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Quality of black bean seeds harvested with different moisture contents and submitted to two different storage systems

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Abstract

Bean (*Phaseolus vulgaris* L.) is one of the main foods of the Brazilian diet. However, to achieve high yields, one of the determining factors is seed quality, which can be influenced by harvesting time and storage. The objective of this work was to evaluate the physical quality and physiological performance of black bean seeds as function of the moisture content at harvest and storage method. For that, black bean seeds, cultivar BRS Campeiro, were used. The harvest was performed when the seeds reached moisture contents of 26.2, 16.6 and 13.5 %. The storage was carried out in hermetic (PET bottles) and conventional (paper bags) systems for 240 days. There was a reduction in the physical quality and the physiological performance of the bean seeds according to the storage time and the harvest delay. However, the seeds stored in a sealed system showed less reduction in physical quality and physiological performance over time, regardless of the harvest moisture content. The harvest of black bean seeds, cultivar BRS Campeiro, with moisture contents between 16.6 and 26.2 % and stored in hermetic system present better physical quality and physiological performance.

Keywords: *Phaseolus vulgaris* L., harvest delay, deterioration, hermetic system

1 Introduction

Bean (*Phaseolus vulgaris* L.) is considered one of the main grains of the Brazilian population diet. In addition, bean cultivation is one of the main sources of income for family farmers with low technological level (Silva & Wander, 2013). The total production of beans in 2017/18 was estimated at about 3.3 million tons, with a sown area of approximately 3.2 million hectares and an average yield of 1,043 kg ha^{-1} (Conab, 2018).

One of the limiting factors for high yields in the bean crop is seed quality, since it directly influences the stand and establishment of the plants in the field (Binotti *et al.*, 2008). The quality of a seed is characterised primarily by its physical state and physiological performance. However, the maximum seed quality potential is observed at the physiological maturity, which can reduce in proportion to the time that the seed remain in the field until harvest, depending on the climatic conditions such as relative humidity and temperature. In this way, the permanence in the field can negatively affect the quality of the seeds. In this sense, anticipation of harvesting appears as an alternative to reduce the risks of seed deterioration in the field, and can favour grain quality, since they are harvested closer to the physiological maturity (Siddique & Wright, 2003; Farrer *et al.*, 2006).

Another important factor for obtaining high quality seeds is the storage, since this does not provide an increase in seed quality, but can contribute significantly to the reduction of quality when improperly handled. One of the factors that may influence storage quality is the ability of the system to avoid gas exchange with ambient air, since these directly influence the respiratory rates of the seeds. In this sense, conventional storage, carried out in sacks or in non-hermetic silos, can promote the acceleration of the degradation of the seeds, when carried out in environments unfavourable to conservation. In this context, a hermetic storage

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can provide a conservation of the seeds for a longer time in comparison to a conventional storage, while it prevents the gas exchanges between the seed mass and the external environment, thus reducing the respiratory rate, the attack of pests and, consequently, the deterioration (Jonfia-Essien *et al.*, 2010; Tubbs *et al.*, 2016).

In addition, the physical state and physiological performance of the seeds shortly after harvest may influence the quality of the storage, since seeds that have undergone some degradation process due to the delay in harvest or the attack of fungi and insects in the field may have less storage capacity and be subject to higher quality losses over time (Deliberali *et al.*, 2010).

There are some studies that address the behaviour of the physical quality and physiological performance of bean seeds throughout the storage (Santos *et al.*, 2005; Faroni *et al.*, 2006; Cassol *et al.*, 2012; Zucareli *et al.*, 2015; Cassol *et al.*, 2016). However, there are no studies that address the association of different harvest moisture contents with hermetic and conventional storage on the physical quality and physiological performance of bean seeds over time. Therefore, the objective of this work was to evaluate the physical quality and physiological performance of black bean seeds, cultivar BRS Campeiro, according to different moisture contents at the harvest, with subsequent storage in a hermetic and conventional system for 240 days.

2 Materials and methods

The experiment was conducted at the Seeds and Grains Laboratory of the Federal University of Fronteira Sul, Erechim/RS campus, using black bean seeds, cultivar BRS Campeiro, obtained from the 2016/17 crop season. The experiment was conducted under a completely randomized experimental design, arranged in a $3 \times 2 \times 5$ factorial scheme (harvest moisture content × storage system × storage time), with four replications.

Harvest was performed manually when grain moisture content reached 26.2; 16.6 and 13.5 % wet bulb. The monitoring of the moisture content of the grains in the field was carried out with the aid of a portable moisture meter Motomco, model 999-RF, with confirmation by the oven method at 105 ± 3 °C for 24 h (Brasil, 2009). After the harvest the material was submitted to threshing with a mechanised grain thresher. Then the beans were dried in an oven, with forced air circulation, at an average temperature of 38 °C, until they had moisture content close to 12 % w.b.

The storage started in the first half of May of 2016, being carried out under two systems: hermetic and conventional. For the hermetic system, polyethylene terephthalate (PET) bottles and for the conventional kraft paper bags were used, with a volume of 900 and 2500 cm^3, respectively. For the storage of the grains, 120 experimental units were used per treatment, individually consisting of approximately 750 g of grains and constituting a repetition of each treatment. The seeds were stored under environmental conditions for 240 days, during which time, with the aid of a digital thermohygrometer, the biweekly collection of temperature and relative humidity values were recorded at the storage site Erechim (Fig. 1). The average temperature at the storage

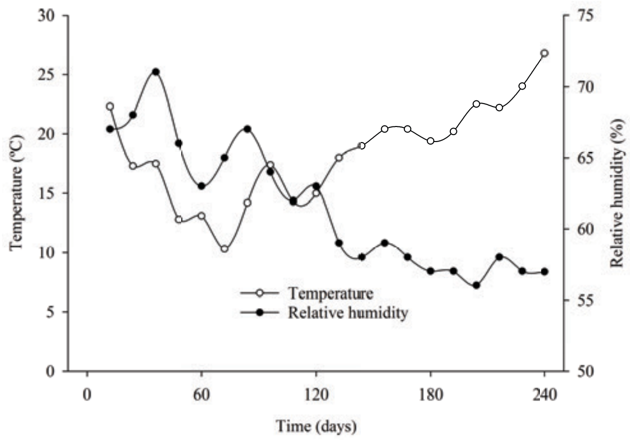

Fig. 1: *Temperature and relative humidity of the air during storage of beans, BRS Campeiro cultivar; data source Erechim, 2016.*

site was 18.3 °C, ranging between 10.3 and 26.8 °C during the 240 day storage period. After 120 days of storage, there was a marked increase in temperature due to the beginning of spring, implying the thermal amplitude during this period. The relative air humidity varied between 56 and 67 %, with average of 63.7 %. After approximately 180 days of storage there was reduction of the relative humidity.

Analyses of the stored product were performed immediately after drying (time zero) and then at 60 day intervals until the end of the storage period, being measured: moisture content, thousand grain weight, hectoliter weight, electrical conductivity, percentage of germination, germination speed index, accelerated aging, shoot length and root length, and seedling dry mass. The moisture content was determined in three replicates per sample by the oven method at 105 ± 3 °C for 24 h (Brasil, 2009). The results were expressed as percentage and Wet Basis (w.b.). The weight of one thousand grains was determined by counting eight replicates of 100 grains per repetition. The result was obtained by multiplying by ten the average weight of the eight replicates, being expressed in grams (Brasil, 2009). The hectoliter weight was determined in three replicates per sample with the aid of a hectoliter balance, the results expressed in kg hL^{-1} (Brasil, 2009). The weight values of one thousand grains and hectoliter weight were adjusted to the moisture content of 13 % w.b. The electrical conductivity was carried out by weighing four replicates of 50 grains per sample, which were deposited in glass containers (Becker) containing 75 mL of distilled water, kept in BOD chambers at 25 ± 3 °C. The evaluations were performed 24 h after placement in the BOD, with the aid of Gehaka conductivity meter, model CG1800. The results were expressed in $\mu S\ cm^{-1}\ g^{-1}$ (Marcos Filho *et al.*, 1987).

The germination test was conducted on Germitest type paper rolls, soaked in distilled water in the ratio 2.5 times its weight and kept in Tecnal germination chamber model TE-405 at 25 ± 3 °C and photoperiod of 12 h. 400 seeds per treatment were used, distributed in eight replicates of 50 seeds. The evaluations were performed according to the Rules for Seed Analysis, the results being expressed as a percentage (Brasil, 2009). The germination speed index was carried out simultaneously to the germination test, by counting the number of normal germinated seeds per day, from sowing until the 5^{th} day, being determined as proposed by Maguire (1962). For the accelerated aging test the seeds were placed in a gerbox, containing 50 mL of distilled water, suspended with fabric and conditioned in a BOD chamber at 41 °C for 72 h (Marcos Filho *et al.*, 1987). After this stage the test was conducted as described for the germination test, being performed on the 5^{th} day after sowing the count of the number of normal seedlings, and the results expressed as a percentage.

The shoot and root length, and the dry matter transfer were determined together with the germination test. The shoot and root length were determined by measuring, with the aid of a ruler graduated in millimeters, the shoot and root parts of 15 seedlings, randomly collected in each roller, the results being expressed in cm. In order to determine the dry matter transfer, the cotyledons were excised from the normal seedlings, which were then oven dried at 80 °C until constant weight. The results were expressed in g per seedling (Menezes & Silveira, 1995).

The data were submitted to analysis of variance by the F test ($p \leq 0.05$). The averages of the qualitative variables were compared by the Tukey test ($p \leq 0.05$) and the quantitative variables submitted to the regression analysis, with the aid of the Statística software 10.0 and Sigma Plot 10.0, respectively. The models were selected based on the significance of the model parameters by the application of the 't' test ($p \leq 0.05$), by the significance of the mathematical model ($p \leq 0.05$), by the determination coefficient (r^2) and by the biological phenomena.

3 Results

The results of the analysis of variance for the moisture content, thousand seed weight and hectoliter weight are presented in Table 1. The moisture content of the seeds,

Table 1: *Summary of analysis of variance, test F, for moisture content (MC), thousand grains weight (TGW) and hectoliter weight (HW) of seeds, cultivar BRS Campeiro, harvested with different moisture contents and submitted to hermetic and conventional storage under environmental conditions for 240 days.*

		p values		
SV	*DP*	*MC*	*TGW*	*HW*
H	2	< 0.0001	< 0.0001	< 0.0001
T	4	< 0.0001	< 0.0001	< 0.0001
SS	1	< 0.0001	< 0.0001	< 0.0001
H × T	8	< 0.0001	0.0078	< 0.0001
H × SS	2	< 0.0001	0.2213	0.7677
T × SS	4	< 0.0001	0.0028	0.0871
H × T × SS	8	0.0685	0.4743	0.4836

SV: sources of variation; H: harvest; T: time; SS: storage system; DF: degrees of freedom

for the three harvesting conditions, increased up to approximately 130 days of storage, decreasing the values observed after this period (Fig. 2A). The average moisture content of the crops in each system, throughout the entire storage, varied according to the moisture content reached with the drying and the psychrometric air conditions, in the case of the conventional system. However, the moisture content of the seeds stored in a sealed system was lower for all harvests when compared to the conventional system (Table 2).

Table 2: *Average moisture content of bean seeds, BRS Campeiro cultivar, harvested with different moisture contents and submitted to conventional and hermetic storage, regardless of storage time.*

Moisture content at harvest (%)	*Storage system*	
	conventional	*hermetic*
26.2	11.6 ^{cA*}	10.8 ^{bB}
16.6	11.9 ^{bA}	10.7 ^{bB}
13.5	12.2 ^{aA}	11.1 ^{aB}
CV (%)	1.56	

*Averages followed by the same letter, lowercase for lines and uppercase for columns, do not differ statistically by the Tukey test ($p \leq 0.05$).

The behaviour of the moisture content of the seeds stored in the two systems was different. The hermetically conditioned seeds increased of moisture value content up to 60

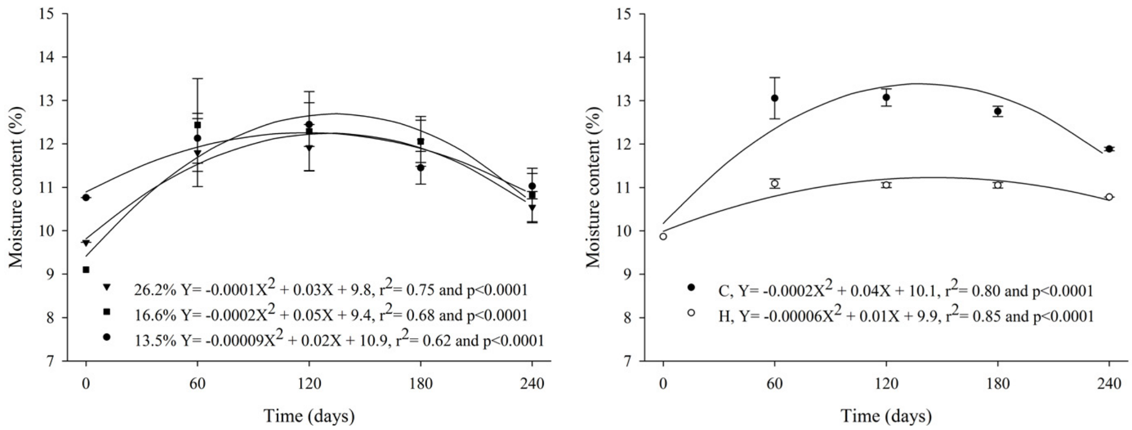

Fig. 2: *Moisture content of bean seeds, BRS Campeiro cultivar, harvested with different moisture contents (26.2, 16.5 and 13.5 %) and submitted to hermetic (H) and conventional storage (C); data source Erechim, 2016.*

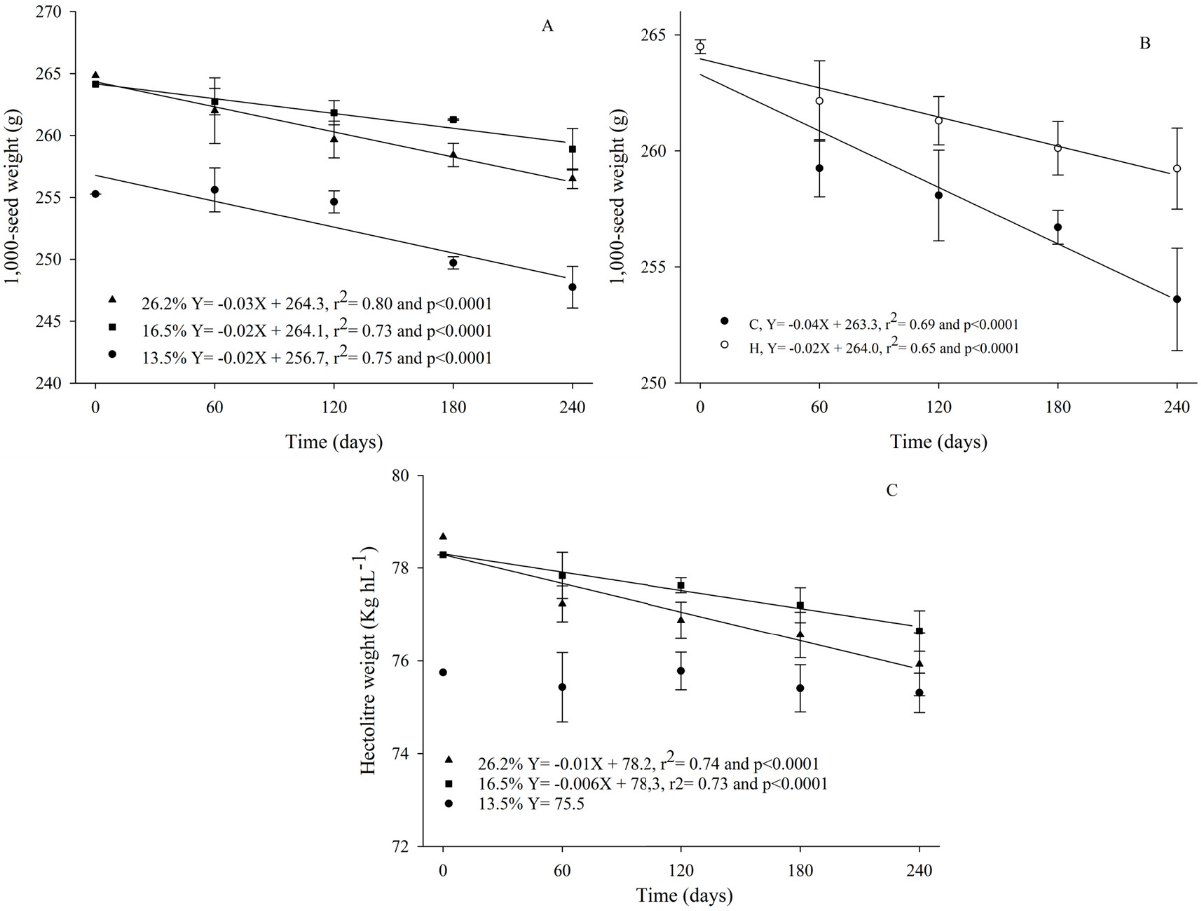

Fig. 3: *Thousand grain weight (A and B) and hectoliter weight (C) of bean seeds, BRS Campeiro cultivar, harvested with diferente moisture contents (26.2, 16.5 and 13.5 %) and submitted to hermetic (H) and conventional (C) storage; data source Erechim, 2016.*

days of storage, after which they did not present significant variation between the evaluation times. In addition, they presented lower values of moisture content along the storage, when compared to the seeds stored in conventional system (Fig. 2).

The thousand grain weight reduced according to the storage time for all the harvest conditions, the lowest values being obtained for the seeds submitted to a delayed harvest (13.5 %; Fig. 3A). In addition, the weight reduction of thousand grains was less pronounced in the hermetic system

Table 3: *Summary of variance analysis, F test, for germination (G), germination speed index (GSI), accelerated aging (AA), electrical conductivity (EC), seedling dry matter (DM), shoot (SL) and root (RL) length of bean seeds, BRS Campeiro cultivar, harvested with different moisture contents and submitted to hermetic and conventional storage under environmental conditions for 240 days.*

		p values						
SV	*DF*	*G*	*GSI*	*AA*	*DM*	*SL*	*RL*	*EC*
H	2	< 0.0001	< 0.0001	< 0.0001	0.0005	0.5772	0.0575	< 0.0001
T	4	0.0010	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001	< 0.0001
SS	1	0.7551	0.4135	< 0.0001	0.3982	0.1636	0.7145	< 0.0001
H × T	8	< 0.0001	< 0.0001	< 0.0001	0.0057	0.5013	0.8817	< 0.0001
H × SS	2	0.4696	0.9656	0.8930	0.4462	0.9903	0.4972	0.0048
T × SS	4	0.3463	0.5599	< 0.0001	0.2590	0.2993	0.4413	< 0.0001
H × T × SS	8	0.3244	0.1082	0.0039	0.9144	0.4265	0.1812	0.3605

SV: sources of variation; H: harvest; T: time; SS: storage system; DF: degrees of freedom

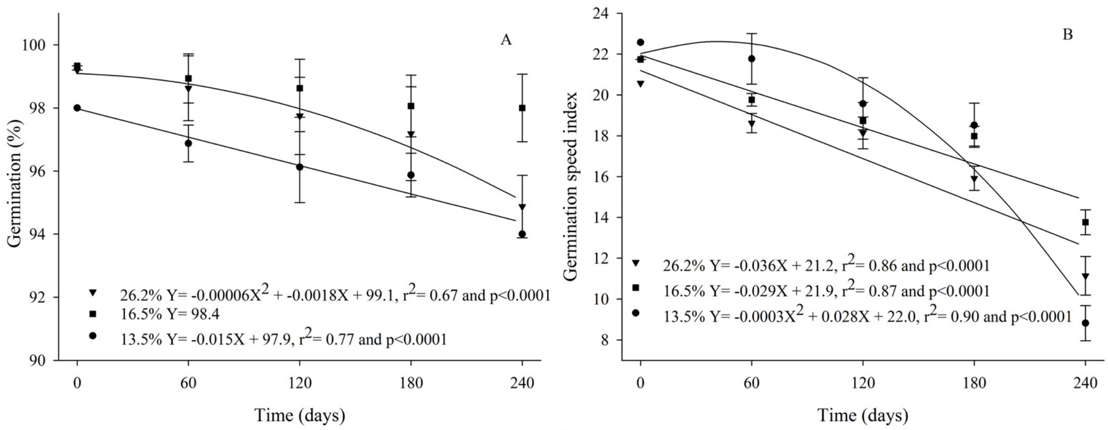

Fig. 4: *Germination (A) and germination speed index (B) of bean seeds, BRS Campeiro cultivar, harvested with different moisture contents (26.2, 16.5 and 13.5 %) and submitted to hermetic and conventional storage; data source Erechim, 2016.*

when compared to conventional, maintaining higher values throughout the storage period (Fig. 3B).

The hectoliter weight decreased over storage time for seeds harvested with higher moisture content at harvest (26.2 and 16.6 %), while for the late harvest (13.5 %) there was no reduction in the values over time (Fig. 3C). However, shortly after harvesting and throughout the storage period, seeds harvested belatedly presented lower values of hectoliter than those obtained in the other harvests. In addition, there was a statistically significant difference for the hectoliter weight between the two storage systems, regardless of the time and moisture content at harvest, with average values of 77.0 and 76.6 kg hL^{-1} for conventional and hermetic systems, respectively.

The results of the analysis of variance for germination, germination speed index, accelerated aging, electrical conductivity, dry matter of seedlings, and length of shoot and root are described in Table 3.

The percentage of germination of the seeds harvested with moisture content of 26.2 and 13.5 % reduced throughout the storage, whereas for the seeds harvested with 16.5 % there was no significant variation in the percentage of germination during the same period, independently of the storage system (Fig. 4A). However, the seeds submitted to delay in harvest had the lowest values of germination soon after the harvest, remaining this way during the whole period of storage.

The germination speed of the seeds reduced throughout the storage period for the three harvest conditions, not being verified for the effect of the storage systems (Fig. 4B). Soon after harvest and up to approximately 180 days of storage, the seeds harvested late (13.5 %) presented a higher speed of germination, when compared to those harvested under the other conditions. However, from that moment on the earlier harvested seeds showed a more pronounced decrease in germination speed, when compared to the seeds harvested with higher moisture contents.

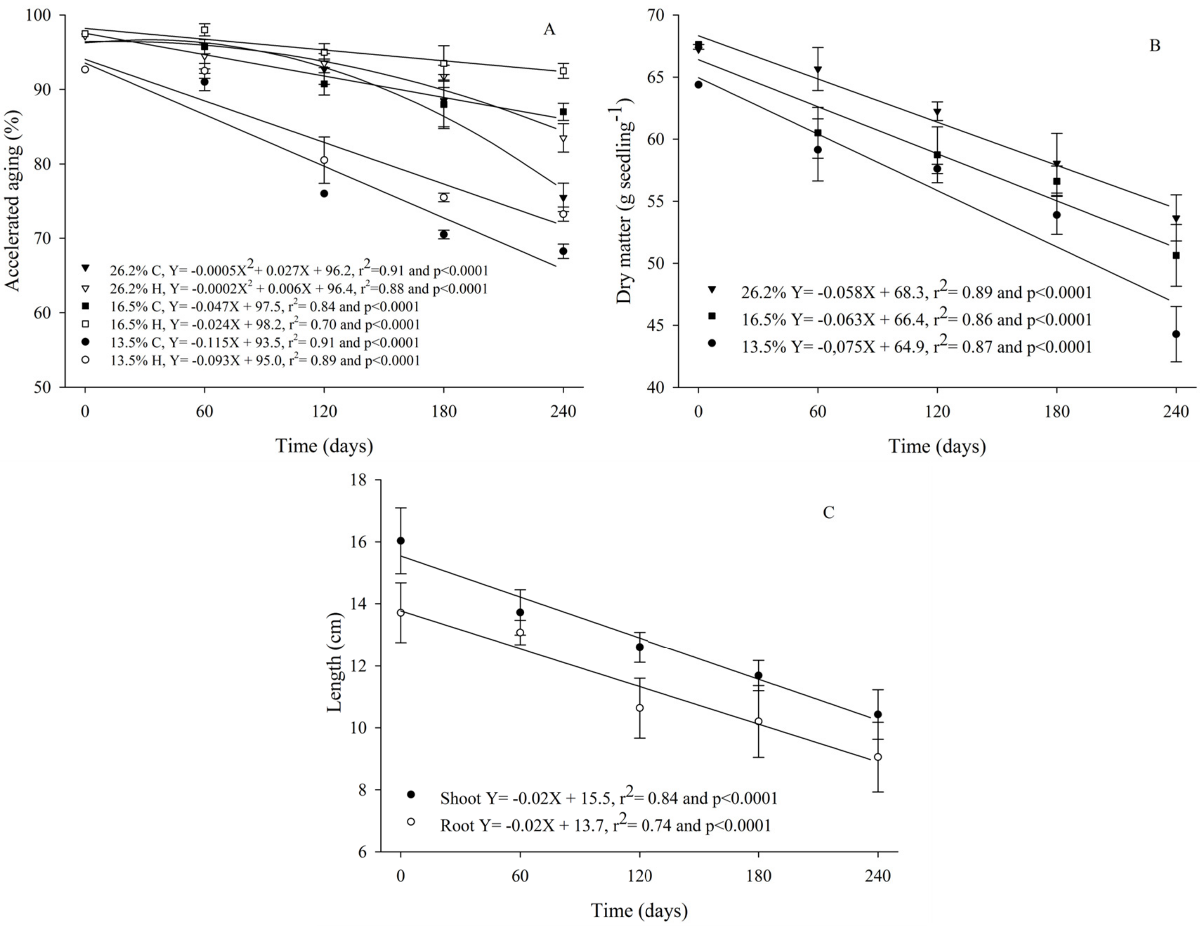

Fig. 5: *Percentage of normal seedlings by accelerated aging test (A), dry matter of seedlings (B) shoot and root length (C) of bean seeds, BRS Campeiro cultivar, harvested with different moisture contents (26.2; 16.5 and 13.5 %) and submitted to hermetic (H) and conventional storage (C); data source Erechim, 2016.*

According to the accelerated aging test, the vigour of the bean seeds reduced throughout the storage for all harvests and both storage systems. The highest values of vigour were observed for the seeds harvested with moisture content of 16.6 % and stored in a hermetic system. However, seeds stored in a sealed system presented greater vigour when compared to those stored in a conventional system at each harvest condition (Fig. 5A). On the other hand, the seeds submitted to the delay in harvest showed less vigour during the whole storage period, when compared to the other harvest periods, independently of the storage system, evidencing the damages caused by the harvest delay.

The dry matter values of the seedlings were reduced for all harvest moisture contents over the storage time, and no effect of the storage systems was observed (Fig. 5B). However, the seeds submitted to the delay in harvest showed lower values of dry matter during the whole storage period, when compared with the harvests with higher moisture contents. For the length of shoot and root of the seedlings it decreased linearly over time, regardless of moisture content and storage system (Fig. 5C).

The electrical conductivity of bean seeds increased over time for different harvesting conditions and both storage systems (Fig. 6). Seeds harvested with a higher moisture content (26.2 %) showed a more pronounced increase in the electrical conductivity values along the storage until 100 days of storage, when compared to seeds from other harvest conditions, which presented similar values of conductivity (Fig. 6A).

The average electrical conductivity of the harvests in each system, regardless of storage time, were higher for the seeds harvested with moisture content of 26.2 and 13.5 %. The seeds stored in a sealed system presented lower values of electrical conductivity along the storage, when compared to those stored in a conventional system (Fig. 6B and Table 4).

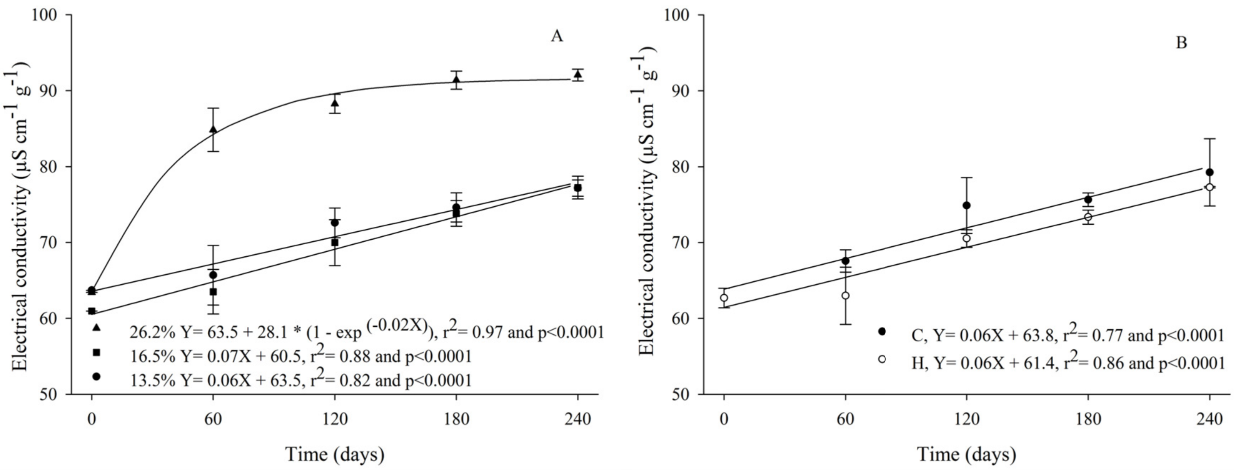

Fig. 6: *Electric conductivity of bean seeds, BRS Campeiro cultivar, harvested with different moisture contents (26.2, 16.5 and 13.5 %) and submitted to hermetic (H) and conventional (C) storage; data source Erechim, 2016.*

Table 4: *Average electric conductivity of bean seeds, BRS Campeiro cultivar, harvested with different moisture contents and submitted to conventional and hermetic storage, regardless of storage time.*

Moisture content at harvest (%)	*Storage system*	
	conventional	*hermetic*
26.2	86.3 ^{aA*}	81.8 ^{aB}
16.6	69.8 ^{cA}	68.3 ^{bB}
13.5	72.1^{bA}	69.4 ^{bB}
CV (%)	2.54	

*Averages followed by the same letter, lowercase for lines and uppercase for columns, do not differ statistically by the Tukey test ($p \leq 0.05$).

4 Discussion

The oscillations in the moisture content of the seeds along the storage are due to the fact that they tend to a hygroscopic equilibrium with the ambient air, so when the relative humidity of the air increases there is an increase in the moisture content of the seeds (Nahar *et al*., 2009). The reduction in the moisture content of the seeds may be due to the sharp drop in the relative humidity of the air of the storage environment after 130 days, as can be seen in Fig. 1. Similar results were found by Zucareli *et al*. (2015) and Cassol *et al*. (2016) in bean seeds, in which they verified the oscillation of the moisture content of the seeds according to the variations in the relative humidity of the air of the storage environment.

The increase of the moisture content of the seeds stored in a hermetic system in the initial storage period may be a consequence of the migration of the moisture contained in the intergranular spaces to the grains, increasing the moisture content of the seeds until it enters a hygroscopic equilibrium with the air. In addition, respiration, due to residual O_2, can lead to an increase in the moisture content of the grains, since its main by-products are CO_2 and water. Similar results were obtained by Nahar *et al*. (2009) in bean seeds, which verified that, regardless of the storage system, there were oscillations in the moisture content of the seeds, however, those stored in a hermetic system had lower moisture contents during storage. This result is due to the hermetic system's ability to prevent gas exchange with the external environment of the system, providing less interference of the psychometric characteristics of the ambient air and, consequently, lower oscillations in the moisture content of the seeds, which does not occur in the conventional system (Jonfia-Essien *et al*., 2010).

The results found for the thousand grains weight are according to Hafeel *et al*. (2008) and Cassol *et al*. (2012), who verified the weight reduction of one thousand seeds of rice and beans, respectively, with storage time. The reduction of the weight of a thousand seeds throughout the storage can be related to the respiratory process, which generates consumption of the dry matter contained in the form of reserves in the seeds and, consequently, reflects in weight loss (Ferrari Filho *et al*., 2012).

As for storage systems the results are in agreement with Hafeel *et al*. (2008) in which they verified a smaller reduction of the weight of thousand rice seeds when stored in a hermetic system. This result can be due to the reduction of the respiratory rate of the seeds, due to the higher CO_2 concentration in the internal atmosphere, besides the lower oscillation in the moisture content of the seeds when stored in a hermetic system (Adhikarinayake *et al*., 2006; Ferrari Filho *et al*., 2012).

As for the results of hectoliter weight, these are in agreement with those obtained by Ferrari Filho *et al.* (2012) in which they verified a reduction of the hectoliter weight of wheat seeds after 270 days, independently of the storage system. The reduction of the hectoliter weight during storage, as well as for the thousand grains weight, is due to the respiratory process of the seeds. In addition, for the hectoliter weight, damage caused by insects and fungi, which consume and degrade the seeds, can cause weight loss, but will maintain the volume, since the consumption starts in the internal part, thus reducing the density of the seeds (Ferrari Filho *et al.*, 2012). The low values of hectoliter weight and the weight of thousand seeds verified after harvest and during the entire storage period, for the late harvest (13.5 %), are in agreement with the studies of Tunes *et al.* (2008) and Elias *et al.* (2009), who observed a reduction in the weight of one thousand barley seeds and the hectoliter weight of wheat, respectively, in relation with a harvest delay. This initial reduction may be a reflection of the increase in the respiratory rate of the seeds and consequent consumption of reserves, due to the fluctuations of temperature and relative humidity, wetting periods and pest attack to which they were exposed in the field (Hirano, 1976; Bhatt *et al.*, 1981).

The results obtained in the germination test are in agreement with Cassol *et al.* (2016) in which they verified the reduction of the germination percentage of bean seeds during the conventional storage for 360 days. Tunes *et al.* (2010) and Diniz *et al.* (2013) verified the reduction of the germination percentage of barley and soybean seeds, respectively, compared to seed harvest delay. According to the authors, the reduction of germination percentage, due to delayed harvest, may be due to loss of seed storage potential due to the adverse conditions that the seeds were exposed to in the field, such as intermittent wet and dry periods, besides temperature fluctuations. The reduction of germination percentage observed for the harvest with higher moisture content may be a reflection of the damages caused during the post-harvest operations, such as drying, since seeds with higher moisture contents, when submitted to drying, present higher susceptibility to thermal damage, which can lead to reduced quality during storage (Corrêa & Afonso Júnior, 1999). The more pronounced germination reduction observed for seeds harvested at 26.2 and 13.5 % may also be related to the mechanical damages suffered in the threshing process, since seeds with high or low moisture contents are more susceptible to mechanical damages by kneading and breaking, respectively, as verified in the study by Faroni *et al.* (2006), in which they verified that bean seeds harvested with high (20.7 %) and low (11.7 %) moisture contents presented a larger number of broken, cracked and crushed grains, when compared to those harvested with intermediate moisture content (18.7 %).

As for germination speed index, similar results were obtained by Smaniotto *et al.* (2014) and Cassol *et al.* (2016) who verified the reduction of the germination rate of soybean and bean seeds throughout the storage in environmental conditions for 180 and 360 days, respectively. The lowest values found for harvests with higher moisture contents (26.2 and 16.6 %) in the initial storage period may be due to the action of germination inhibiting hormones, such as abscisic acid (ABA), which, according to Rock & Quatrano (1995), are present in a higher concentration in the initial stages of seed development and decrease according to the embryo maturation, reflecting in lower germination speed of the seeds harvested with higher moisture content. On the other hand, the most pronounced reduction of the germination speed was observed in the seeds harvested with a moisture content of 13.5 %, from 60 days of storage onwards, evidencing the latent damages caused by the harvest delay, culminating in the loss of storage potential.

The reduction of seed vigour verified by the accelerated aging test for the different harvests and both storage systems is in accordance with the studies of Zucareli *et al.* (2015), in which they verified, through the accelerated aging test, the reduction of bean seed vigour over 18 months of storage, regardless of the storage conditions. However, the authors verified that the seeds stored under environmental conditions presented lower values and a more pronounced reduction of vigour throughout the storage, when compared to those stored under controlled conditions, a result similar to the one obtained in this work. This fact can be related to the reduction of the degradation provided in the hermetic system, due to the higher concentration of CO_2 in the intergranular atmosphere (Jonfia-Essien *et al.*, 2010), which reduces the respiration of the seeds, slowing down the degradation process, as proven in studies by Aguiar *et al.* (2015) in rice seeds, demonstrating that seeds stored under high CO_2 concentrations had a higher percentage of germination during storage. In addition, the most pronounced reduction of vigour, verified for seeds submitted to delayed harvest, is due to inadequate conservation conditions at which seeds are exposed in the field, reducing storage potential.

The results of shoot and root length are in agreement with those obtained by Santos *et al.* (2005) and Dan *et al.* (2010), in which they verified the reduction of shoot and root length of bean and soybean seeds over 240 and 45 days of storage, respectively. Cardoso *et al.* (2012) verified the reduction of the length of crambe seedlings during nine months, independently of the storage system. Measurement of the length, as well as the determination of the dry matter of the seedlings, provides estimates of vigour, since more vigorous seeds have greater capacity to nourish the embryonic axis, resulting in seedlings with higher growth rates and accumulation of dry matter (Dan *et al.*, 1987).

The triple interaction between the factors tested, observed in the accelerated aging test, demonstrates the greater accuracy of this test to classify seed vigour, since it allowed to verify the effect of the diferente moisture contents at harvest combined with both storage systems along time, which the other tests of vigour did not provide. According to Fanan *et al.* (2006) the high temperature, combined with the high relative humidity of the air used in the test, accelerate the degradation of the seeds, enabling a more accurate classification of different seed lots as to their vigour. The results obtained in the electrical conductivity test are in agreement with Zucareli *et al.* (2015) and Smaniotto *et al.* (2014) in which they verified the electrical conductivity increase of bean and soybean seeds, respectively, according to the time and independently of the storage conditions. However, Rubim *et al.* (2013) verified that anise seeds stored in waterproof systems presented lower values of electrical conductivity along the storage, when compared to the permeable system. The increase of the electrical conductivity during storage is an indication of deterioration and loss of physiological quality, since the disruption of the cellular membranes is one of the first deteriorating events, a fact that leads to an increase in solute leaching and, consequently, an increase in the electrical conductivity (Santos *et al.*, 2005). Thus, the lower values of electrical conductivity observed for seeds stored in a hermetic system may be due to the lower respiratory rate provided by the system, which results in a lower rate of degradation. The highest values of electrical conductivity observed in seeds harvested at 26.2 % moisture content are in agreement with those obtained by Faroni *et al.* (2006), in which they verified higher values of electrical conductivity in bean seeds harvested with a higher moisture content (20.6 %) when compared to seeds harvested with low moisture contents (18.7 %) or submitted to harvest delay (11.7 %) during 90 days of storage. This result can be attributed to the higher susceptibility of seeds harvested with higher moisture content to damages during the post-harvest processes, causing a greater increase in the electrical conductivity values, when compared to the seeds harvested with lower moisture contents, as verified in the studies of Andrade *et al.* (1999) and Scariot *et al.* (2017), evaluating the electric conductivity of bean seeds harvested with different moisture contents and submitted to different impact velocities and drying temperatures, respectively.

The non-verification of the statistical difference between the storage systems in some physiological tests can be a reflection of the conditions of the environment in which the seeds were conditioned, mainly in relation to the temperature, which presented an average value of 18.3 ºC, being considered good for the maintenance of the quality of bean seeds along the storage. According to the studies of Zucareli *et al.* (2014), the temperature of the storage environment at 20 °C provided a less marked reduction of seed quality compared to higher temperatures.

Hermetic storage may be an alternative to store seeds at small and medium farms, since it provides the conservation of seeds for a longer time. The use of materials such as polyethylene terephthalate bottles, cans, plastic bags with a thickness of more than 0.125 mm, among other materials, make it possible to seal the stored seeds. The study by Silva *et al.* (2010) demonstrated the feasibility of hermetic storage in polyethylene terephthalate bottles for rice, maize and bean seeds at small farms in Brazil.

5 Conclusions

Harvest delay, as well as storage time, negatively influences the physical and physiological quality of black bean seeds, BRS Campeiro cultivar. Hermetic storage presented better conditions for the conservation of black bean seeds, BRS campeiro cultivar, over time compared to the conventional system, since it provided lower loss of physical quality and seed vigour. Black bean seeds, BRS Campeiro cultivar, harvested with moisture contents between 16.5 and 26.2 % and submitted to hermetic storage present better physical and physiological quality during 240 days of storage.

Conflict of interest

Authors state they have no conflict of interests.

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