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Physiological quality of sesame seed harvested at different plant positions and maturity stages

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Being peculiar for its unique chemical and nutritional characteristics, sesame (*Sesamum indicum* L.) is a good option for farmers. It is used as human food, animal feed and has great potential for the production of bio diesel. Despite these potentials, studies on ideal maturity stage for harvesting and physiological quality of sesame seeds in different parts of the plant are rare and also there is insufficient information on it. In this context, this study aims to evaluate the physiological quality of sesame seeds harvested at different maturity stages and plant positions. It employs complete randomized design consisting of factorial scheme 2 × 3 × 3, with four replications. Treatments are composed of two beige and black sesame seed cultivars, harvested at three maturity stages (50, 70 and 90%) and in three parts of the plant (superior, medial and inferior). The unproductive part was discharged and the productive part was divided into three equal parts. The evaluation of physiological quality of seeds in treatment was verified by the following tests: Standard Germination Test (TPG - Teste Padrão de Germinação), first count, plant length, speedy aging and electrical conductivity. The data were subjected to variation analysis, and when suitable, it was subjected to the Skott and Knott test at 5% probability. The results of physiological analysis indicated that the seeds harvested with 90% of mature capsules have higher percentages mean values for vigor and viability. Therefore, the realization of harvest in these conditions it is the most appropriate to obtain a high quality product.

Key words: *Sesamum indicum* L., maturity stages, seed position viability, vigor.

INTRODUCTION

The sesame (*Sesamum indicum* L.) is from the Pedaliaceae family and considered to be one of the oldest oil seeds used by humans. There have been registers of its cropping since 5,000 B.C., in Asia and it is widely grown in tropical and subtropical regions (Ashri, 1998; Banerjee and Kole, 2009). It thrives well in drained soil with moderate fertility at pH 5.4 to 6.7 and can effectively use stored soil moisture (Morris, 2009).

In 2011, there was a worldwide production of 3.3 million tons in an area of 7.5 million hectare; India and Myanmar are the largest producers of sesame in the world, with a productivity of 443 kg ha^{-1} (FAO, 2012). The crop production can be considered poor, mainly attributed to low yield of the cultivars with an indeterminate growth

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habit, high cost of sowing, pests and diseases occurrence, insufficient weed control, uneven ripening of capsules, seed shattering, susceptibility to environmental stresses, lack of mechanized harvest and lack of adequate research (Furat and Uzun, 2010; Azum et al., 2012). However, the potential yields of sesame as high as 6000 kg ha^{-1}, as reported by Raikwar and Srivastva (2013).

Its broad adaptability to edaphoclimatic conditions in countries with hot weather and with a good level of resistance to drought as well as its easy harvesting makes the sesame culture an excellent option for agricultural diversification with a great economic viability (Ashri, 2007). It is featured as an annual or perennial plant, with variable height between 0.5 and 3 m, straight stalk, with or without branching. Sesame seeds are hairy capsules with longitudinal dehiscence and episodes of indehiscence (Ashi et al., 2007; Morris, 2009).

Its seeds vary in size between 2 and 8 cm long and 0.5 and 2 cm of diameter; 100-seed weight ranges from 0.11 to 0.46 g. The seed is a main source of edible oil and largely used as seasoning. It presents itself as a rich food source due to its high oil content that ranges from 34 to 59%, of excellent nutritional, medicinal and cosmetic quality (Ashri, 1998; Morris, 2009). Its oil is rich in unsaturated oil, such as oleic (47%) and linoleic (41%), and it portrays several secondary components which are the most important for the definition of its chemical properties, like sesamol, sesamin and sesamolin (Arslan et al., 2007; Uzun et al., 2008). Sesamol, with its high antioxidant properties, grants the oil prominent chemical stability avoiding rancidity; it has the greatest resistance to oxidation amongst other oils of vegetal origin (Erbas et al., 2009; Emamgholizadeh et al., 2015).

Most of the sesame traded in the world market is light seeded; only seed coats of landraces vary from white to black (Langham and Wiemers, 2008). In a study conducted by da Silva et al. (2011), comparing the chemical composition of beige and black sesame seeds, it was observed that black sesame seeds display the highest rates of soluble phenolic compounds and phytates, besides having a higher capacity of holding free radicals and having a potential related to a significantly greater antioxidant activity. According to Queiroga et al. (2010a), black sesame seeds stand out in relation to others (BRS silk and CNPA 4) white and beige, for they show a high concentration of calcium (Ca) and sulphur (S) minerals.

Amongst the developed operations with this culture, harvest is an operation of great relevance; product quality depends mostly on the careful way and the right moment of manual harvest of plants. The right harvest moment occurs when the seeds in the base of the stem start to open, yielding seeds in a greater number and size (Lago et al., 2001; Queiroga et al., 2009). This is the right harvesting time, because from this point the fruit located at the top of the plants (Doo et al., 2003).

It is also noteworthy that determining the ideal harvest moment for dehiscent sesame is hard because capsule maturity is uneven, for it is a plant that has undetermined growth (Banerjee and Kole, 2009). Regarding the cultivar, premature super BRS silk, the quality of seeds in the apical part of the plant can be harmed because they have not reached physiological maturity in this stage of harvest. This seed prematurity is characterized as the stage in which it stops getting nutrients from the plant (Queiroga et al., 2008).

A common feature in most cultivars, especially in dehiscent ones, is the speedy process of natural dehiscence of fruits (capsules), with eventual grain fall. This happens right after the best maturity stage, which, in case of late harvests, can mean great losses in production (Doo et al., 2003).

According to Weiss (1983), sesame seeds rapidly lose quality when handled without proper care. Unseasonal harvests (the best is to plan harvests in absence of rain), mechanic damage during fanning, inappropriate drying (high humidity) and storage temperature seem to be the main agents which affect food quality of stored seeds (Popinigis, 1985). Whatever is the drying method, the most important is not to alter seed quality, such as its physical integrity (high purity), taste and chemical characteristics (Queiroga et al., 2008).

Taking into account the aforementioned, one can assert that research on the physiological quality of beige and black sesame seeds, harvested with different maturity percentage and plant positioning, is of great relevance for technicians and producers. It will lead to a better data base on the correct procedures to obtain superior quality seeds. Currently, studies on ideal maturity percentage for harvesting and physiological quality of seeds are scarce. There is a need for a more detailed investigation which might transmit safety to producers in search of profit.

MATERIALS AND METHODS

Seeds used in the experiment were produced in Emater's trial area in Anapolis - Goias, from December 2013 to April 2014. The produced cultivars were: BRS6/CNPA (beige) and black. The black cultivar is a local matter from late cycle (120 days), and the seeds used in the crop came from the Northern of Goias. After the harvest, both cultivars were stored in cool chamber at 10 ± 2°C and 45% relative humidity, up to the kick off of tests.

Tests were developed in the Laboratório de Secagem e Armazenamento de Produtos Vegetais from the Agricultural Engineering course in Anápolis-GO, from November 2014 to December 2014. Treatments consisted of two beige and black sesame seed cultivars, harvested at three maturity stages (50, 70 and 90%) and in three parts of the plant (superior, medial and inferior). The unproductive part was discharged and the productive one was divided in three equal parts.

Simultaneously with the physiological evaluation, the amount of water in the seeds was determined according to the Seed Analysis Rule (RAS - Regra de Análise de Sementes), using standard greenhouse method, where seeds were subjected to dry at 105 ±

Table 1. Summary of the variation analysis from average germination sums (TPG), first count (PC), speedy aging (EV) electrical conductivity (CE) and plant length (CP) for sesame seeds (beige and black), harvested at different maturity stages and plant positioning.

Source of variation	LG	Mean square				
		TPG	PC	EV	CE	CP
Cultivar (C)	1	323.8513**	323.8513**	1671.3830**	56.5339^{ns}	144.0050**
Third (T)	2	129.5412*	129.5412*	71.4956^{ns}	1005.8490**	97.1843**
Stage (E)	2	59.2917^{ns}	59.2917^{ns}	35.0068^{ns}	593.2154**	5.7906^{ns}
C x T	2	88.9054^{ns}	88.9054^{ns}	19.6622^{ns}	97.0135*	27.5513*
C x E	2	113.2717*	113.2717*	179.5443*	435.6110**	8.5717^{ns}
T x E	4	24.1692^{ns}	24.1692^{ns}	18.5116^{ns}	65.7279*	37.3281**
C x T x E	4	22.8833^{ns}	22.8833^{ns}	100.3612^{ns}	35.4968^{ns}	17.9954^{ns}
Error	54	34.7225	34.7225	42.4457	21.4745	6.7252
C.V.(%)	-	7.1726	7.1726	8.1923	7.6967	15.714

L.G. Liberty grades; *Significant at 5% of probability by F test, ** Significant at 1% by F test; ^{ns} Not meaningful.

3°C for 24 h. The results are displayed in percentage (Brasil, 2009).

The evaluation of physiological quality of seeds in treatment was verified by the following tests: Standard Germination Test (TPG - Teste Padrão de Germinação), first count, plant length, speedy aging and electrical conductivity.

With the Standard Germination Test (TPG), viability was evaluated, with four 50-seed replications placed in an acrylic box (gerbox), containing a substratum. The germitest paper, previously moisturized with distilled water, is equivalent to paper weight threefold. The gerboxes were stored in a germinator at 25°C. An evaluation was carried out on the sixth day after test performance. The percentage of normal plants was taken into account (Brasil, 2009).

The first count test for germinations was conducted with TPG, with the aim to evaluate vigor, considering the percentage of normal plants present in the third day after the beginning of tests.

In order to reinforce vigor outcomes, the length of the plants was measured (radicle + hypocotyl) with four 10-seed replications. It was distributed in a straight longitudinal line, on the superior part of the germitest paper. It was cut to fit the gerbox (11 × 11 cm), previously moisturized with distilled water in threefold paper weight. Previously, they were placed in a germinator at 45º inclination and at 25ºC. After the third day, each plant size was measured with a millimeter rule (Nakagawa, 1999).

The speedy aging test is also characterized as a vigor test, where a 100- seed/replication was distributed onto the surface of a metal net fixed inside the plastic box - gerbox containing 40 ml of water. It was kept at 42ºC inside a germinator (Krzyzanowski et al., 1999). After this period, seeds were subjected to TPG, previously mentioned, to determine the percentage of normal plants after the third day of the test.

In addition to vigor measures, procedures described by Krzyzanowski et al. (1999) were applied for electric conductivity test. Four 50-seed replications, previously weighted in precision scales at 0.01 g, were moisturized in plastic cups (200 ml) with 75 ml of deionized water and stored in a germinator with steady temperature at 25ºC for 24 h. Electrical conductivity reading was performed using a field meter DIGIMED CD-21 and the outcomes were expressed in µS cm^{-3} g^{-1} of seeds.

The data were subjected to variation analysis, and when suitable, it was subjected to the Skott and Knott test at 5% probability.

RESULTS AND DISCUSSION

It has been observed through variation analysis that the cultivar factor (C) influenced the germination test (TPG), first count (PC), speedy aging (EV) and plant length (CP) at 1% probability; whereas the factor stage (E) influenced only the conductivity test (CE) at probability 1%. The factor third (T), influenced the test TPG and PC at 5% probability, CE and CP at 1% probability (Table 1). The interactions C x T and T x E present significant difference only in the electrical conductivity test (at 5% probability) and plant length (at 5 and 1% probability, respectively), whereas the interaction C x E influenced the standard germination tests, first count and speedy aging at 5% probability and electrical conductivity at 1% probability. The triple interaction C x T x E has not significantly influenced the outcomes in any of the tests (Table 1).

It was observed that seeds harvested with 90% of mature seed capsules, present a higher percentage average value for the test of first count (84.9%) (Table 2). Seeds harvested with 70 and 50% of mature seed capsules presented average figures for first count at 81.95 and 79.61%, respectively. Premature seed harvest causes termination of physiological maturity process, bringing about loss in physiological quality, damaging vigor and viability. Sesame seeds that stay longer in the fields reach a higher uniformity in physiological maturity, yielding higher percentage values of physiological maturity. Similar results were found by Vidigal et al. (2009) for pepper seeds.

The beige cultivar has not presented significant difference for the maturity stages in the study; on the other hand, the black cultivar differed statistically in relation to all maturity stages. There was a significant difference among cultivars for all maturity stages. The maturity stage where seeds were harvested with 90% of mature capsules could show higher average percentage germination figures than others. This is due to the fact that most seeds have reached physiological maturity; the higher the percentage of mature capsules, the lower is its seed immaturity (Langham and Wiemers, 2008).

The first count test was conducted simultaneously

Table 2. Average percentage figures for first count of germination (%) applied to sesame seeds for interaction stage x cultivar.

Cultivar	Maturity stage (percentage of mature capsules)		
	90%	**70%**	**50%**
Beige	86.79^{Aa}	83.81^{Aa}	82.22^{Aa}
Black	83.00^{Ab}	80.10^{Bb}	77.00^{Cb}
Averages	84.90	81.95	79.61

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

Table 3. Average for germination (%) applied to sesame seeds for the interaction stage x cultivar.

Cultivar	Maturity stage (percentage of mature capsules)		
	90%	**70%**	**50%**
Beige	86.79^{Aa}	83.81^{Aa}	82.22^{Aa}
Black	83.00^{Ab}	80.10^{Bb}	77.00^{Cb}
Averagess	84.90	81.95	79.61

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

Table 4. Average percentage results for speeded aging (%) applied for sesame seed for the interaction stage x cultivar.

Cultivar	Maturity stage (percentage of mature capsules)		
	90%	**70%**	**50%**
Beige	87.12^{Aa}	80.70^{Aa}	85.21^{Aa}
Black	76.38^{Ab}	71.66^{Bb}	76.08^{Ab}
Averages	81.75	76.18	80.64

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

along with standard germination test. After that, seeds germinated mostly in the first count. The ones that remained in the second count, and for the registration of the standard germination test, presented themselves moldy or hard, delivering equal average percentage values either for the first count or for the standard germination test and for the interaction Stage x Cultivar (Table 3). The three maturity stages in the study presented average percentage germination figures above 70%, highlighting that even seeds harvested with 50% of mature capsules could be commercialized. In Brazil, the legislation demands that the minimum percentage for sesame seed germination be at 70% (Brasil, 2009).

In Table 4 it was observed that seeds harvested with 90% of mature capsules presented higher percentage average figures for the speedy aging test (81.75%), followed by maturity stages at 50 and 70% with 80.64 and 76.18, respectively. This means that, seeds harvested with 90% of mature capsules deliver more vigor, that is, higher potential in yielding normal plants, in relation to other maturity stages in the study (Pollock and Ross, 1972).

The seeds of the beige cultivar did not differ statistically in relation to maturity stages in the study. Now the black cultivar presented significant difference between the maturity stages at 70 and 90% and 70 and 50%. Maturity stages of 90 and 50% did not differ significantly. Regarding cultivars, there was a significant difference in this one than all other maturity stages in the study. Against the odds, the maturity stage at 50% presented higher measures than the maturity stage at 70%. Seeds harvested with 50% of mature capsules in the plant presented greater amount of immature seeds, yielding a less vigorous lot of seeds. This was not observed in this test.

For electrical conductivity tests (Table 5), it has been observed that the inferior part presented higher average results (67.59%), followed by the superior (57.33%) and

Table 5. Average percentage values for electrical conductivity (µS $cm^{-1}g^{-1}$) applied to sesame seeds in the interaction third x cultivar.

Cultivar	Third		
	Superior	**Medial**	**Inferior**
Beige	55.85^{Bb}	53.12^{Bb}	68.99^{Ab}
Black	59.21^{Ba}	57.88^{Ca}	69.19^{Aa}
Averages	57.53	55.50	67.59

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

Table 6. Average percentage values for electrical conductivity (µS $cm^{-1}g^{-1}$) applied to sesame seeds in the interaction stage x cultivar.

Cultivar	Maturity stage (percentage of mature capsules)		
	90%	**70%**	**50%**
Beige	51.08^{Cb}	57.63^{Bb}	69.26^{Ab}
Black	60.22^{Ba}	60.93^{Ba}	62.13^{Aa}
Averages	55.65	59.28	65.69

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

medial (55.5%) parts. From data presented in Table 5, it can be stated that seeds in the inferior part are less vigorous. The higher the value for electric conductivity, the lower is its seed vigor, revealing a higher intensity of membrane system disorder in the cells (Vieira et al., 2002). Seeds in the superior part presented intermediate average results. This shows that behavior in capsule maturity for sesame seeds (starts from bottom to top) ends up in a greater number of immature seeds in the superior part. Consequently, the malformation of the tegmen results in a lesser seed vigor (Queiroga et al., 2010b). This is due to the fact that seeds in the inferior part have matured first and undergone some kind of infield hazard while waiting for harvest; the superior part has a greater number of immature seeds. The medial part delivered more vigorous seeds; it presented the lowest average percentage values for electric conductivity test (Queiroga et al., 2009; Martins et al., 2009).

The beige cultivar seeds presented a significant difference between the inferior/superior and inferior/medial parts; on the other hand, the seeds of the black cultivar presented a significant difference among the parts in the study. The black cultivar presented a significant difference among the parts because this cultivar has a longer cycle, and harvest is performed three weeks after the beige one. In this period, there are drought and high temperatures, providing a sharp drop in humidity and seed breakage. This results in loss in their physiological quality (Lago et al., 2001).

Table 6 presents the average percentage values for electrical conductivity, where the maturity stages at 50, 70, and 90% presented averages of 65.69, 59.28 and 55.65% respectively. It was observed that the maturity stage at 50% presented the highest average for electrical conductivity test, highlighting that premature harvests jeopardize sesame seed vigor due to an early interruption in nutrient delivery by the plant (Queiroga et al., 2010b).

The beige cultivar presented a significant difference for all maturity stages in the study, whereas the black ones differed significantly between maturity stage at 50 and 70%, and between 50 and 90%. However, maturity stages at 90 and 70% did not differ significantly for this cultivar. There was a significant difference among cultivars for all different maturity stages. Black sesame seeds are more sensitive when harvest is performed in the maturity stages. Seeds' maturity behavior does not occur in comparison to beige cultivar, since it has undergone genetic enhancement, and it has a more uniform behavior in relation to capsule maturity.

Data presented in Table 7 indicated that seeds harvested at 50, 70 and 90% of mature capsules presented average percentage values for electrical conductivity at 65.70, 59.04 and 55.9% respectively. The maturity stage at 50% delivered the highest percentage value for electrical conductivity test, showing that seeds harvested in this stage are less vigorous than the others due to a higher intensity of disorder in the membrane system in the cells (Vieira et al., 2002).

The superior, medial and inferior parts presented a significant difference for all maturity stages in the study. The maturity stage at 90% was the only one that did not

Table 7. Average percentage values for electrical conductivity ($\mu S\ cm^{-1}g^{-1}$) applied to sesame seeds in the interaction stage x third.

Third	Maturity stage (percentage of mature capsules)		
	90%	**70%**	**50%**
Superior	54.14^{Cb}	56.36^{Bb}	62.09^{Ab}
Medial	53.59^{Cb}	53.90^{Bc}	59.02^{Ac}
Inferior	59.98^{Ca}	66.86^{Ba}	75.98^{Aa}
Averages	55.9	59.04	65.70

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

Table 8. Average percentage values for plant length (mm) applied to sesame seeds in the interaction third x cultivar.

Cultivar	Third		
	Superior	**Medial**	**Inferior**
Beige	19.71^{Aa}	17.34^{Ba}	16.23^{Ba}
Black	17.27^{Ab}	16.27^{Bb}	12.19^{Cb}
Averages	18.49	16.80	14.21

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

differ statistically in relation to superior and medial parts. This outcome can be explained due to the fact that seeds harvested with 90% of mature capsules present well formed tegmen and higher percentage of mature seeds in all parts, delivering more vigorous seeds than the other maturity stages in the study (França Neto and Potts, 1979).

In the plant length test (Table 8), seeds harvested in the superior, medial and inferior parts presented average percentage values of 19.49, 16.80 and 14.21 mm, respectively. The superior part presented the highest average percentage value for plant length, highlighting that seeds harvested in this part are more vigorous. Consequently, they will deliver plants with a higher growth rate, because they present a higher capacity of transformation in the storage tissue reserves and higher share by the embryo axel (Dan et al., 1987).

The seeds from the beige cultivar presented a significant difference between superior/medial and superior/inferior parts, whereas the black cultivar presented significant difference for all parts in the study. The black sesame seeds portrayed more sensitivity regarding positioning of capsules in the plant, since the lower the position, the shorter is the plant; consequently, the lower the vigor. The seeds of the beige cultivar also presented shortage in plant growth, provided that the capsule was closer to the inferior part. However, this shortage was smaller than that of the black cultivar, showing that they are more vigorous, independent of plant position. Capsules that develop in the inferior part of the plant are prematurely exposed to agents such as high temperature and humidity, leading to seed deterioration in field and vigor depletion.

In Table 9 it has been observed that seeds harvested with 90, 50 and 70% of the capsules in mature plants presented average percentage values for plant length of 18..26, 16.17 and 15.08 mm, respectively. Seeds harvested with 90% of mature capsules presented the highest average percentage value for plant length, depicting that this maturity stage has more vigorous seeds. This is because plant growth test indicates that samples which present higher values of average length for normal plants or parts of them are considered to be more vigorous (Nakagawa, 1994). Against all odds, seeds harvested with 50% of mature capsules had higher averages than the ones harvested at 70%, because the higher the number of mature seeds, the better the chances of them to present higher vigor (Vidigal et al., 2009).

The superior, medial and inferior parts present significant differences for all maturity stages in the study; all maturity stages differ statistically among the parts. These results strengthen that there is sensitivity from seeds regarding positioning of capsules in the plant and maturity stages for plant length. Even with all external and intrinsic agents of the plant, the seeds harvested with 90% of mature capsules show higher vigor.

Conclusions

The maturity stage at 90% had the lowest vigor and

Table 9. Average percentage values for plant length (mm) applied to sesame seeds in the interaction stage x third.

Third	Maturity stage (Percentage of mature capsules)		
	90%	**70%**	**50%**
Superior	20.66^{Aa}	15.19^{Ca}	18.11^{Ba}
Medial	18.70^{Ab}	16.51^{Cb}	16.71^{Bb}
Inferior	15.41^{Ac}	13.53^{Cb}	13.70^{Bc}
Averages	18.26	15.08	16.17

Averages followed by the same capital letter in line and lower case in column, do not differ statistically among themselves, by Scott and Knott test at 5% probability.

viability loss for both cultivars. Beige cultivar seeds presented more viability than black cultivar seeds, independent of maturity stages. For speedy aging test, seeds harvested with 90% of mature capsules presented higher vigor than the remaining parts for both cultivars. The electrical conductivity test has pointed out the seeds of both cultivars are less vigorous when harvested in the inferior part and with 50% of mature capsules in the plant. Black sesame seeds showed more sensitivity to positioning of capsules in the plant, since the lower its positioning, the shorter the plant and therefore, lower vigor. The beige cultivar seeds also presented shortage in plant length, as the position of the capsule was closer to the inferior part; however, this shortage was lesser than that of the black cultivar, showing that those seeds are more vigorous, independent of plant positioning.

Conflict of Interests

The authors have not declared any conflict of interests.

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