumpkin (*Cucurbita moschata*) seeds from the commercial cultivars 'Rajada Seca Melhorada' and 'Jacarezinho' with moisture content ranging from 0.670 to 0.094 decimal (dry basis – d.b.) and 0.923 to 0.033 decimal (d.b.), respectively, were used. The determination of the compressive strength of the seeds was carried out by means of uniaxial compression tests. The seeds were compressed in their natural resting position, at a constant speed (force application rate) of 0.0001 m s^{-1}. The average force for deformations varied between 43.90 and 0.56 N for 'Rajada Seca Melhorada' and between 13.20 and 0.20 N for 'Jacarezinho', and the values of the proportional deformation modulus from 8.05 to 23.68 x 10^7 N m^{-2} for the cultivar 'Rajada Seca Melhorada' and from 2.05 to 21.64 x 10^7 N m^{-2} for 'Jacarezinho'. It is concluded that the necessary force for deformation of pumpkin seeds decreases with the increase of the moisture content. There is an increase in the values of the proportional deformation modulus with the reduction of moisture content, for the cultivars 'Rajada Seca Melhorada' and 'Jacarezinho'. It can be seen that seeds of 'Rajada Seca Melhorada' pumpkin have a greater resistance to the deformation force than those of 'Jacarezinho'.

Keywords: *Cucurbita moschata,* drying, proportional deformation modulus

Introduction

Pumpkin (*Cucurbita moschata*) is native to the Americas and is highly cultivated worldwide for its nutritional characteristics and for its use, in both human and animal diet (Pasqualetto et al., 2001).

It should also be highlighted that pumpkin production generates jobs directly and indirectly, thus contributing to an important social issue, due to the great demand for labor in all stages of production (Resende et al., 2013).

In Brazil, before colonization, pumpkin was already part of indigenous food, and today it contributes significantly to Brazilian agribusiness, being one of the most cultivated vegetables in the country (Figueiredo Neto, 2012).

The objective with the drying of agricultural products is to remove part of the water contained in them, maintaining the viability of the product. Reducing the water of the products to safe levels generates benefits such as the inhibition of the growth of microorganisms and development of insects and pests, but care should be taken not to cause losses by leaching of solutes (Rodrigues et al., 2019). Drying methods are basically natural, caused by the action of the sun or wind, and artificial, which requires energy supply (Santos et al., 2010).

During the production processes, agricultural products go through several steps, in which they undergo some impacts, which end up generating damage such as crushing and cracking. The magnitude of the damage caused during the processing of a product depends on the physical and mechanical properties of the seeds (Resende et al., 2007).

According to Couto et al. (2002), how a material behaves mechanically is critical to determining how much load it can withstand and also how much load

Received: 02 September 2020
Accepted: 07 February 2022

machines will have to exert on the product. Knowledge on the mechanical properties of seeds is fundamental for developing projects of machines that help from sowing to processing and marketing (Karababa & Coskuner, 2014).

Several studies have described the mechanical properties of plant products at different moisture contents including: tomato fruits (Oliveira et al., 2015), baru fruits (Oliveira et al., 2017), forage turnip seeds (Sousa et al., 2018), crambe grains (Resende et al., 2018), sweet sorghum seeds (Ribeiro et al., 2019) and bean grains (BRSMG Majestic) coated with carnaúba wax (Corrêa et al., 2019).

Due to the lack of information on the mechanical properties of pumpkin seeds and the need to develop equipment that can be used more efficiently for their processing, the objective with this project was to study the mechanical properties of commercial pumpkin seeds.

Material and Methods

The experiment was carried out in the Plant Science Laboratory of the Federal Institute of Education, Science and Technology of Goiás - Iporá Campus and in the Laboratory of Post-harvest of Plant Products of the Federal Institute of Education, Science and Technology of Goiás - Rio Verde Campus.

The pumpkin (*Cucurbita moschata*) seeds used came from the commercial cultivars 'Jacarezinho' and 'Rajada Seca Melhorada', harvested manually in the experimental area of IF Goiano - Iporá Campus, with initial moisture content from 0.670 to 0.923 decimal (dry basis – d.b.).

Moisture content was determined through the calculation of water loss with the masses. Samples of 25 grams were collected for each moisture content, taken to the oven at 45 °C, and a corresponding weight was determined for each moisture content. These samples were then weighed and, when the expected weight was reached, the sample was removed.

After the end of the weighing processes, the initial moisture content of the seeds of each cultivar was determined. The moisture contents of the seeds were determined by gravimetry after drying in an oven at 105 ± 3 °C for 24 h, in two replications (Brasil, 2009).

For each moisture content obtained, in the cultivar 'Rajada Seca Melhorada' (0.670; 0.453; 0.329; 0.229, 0.122 and 0.094 decimal - d.b.) and cultivar 'Jacarezinho' (0.923; 0.660; 0.509; 0.411; 0.299; 0.238 and 0.033 decimal - d.b.), the samples were homogenized and subjected to the compression test at a controlled temperature of 22±2 °C.

The compressive strength of the seeds was determined by means of uniaxial compression tests in a sample of 10 seeds for each moisture content. The experimental seed compression tests, analyzed individually, were performed in a "TA Hdi Texture Analyser" universal testing machine, using a load cell of 250 N.

The seeds were compressed in their natural resting position, that is, in the direction of thickness (shortest axis) (Figure 1) at a constant velocity (force application rate) of 0.0001 m s^{-1}.

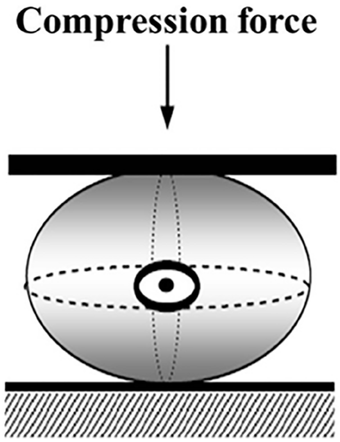

Figure 1 - Orientation of pumpkin seeds during compression tests (shortest axis -thickness).

After data acquisition, compression force curves as a function of seed deformation were constructed for each moisture content studied, with Sigma Plot 11.0 software. For this, the deformations used were 0.2, 0.4, 0.6, 0.8, 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 (x 10^{-3} m), adapted from Batista et al. (2003) and Resende et al. (2007). Moisture content x compression force curves were also construction for each deformation evaluated.

The proportional deformation modulus was determined using equation 1, according to Batista et al. (2003).

$$Ep = \frac{0.531 \cdot F}{D^{3/2}} \cdot \left[2 \cdot \left(\frac{1}{r} + \frac{1}{R} \right)^{1/3} \right]^{3/2} \quad (1)$$

where:

Ep: proportional deformation modulus, Pa;

F: compression force, N;

D: total deformation (elastic and plastic) of the body at the points of contact with the upper and lower plate, m;

R, r: curvature radii at the point of contact, m.

The values of the curvature radii (r and R) of the seeds at the point of contact were obtained by adjusting a circumference to the curvatures of the body, according to the coordinate plane of the compression position of the seeds for the two cultivars studied, as illustrated in Figure 2.

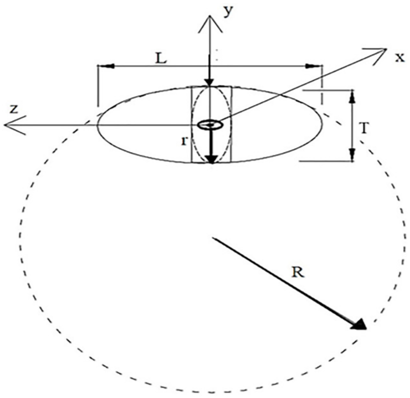

Figure 2 - Curvature radii of pumpkin seeds (r and R) in the region of contact between the product and the compression plate. L= length, T= thickness.

The assay was conducted in a completely randomized design with the 10 deformations evaluated. The data were analyzed by analysis of variance and regression, and the model was selected based on the significance of the regression coefficients, using the t-test and adopting a 5% significance level, on the magnitude of the coefficient of determination and also on the knowledge of the evolution of the biological phenomenon.

Results and Discussion

Table 1 shows the mean values of the curvature radii of pumpkin seeds of the cultivars 'Jacarezinho' and 'Rajada Seca Melhorada' for each moisture content, used in the calculations to determine the proportional deformation modulus.

A variation in the mean values of curvature radii according to the moisture content of the product can be observed, but without the occurrence of a clear trend in relation to the variables. This variation can be clarified by the fact that pumpkin seeds, of the two cultivars, have varied shapes, as observed in baru by Oliveira et al. (2017), who obtained a variation of the radii according to the moisture content.

Figure 3 shows the mean values of the deformation force on the two pumpkin cultivars as a function of the moisture content on dry basis (d.b.) for the various deformations. It can be noted that the force required to deform pumpkin seeds, for 'Rajada Seca Melhorada' and 'Jacarezinho', decreases with the increase in moisture content, indicating that seeds with higher moisture content have a lower compressive strength, which can be explained by a change that occurs in the integrity of the cellular matrix with the reduction of moisture content (Gupta & Das, 2000).

Table 1. Mean values of the curvature radii of 'Jacarezinho' and 'Rajada Seca Melhorada' pumpkin seeds (m) for each moisture content (d.b.).

'Jacarezinho'			'Rajada Seca Melhorada'		
Moisture content (d.b.)	R (m)	r (m)	Moisture content (d.b.)	R (m)	r (m)
0.923	0.033	0.011	0.6700	0.033	0.012
0.660	0.034	0.013	0.4531	0.033	0.013
0.509	0.031	0.013	0.3293	0.042	0.015
0.411	0.038	0.015	0.2299	0.039	0.013
0.299	0.037	0.014	0.1223	0.045	0.016
0.238	0.035	0.014	0.0944	0.038	0.013
0.033	0.034	0.013			

(A) (B)

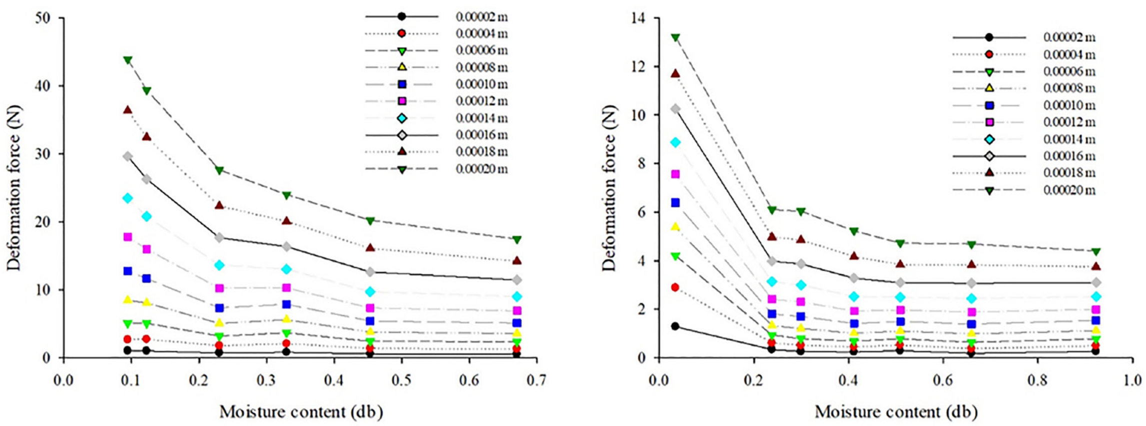

Figure 3. Mean values of deformation force (N) and different levels of deformation (m) as a function of moisture content (d.b.) of pumpkin seeds from the cultivars 'Rajada Seca Melhorada' (A) and 'Jacarezinho' (B).

The mean force required for the deformations varied between 43.90 and 0.56 N for the cultivar 'Rajada Seca Melhorada' and between 13.20 and 0.20 N for the cultivar 'Jacarezinho', as a function of moisture content. Fernandes et al. (2014), working with wheat, obtained an average strength between 139.8 and 21.4 N with moisture contents ranging from 0.14 to 0.26 dry basis (d.b.). Sousa et al. (2018), in a study with *Raphanus sativus L.* seeds, obtained a force between 27.08 and 15.03 N with moisture contents from 0.05 to 0.31 dry basis (d.b.).

Ribeiro et al. (2007), analyzing soybean grains in relation to the mean force required for deformation in different positions, obtained the following values: between 302.72 and 72.5 N for position P1; between 127.64 and 41.19 N for position P2, and between 110.86 and 21.72 N for position P3, with moisture content ranging from 0.093 to 0.58 dry basis (d.b.).

Resende et al. (2007), when analyzing the maximum compression force for different positions in bean grains, obtained different mean values: from 551.7 to 22.3 N for position P_1; from 253.1 to 10.5 N for position P_2 and from 143 to 11.6 N for position P_3, for moisture contents from 0.13 to 0.45 dry basis (d.b.). The two studies show that the force required for deformation decreases with the increase in moisture content.

Resende et al. (2013) studied the compression force in rough and dehulled rice grains and found an increase in the force required to cause deformation, with values ranging from 48.0 to 79.5 N for rough rice and 37.2 to 70.6 N for dehulled rice. The increments were approximately 2.1 N for rough rice and 1.9 N for dehulled rice, as the moisture content was reduced from 0.30 to 0.12 dry basis (d.b.), evidencing that the rupture force of these grains is dependent on the moisture content.

As expected, the force increased in response to the increase in seed deformation. For the cultivar 'Rajada Seca Melhorada', a force ranging from 0.56 to 1.07 N was required to cause deformation of 0.00002 m, whereas to cause deformation of 0.00020 m the force required ranged from 17.46 to 43.88 N, with moisture content of 0.67 and 0.09 dry basis (d.b.).

For the cultivar 'Jacarezinho' a deformation of 0.00002 m required a force ranging from 0.27 to 1.29 N, whereas a deformation of 0.00020 m required a force ranging from 4.41 to 13.22 N, with moisture content of 0.92 and 0.03 dry basis (d.b.).

Table 2 presents the regression equations fitted to the experimental values of the proportional deformation modulus of 'Rajada Seca Melhorada' and 'Jacarezinho' pumpkin seeds, as a function of moisture content and deformation.

In view of the results found, it can be noted that the fitted equations were significant, showing a high coefficients of determination (R^2) for the cultivars 'Rajada Seca Melhorada' and 'Jacarezinho', being significant at 1% level by the F test.

Table 2. Models fitted to the experimental values of the proportional deformation modulus of 'Rajada Seca Melhorada' and 'Jacarezinho' (Ep) pumpkin seeds as a function of the moisture content (X) and deformation (D).

Cultivar	Equation	R^2
'Rajada Seca Melhorada'	$Ep = 21.7792 - 48.4154 X - 12578.5634 D + 48.7056 X^2 + 202224479.0486 D^2 - 52963.7285 X D$	0.9257*
'Jacarezinho'	$Ep = 17.2768 - 36.8600 X - 89384.4805 D + 25.0178 X^2 + 232845727.0132 D^2 - 51845.4207 X D$	0.7698*

*Significant at 1% level by F test.

Figure 4 shows the fitted response surfaces according to the previously obtained equations, for the proportional deformation modulus of 'Rajada Seca Melhorada' and 'Jacarezinho' pumpkin seeds, as a function of moisture content and deformation.

It can be noted that there is an increase in the values of the proportional deformation modulus with the reduction of moisture content. When the proportional deformation modulus has a high value, it is necessary to apply a greater force to the product to cause a certain deformation (Batista et al., 2003).

The values of the proportional deformation modulus ranged from 8.05 to 23.68 x 10^7 N m^{-2} for the cultivar 'Rajada Seca Melhorada' and from 2.05 to 21.64 x 10^7 N m^{-2} for the cultivar 'Jacarezinho', within the studied range of moisture content.

Fernandes et al. (2014) analyzed the proportional deformation modulus in wheat grains of the cultivar 'Brilhante' with moisture contents ranging from 0.26 to 0.14 dry basis (d.b.) and obtained values between 8.9 and 51.2 x 10^7 Pa.

Sousa et al. (2018) determined the proportional deformation modulus of *Raphanus sativus L.* seeds with moisture content ranging from 0.31 to 0.05 dry basis (d.b.) and found lower values, from 0.11 to 1.72 x 10^7 Pa. In the two results consulted there was an increase in the proportional deformation modulus with the reduction of moisture content, corroborating the result obtained in the present study.

Also in Figure 4, in general, it can be observed that the proportional deformation modulus increases with the reduction of seed deformation for the cultivars 'Rajada Seca Melhorada' and 'Jacarezinho'. Similar results were obtained by Resende et al. (2007) for bean grains.

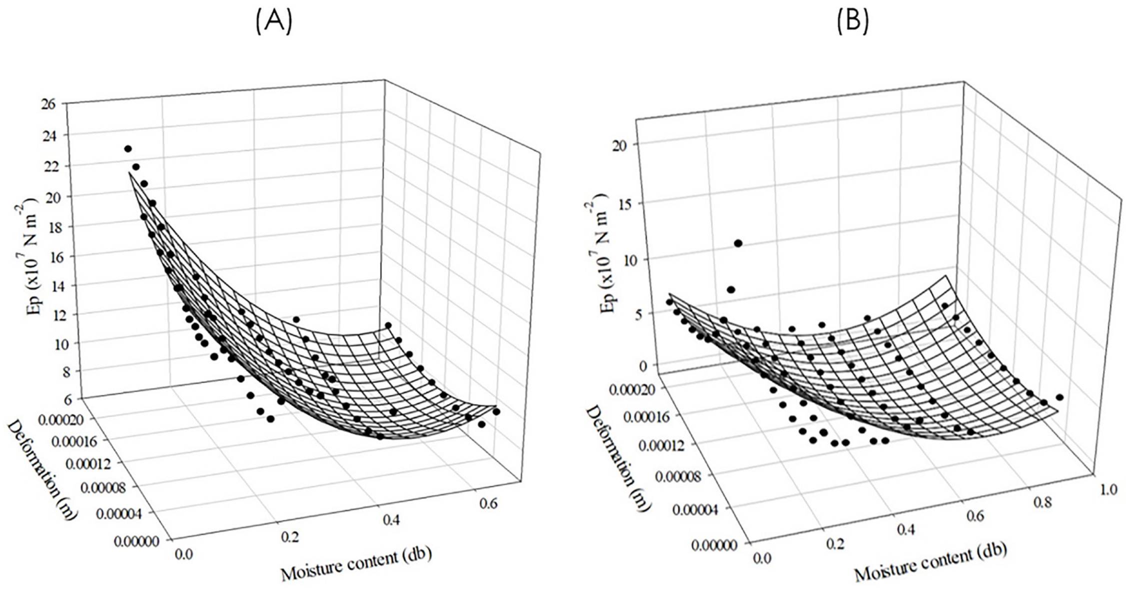

Figure 4. Mean values of the proportional deformation modulus of pumpkin seeds from the cultivars 'Rajada Seca Melhorada' (A) and 'Jacarezinho' (B) (x10^7 N m^{-2}), as a function of moisture content (d.b.) and deformation (m).

Conclusions

The force required for deformation of pumpkin seeds decreases with the increase of moisture content, for the cultivars 'Rajada Seca Melhorada' and 'Jacarezinho'.

There is an increase in the values of the proportional deformation modulus with the reduction of moisture content, for the cultivars 'Rajada Seca Melhorada' and 'Jacarezinho'.

The results obtained showed that seeds of the pumpkin cultivar 'Rajada Seca Melhorada' have a greater resistance to the deformation force than those of 'Jacarezinho'.

Acknowledgments

The authors thank IF Goiano, CAPES, FAPEG, FINEP and CNPq for the indispensable financial support to conduct this study.

References

Batista, C.S., Couto, S.M., Cecon, P.R., Peixoto, A.B. 2003. Efeito da temperatura do ar de secagem, do teor de umidade e do estádio de maturação no módulo de deformidade de frutos de café (*Coffea arabica* L.). *Revista Brasileira de Armazenamento* Especial café : 42-53.

Brasil, Ministério da Agricultura e Reforma Agrária. Secretaria Nacional de Defesa Agropecuária. 2009. *Regras para Análise de Sementes*. ACS, Brasília, Brazil. 395 p.

Corrêa, V.C., Paixão, A.A. da., Baptestini, F.M., Vanegas, J.D.B., Zeymer, J.S. 2019. mechanical properties of bean grains (BRSMG Majestic) coated with carnaúba wax. Ciência Rural 49: 09.

Couto, S.A., Batista, C.S., Peixoto, A.B., Devilla, I.A. 2002. Comportamento mecânico de frutos de café: Módulo de deformidade. *Revista Brasileira de Engenharia Agrícola e Ambiental* 6: 285-294.

Fernandes, L.S., Corrêa, P.C., Diniz, M.D.M.S., Leite, D.M., Vasconcellos, D.S.L. 2014. Influência do teor de água nas propriedades mecânicas dos grãos de trigo submetidos à compressão. *Bioscience Journal* 30: 219–223.

Figueiredo Neto, A. 2012. *Cinética das propriedades mecânicas durante a maturação dos frutos e avaliação da qualidade fisiológica das sementes de abóbora*. 112f. (Tese de Doutorado) - Universidade Federal de Campina Grande, Campina Grande, Brasil.

Gupta, R.K.; Das, S.K. 2000. Fracture resistance of sunflower seed and kernel to compressive loading. *Journal of Food Engineering* 46: 1–8.

Karababa, E., & Coskuner, B. 2013. Physical properties of carob bean (*Ceratonia siliqua* L.): An industrial gum yielding crop. Industrial Crops and Products. 42: 440–446

Oliveira, D.E.C., Resende, O., Devilla, I.A. 2017. Mechanical properties of baru fruit (*Dipteryx alata Vogel*). Semina: Ciências Agrárias 38: 185–196.

Oliveira, G.H.H., Corrêa, P.C., Botelho, F.M., Oliveira, A.P.L.R. 2015. Mechanical properties of tomatoes subjected to an induced compression during storage. Journal of Texture Studies 46: 293-301.

Pasqualetto, A., Silva, N.F., Ordonez, G.P., Barcelos, R.W. 2001. Produção de frutos de abóbora híbrida pela aplicação de 2,4-D nas flores. *Pesquisa Agropecuária Tropical* 31: 23–27.

Resende, O., Ferreira, R.B., Ullmann, R., Oliveira, D.E.C., Corrêa, P.C., Costa, L.M. 2018. Moisture content on the mechanical behavior of crambe grains. Ciência Rural 48: e20160748.

Resende, O., Corrêa, P.C., Oliveira, G.H.H., Goneli, A.L.D., Jarén, C. 2013. Mechanical properties of rough and dehulled rice during drying. International Journal of Food Studies 2: 158–166.

Resende, G.M., Borges, R.M.E., Gonçalves, N.P.S. 2013. Produtividade da cultura da abóbora em diferentes densidades de plantio no Vale do São Francisco. *Horticultura Brasileira* 31: 504-508.

Resende, O., Corrêa, P.C., Ribeiro, D. M., Figueiredo Neto, A. 2007. Comportamento mecânico dos grãos de feijão submetidos à compressão. *Revista Brasileira de Engenharia Agrícola e Ambiental* 11: 404–409.

Ribeiro, L.K.M., Taveira, J.H.S., Silva, P.C., Resende, O., Oliveira, D.E.C., Costa, D.R. 2019. Mechanical properties of saccharine sorghum (*Sorghum bicolor* L. Moench) seeds. IDESIA 37: 11-17.

Ribeiro, D.M., Corrêa, P.C., Furtado, B.F., Goneli, A.L.D., Resende, O. 2007. Propriedades mecânicas dos grãos de soja em função do teor de água. *Engenharia Agrícola* 27: 493-500.

Rodrigues, B.G., Resende, O., Oliveira, D.E.C.de., Sousa, K.A.de. 2019. Propriedades físicas das sementes de sorgo granífero em função do teor de água. *Engenharia na Agricultura* 27: 490-497.

Santos, C.T., Bonomo, R.F., Chaves, M.A., Fontan, R.C.I., Bonomo, P. 2010. Cinética e modelagem da secagem de carambola (*Averrhoa carambola* L.) em secador de bandeja. *Acta Scientiarum* 32: 309–313.

Sousa, K.A., Resende, O., Ullmann, R., Smaniotto, T.A.S. 2018. Mechanical properties of *Raphanus sativus* L. seeds. *Revista Ciência Agronômica* 49: 437–442.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.