

Physical properties of sesame seeds harvested at different maturation stages and thirds of the plant

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ABSTRACT

The quality of sesame (*Sesamum indicum* L.) seeds is directly influenced by their physical characteristics, which are seldom studied notwithstanding their extreme importance in the entire production chain. Therefore, the objective of this study was to quantify the physical properties of two types of sesame seeds, collected at three points in the plant with different maturation levels, measured with digital caliper, and to evaluate the feasibility of using a digital image to determine their physical characteristics. The seeds were initially evaluated for water content and mass of 1000 seeds, and later with the data of the characteristic dimensions A (length), B (width), and C (thickness), obtained by a caliper and digital images, we determined their sphericity, circularity, projected area, and geometric diameter. We observed that water content did not affect the physical properties of the cream (CNPA G4) and black sesame cultivars. In addition, seeds of the black cultivar presented higher results than the seeds of the cream cultivar for the mass of 1000 seeds (2.7 ± 0.08 g), sphericity ($58.8 \pm 0.47\%$), projected area (4.03 ± 0.12 mm²), and geometric diameter (1.65 ± 0.03 mm). Seed batches harvested after 70% maturation had the highest mass of 1000 seeds (2.7 ± 0.12 g). The results of the physical analyses of sesame seeds performed with caliper and digital image are equivalent, which shows that digital images can be used as tools to obtain the physical properties of seeds.

Key words: Image analysis, post-harvest, seed weight, *Sesamum indicum*, size and shape of seeds.

INTRODUCTION

Sesame (*Sesamum indicum* L.) is the earliest known oleaginous, belonging to the Pedaliaceae family, and its center of origin is the African continent (Silva et al., 2014a). Resistant to drought, this species has a social function in the rural environment, since it is mainly produced by small and medium farmers in regions where the lack of water becomes an obstacle to the cultivation of other crops (Araújo et al., 2014a). Sesame is grown in several countries, especially in Africa and Asia, and plays an important role in human consumption and in the pharmaceutical and cosmetic industries with the production of seeds and oil (Anilakumar et al., 2010). The oil in the seeds represents between 34% and 59% of its constitution (Emamgholizadeh et al., 2015) and it is considered noble; its application can be seen in several sectors of the industry, such as in the manufacture of pies, margarine, lubricants, soap, perfumes, and drugs (Dias et al., 2017).

World production of sesame seeds was 6.2 million tons in an area of 10.8 million hectares in 2016, with an average production of 576 kg ha⁻¹ (FAO, 2018). The production of this crop is considered insufficient to meet the consumer demand, which is attributed to the low yield of the cultivars, indeterminate growth, high sowing cost, uneven maturation of the capsules, as well as the lack of mechanized harvesting (Furat and Uzun, 2010; Uzun et al., 2012).

The expansion of this oleaginous tree in the world finds several obstacles, such as the lack of technologies appropriate to mechanized cultivation, mainly in the harvesting process (Queiroga et al., 2009). Therefore, most of the production areas of this seed are harvested manually, which increases the time of exposure of the fruits to the climatic conditions and consequently intensification of losses (Georgiev et al., 2008). Such losses may occur from dehiscence (opening) presented by the fruits after maturation. In addition, the maturation of the sesame fruits is uneven throughout the canopy of the plant, which promotes the opening of the capsules from the base to the apex, making the harvest a determining factor in the quality of the seeds (Nobre et al., 2013).

The physical part is another factor that directly affects seed quality. The knowledge of the relations between physical properties and spoilage factors can help in the solution of problems related to heat and mass transfer during the drying and aeration stages, in the design of seeders and harvesters, in the project and design of transport, cleaning, and separation equipment, and in the use of techniques adopted in the storage and construction of silos and other packaging devices (Goneli et al., 2011).

However, although the physical characteristics are extremely important in the seed production chain, studies on such characteristics are scarce and vague for sesame seeds in the literature. Therefore, the objectives of this study were to quantify the physical properties of two types of sesame seeds, collected at three points in the plant with different levels of maturation, measured with digital caliper, and to evaluate the feasibility of using a digital image to determine their physical characteristics.

MATERIALS AND METHODS

The seeds used in the experiment were produced in the “waters” crop of the agricultural year of 2013-2014 in the research area of Emater in Anápolis-Goiás (16°19'49" S, 48°57'12" W; 1000 m a.s.l.), Brazil, where the predominant climate is classified as Aw, with two well defined seasons, rainy season from October to April and dry season from May to September. We produced seeds of the CNPA G4 (cream) and black cultivars. The plants were harvested entire and taken to the laboratory, where they were separated in three thirds of equal size, disregarding the unproductive part. The capsules were opened manually to avoid possible damage to the seeds. After harvest, both cultivars were stored in a cold room at 10 ± 2 °C and 45% RH until the beginning of the tests.

The tests were carried out in the Laboratory of Drying and Storage of plant products, of the Agricultural Engineering course of the State University of Goiás, Anápolis-Goiás. We used the completely randomized design, in a $2 \times 3 \times 3$ factorial design. The treatments consisted of sesame seeds of cultivars CNPA G4 and Black, collected at three positions in the canopy of the plant (lower, middle, and upper third), in three maturation stages (50%, 70%, and 90%). The maturation stages were defined when 50%, 70% and 90% of the capsules were mature. The maturation was defined by the characteristic color of the capsules after physiological maturation (straw brown).

The water content of seeds was determined by the standard greenhouse method, at 105 ± 3 °C, for 24 h, in three replicates, using an accuracy scale of 0.001 g, according to the Rule for Seed Analysis (RAS) methodology (Brasil, 2009).

The mass of 1000 seeds was determined using the counting method (eight replicates of 100 seeds) determining mass in an electronic scale (0.001 g precision) according to RAS methodology (Brasil, 2009). After weighing the eight subsamples, we calculated the variance, standard deviation, and coefficient of variation of the values obtained in the weighing. After these calculations, the mean mass of the eight sub-samples of 100 seeds was multiplied by 10, thus we obtained the mass of 1000 seeds.

The size and shape of sesame seeds, considered as oblate spheroids, were analyzed for length (a), width (b), thickness (c), sphericity, projected area, geometric diameter, and circularity using four replicates of 50 seeds, for each treatment. The dimensions related to length, width, and thickness were evaluated using a digital caliper (Mitutoyo; Sakado, Saitama, Japan) with a 0.01 mm resolution.

The variables of sphericity (E_s) expressed as percentage, projected area (A_p) expressed in mm^2 , geometric diameter (D_g) expressed in mm, and circularity (C) expressed as a percentage of sesame seeds were calculated by Equations [1], [2], [3], [4], respectively, proposed by Mohsenin (1986):

$$E_s = \left[\frac{(abc)^{1/3}}{a} \right] 100 \quad [1]$$

$$A_p = \frac{\pi ab}{4} \quad [2]$$

$$D_g = (abc)^{1/3} \quad [3]$$

$$C = \left(\frac{b}{a}\right) 100 \quad [4]$$

In order to propose a new methodology to obtain the characteristics of size and shape of the seeds as efficient as the methodology using a digital caliper, we also evaluated seeds with digital images, using four replicates of 50 seeds each.

We used an expanded polystyrene (25 mm) platform created in a step shape to acquire the images, where we arranged seeds in line on the first step, by replicate. To capture images, we used a smartphone (Moto X model; Motorola Mobility LLC, Chicago, Illinois, USA), with a 13 megapixels camera, supported on the second step, 0.15 m away from the seed line, so that the lens remained on the seed lines. The images were captured in an environment with only one light source, close to the platform, in order to avoid shadows in the images, as recommended by Silva et al. (2014b). The central seed and the ones at the two ends were measured with a digital caliper (Mitutoyo; Sakado, Saitama, Japan) with a 0.01 mm resolution for image validation.

The image acquired in the first configuration of the platform (Figure 1) was used to determine dimensions A and B. The platform was created so that we could adjust the step so that the bottom was 0.01 m from the edge of the first step. To determine dimension C, we positioned the platform according to Figure 2.

Figure 1. Composition of the platform for image acquisition for length (A) and width (B).

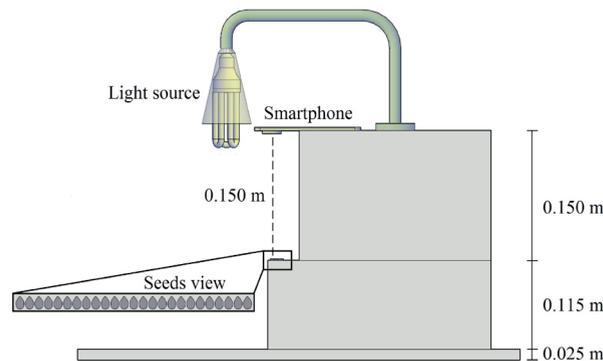
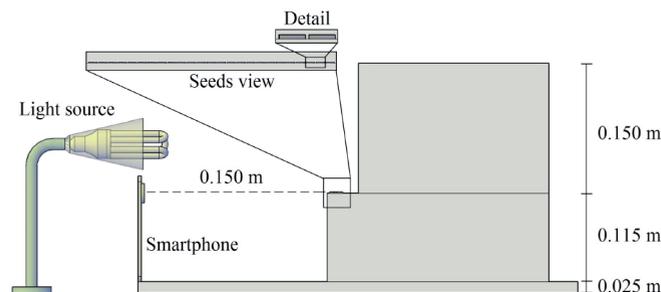


Figure 2. Composition of the platform for image acquisition for thickness (C).



To obtain the data from the digital images, we used the software MATLAB, version R2012b (MathWorks, Natick, Massachusetts, USA), in which the algorithm created provided the values of A (length), B (width), and C (thickness) of the mean dimensions of the seed set and the same values for each seed in the line, which also allowed comparisons between measurements.

The data were submitted to ANOVA and the means were compared by Scott-Knott test at 5% of probability, and we used the software of System for Statistical and Genetics Analysis (SAEG; Federal University of Viçosa, Department of Statistic, Viçosa, Minas Gerais, Brazil).

RESULTS AND DISCUSSION

The mean water contents in the seed batches can be observed in Table 1. These values are close to that found in the work of Ogbonna and Ukaan (2013), whose water content in sesame seeds of 13 different cultivars ranged from 5.12% to 7.80%. The low water content can be explained by the high content of oil found in the seeds, which can exceed 50% depending on the genetic material (Gharby et al., 2017).

The results of the ANOVA show that, except for the factors third of the plant and triple interaction; all other characteristics were influenced by the treatments, for the mass of 1000 seeds. These results can be explained by the characteristic constitution of each cultivar. In addition, the advance in the maturation process allows the seed to synthesize and accumulate more reserves leading to increased mass.

For the physical characteristics obtained with digital caliper, we can observe a significant effect of the factors of cultivar and maturation stage on all variables studied. All interactions, with the exception of the triple interaction, showed significant differences for at least two variables.

We observed a significant effect of the cultivar factor on all variables studied for the physical characteristics obtained by digital image. All interactions, with the exception of the triple interaction, showed significant differences for at least one of the variables studied. The low percentage values of coefficients of variation demonstrate uniformity in the data obtained with the digital image analysis, as we can see in the evaluations using the digital caliper. Thus, we can say that the two methodologies are equivalent in terms of experimental precision.

The Cultivar × Stage interaction influenced the sphericity of the seeds obtained by caliper; this may be a reflection of the different genetic material and accumulation of reserves of each cultivar, which influence size and shape of seeds. We can note that the cream cultivar showed nonsignificant difference between maturation stages, which is different from the black cultivar, which presented higher sphericity means in seeds with 70% ripening (Table 2). We also observe that only the 70% stage showed a significant difference between the two cultivars. When evaluating the sphericity obtained by digital image in this interaction, we can also note that the black cultivar harvested with 50% maturation differed significantly from the other maturation stages (70% and 90%), whereas there was nonsignificant difference between the different stages for the cream cultivar. We can also note that the black cultivar showed higher sphericity when harvested earlier, that is, 50% and 70% maturation. We highlight that only the 90% maturation stage showed nonsignificant difference between evaluated cultivars.

Seeds harvested at the 70% and 90% maturation stages presented a larger mass of 1000 seeds, as the seeds accumulate reserves during the entire ripening process until they reach physiological maturation. In addition, we verified that black seeds presented a larger mass of 1000 seeds when compared to the cream cultivar in the 50% and 70% stages, with nonsignificant difference in the 90% stage. This result may suggest a possible increase in mass gain by the cream seeds in the final maturation stages.

The highest mean value of projected area obtained by caliper occurred at 70% maturation in black seeds (4.1 mm²), followed by the 50% and 90% stages, while the highest mean value was verified in the 70% and 90% stages in the cream

Table 1. Means of the water content (%) of sesame seeds at different maturation stages and thirds of the plant.

Cultivar	Maturation stages	Thirds of the plant		
		Lower	Middle	Upper
CNPA G4	50%	6.48	6.55	6.58
	70%	6.00	6.02	6.04
	90%	5.59	5.66	5.64
Black	50%	6.39	6.51	6.60
	70%	5.89	5.92	5.99
	90%	5.46	5.50	5.55

Table 2. Means of the mass of 1000 seeds, sphericity, projected area, and geometric diameter according to the Cultivar × Maturation stage interaction, obtained by caliper and digital image.

Physical properties	Cultivar	Maturation stages		
		50%	70%	90%
Mass of 1000 seeds, g	CNPA G4	2.4Bb	2.6Ba	2.6Aa
	Black	2.6Ab	2.8Aa	2.7Aa
Sphericity (caliper), %	CNPA G4	58.3Aa	58.4Ba	58.5Aa
	Black	58.7Aa	59.3Ab	58.5Aa
Projected area (caliper), mm ²	CNPA G4	3.7Bb	3.9Ba	3.9Aa
	Black	3.9Ab	4.1Aa	3.9Ab
Geometric diameter (caliper), mm	CNPA G4	1.6Aa	1.6Ba	1.6Aa
	Black	1.6Ab	1.7Aa	1.6Ab
Sphericity (image), %	CNPA G4	58.9Ba	58.5Ba	58.8Aa
	Black	60.1Aa	59.7Ab	59.2Ab
Geometric diameter (image), mm	CNPA G4	1.6Ba	1.6Ba	1.6Ba
	Black	1.7Aa	1.7Aa	1.7Aa

Means followed by the same uppercase letter in the column and lower-case letter in the row do not differ significantly from each other by the Scott-Knott test at 5% probability.

cultivar (3.9 mm²). This characteristic is closely linked to the evolution of the seed along the maturation stages and the change in its characteristic dimensions, which explains the recurrent variation within each cultivar and between them.

From the Cultivar × Maturation stage interaction for the geometric diameter obtained by caliper, we can verify that the highest mean presented was for 70% maturation stage, presenting a mean of 1.7 mm² in black seeds, followed by the 50% and 90% stages. We highlight that the cream CNPA G4 cultivar did not present a significant difference between maturation stages. For the geometric diameter obtained by digital image, we can observe that there was nonsignificant difference within each cultivar in the different maturation stages studied. However, there was a significant difference between the two cultivars for all maturation stages. We highlight that the black seeds presented larger geometric diameter in all maturation stages.

The mass of 1000 sesame seeds was significantly different between the cultivars only when harvested in the upper third of the plant (Table 3). We observed that black cultivar shows uniformity in the mass of 1000 seeds in all thirds of the plant, unlike the cream cultivar, which presents seeds with greater mass in the lower and middle thirds, which reflects the uneven development of the fruits and seeds of this cultivar along the plant canopy.

Table 3. Means of the mass of 1000 seeds, sphericity, projected area, and circularity according to the Cultivar × Thirds of the plant interaction, obtained by caliper and digital image.

Physical properties	Cultivar	Thirds of the plant		
		Lower	Middle	Upper
Mass of 1000 seeds, g	CNPA G4	2.6Aa	2.6Aa	2.5Bb
	Black	2.7Aa	2.7Aa	2.7Aa
Sphericity (caliper), %	CNPA G4	58.1Bb	58.5Aa	58.7Aa
	Black	58.9Aa	58.7Aa	58.9Aa
Projected area (caliper), mm ²	CNPA G4	3.9Ba	3.9Ba	3.8Bb
	Black	4.0Aa	4.1Aa	4.0Aa
Circularity (image), %	CNPA G4	65.5Ab	66.0Aa	65.7Ab
	Black	64.9Bb	64.7Bb	65.9Aa

Means followed by the same uppercase letter in the column and lower-case letter in the row do not differ significantly from each other by the Scott-Knott test at 5% probability.

In the Cultivar × Thirds of the plant interaction for sphericity obtained by caliper, we observed a significant difference for the two cultivars only in the lower third, and the black cultivar had the highest mean. This fact may be related to fruit dehiscence, which occurs first in the lower part of the plant canopy, subjecting the seeds to conditions that may affect their size and shape.

The highest mean value of projected area obtained by caliper was found in the seeds harvested in the middle third of the plant (4.1 mm²), followed by the lower and upper thirds. We highlight that the black cultivar presented nonsignificant difference between thirds, whereas the cream cultivar showed a significant difference between the lower and middle thirds and the upper third. This fact can be explained by the uneven maturation along the canopy of the plant starting from the lower third, causing the seeds of the upper third to have less time to accumulate reserves and making them smaller than the others.

The circularity obtained by digital image was influenced by the Cultivar × Third of the plant (Table 3) and Maturation × Third of the plant (Table 4) interactions. In the first case, we could verify that cream and black cultivars showed a higher circularity when harvested at 70% and 90% maturation. In the second case, higher circularity was verified in the seeds harvested in the upper third of the plant, regardless of the time of harvest. As for circularity obtained by caliper, we can observe that there was a significant difference between the upper third and the lower and middle thirds in the 50% maturation stage in the Maturation stage × Thirds of the plant interaction. We can observe that there is a significant difference between the lower third compared to the other thirds analyzed for the 70% stage, whereas there were no effects from the treatments for the last maturation percentage (90%). Regarding the thirds of the plant, the upper third did not present a significant difference for the maturation stages. On the other hand, the middle and lower thirds showed a significant difference for all maturation stages evaluated.

In general, we can observe that the mass of 1000 sesame seeds was higher when harvested in the middle and upper thirds of the plant, with the exception of 70% maturation stage. In addition, when harvested at 90% maturation, they did not present significant difference between the thirds of the plant (Table 4).

For the results of the Stage × Third of the plant interaction for the projected area obtained by caliper, we can note that only the 50% maturation stage showed a significant difference between maturity thirds (Table 4). For the 50% maturity stage, the seeds found in the middle and upper thirds may not have accumulated as much reserves as the lower third, which would explain this result.

The values obtained for the mass of 1000 seeds are close to those found by Zebib et al. (2015) and Ozkan et al. (2012), who have found values for different cultivars ranging from 2.7 to 3.1 and from 2.7 to 3.9, respectively. However, the values found are lower than those found by Queiroga et al. (2012), who found a minimum 3.0 g value for the mass of

Table 4. Means of the mass of 1000 seeds, projected area, and circularity according to the Maturation stage × Third of the plant interaction, obtained by caliper and digital image.

Physical properties	Maturation stage	Thirds of the plant		
		Lower	Middle	Upper
Mass of 1000 seeds, g	50%	2.5Bb	2.6Aa	2.6Aa
	70%	2.7Ba	2.6Ab	2.6Ab
	90%	2.7Aa	2.7Aa	2.7Aa
Projected area (caliper), mm ²	50%	3.8Bb	3.9Ab	3.9Aa
	70%	4.1Aa	4.1Aa	4.0Aa
	90%	3.9Aa	4.1Aa	3.9Aa
Circularity (caliper), %	50%	64.7Bb	64.6Bb	65.4Aa
	70%	66.1Ab	65.6Aa	65.6Aa
	90%	65.3Aa	65.8Ba	64.9Aa
Circularity (image), %	50%	64.5Bb	64.8Bb	66.1Aa
	70%	65.1Ab	65.6Ab	66.0Aa
	90%	65.4Ab	65.7Aa	65.2Ba

Means followed by the same uppercase letter in the column and lower-case letter in the row do not differ significantly from each other by the Scott-Knott test at 5% probability.

1000 seeds for the BRS Silk cultivar. We highlight that variation in the mass of seeds is common, since this characteristic is related to several factors, including genetic material, season, and crop environment.

The values of sphericity found corroborate those obtained by Silva et al. (2014a), who found sphericity between 57.0% and 65.3% for the BRS Silk and IAC China sesame cultivars, respectively. Vilche et al. (2003), when evaluating the physical properties of quinoa grains, observed that the sphericity of seeds presented values directly proportional to the water content in the grains; however, this behavior was not evidenced in the sesame seeds analyzed, since the water content did not significantly influence any of the analyzed variables.

We found no data in the literature on the projected area for sesame seeds; however, in studies carried out by Araújo et al. (2014b) with peanut seeds, there was a reduced value of the projected area when water content was reduced, a fact that was not observed for sesame seeds, since water content of seeds did nonsignificantly influence any of the studied variables. We also found no circularity values for sesame seeds; however, we can observe that there is no relation between circularity and water content, as observed in oilseeds of similar size, such as quinoa (Vilche et al., 2003).

The means values found for the geometric diameter of the seeds corroborate the values obtained by Tunde-Akintunde and Akintunde (2004), who found a mean geometric diameter value for sesame seeds of 1.7 mm².

Although it is the most used method to measure the characteristic dimensions of seeds, caliper subjects the seeds to compression and crushing actions. As the values found using digital images were coherent and close to those found by the digital caliper, and considering that this method does not subject the seeds to any external action, this new methodology demonstrates potential use to determinate the physical properties of seeds.

CONCLUSIONS

Water content did not affect the physical properties of the cream (CNPA G4) and black sesame cultivars. The seeds of the black cultivar presented higher results than seeds of the cream cultivar for the mass of 1000 seeds (2.7 ± 0.08 g), sphericity ($58.8 \pm 0.47\%$), projected area (4.03 ± 0.12 mm²), and geometric diameter (1.65 ± 0.03 mm). Seed batches harvested after 70% maturation had the highest mass of 1000 seeds (2.7 ± 0.12 g). The results of the physical analyses of sesame seeds performed with caliper and digital image are equivalent, which shows that digital images can be used as tools to obtain the physical properties of seeds.

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