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Experimental silo-dryer-aerator for the storage of soybean grains

Paulo C. Coradi[1] & Ângelo F. C. Lemes[2]

[1] Universidade Federal de Santa Maria/Campus Cachoeira do Sul. Cachoeira do Sul, RS. E-mail: paulo.coradi@ufsm.br (Corresponding author) - ORCID: 0000-0001-9150-2169
[2] Universidade Federal de Mato Grosso do Sul/Campus Chapadão do Sul. Chapadão do Sul, MS. E-mail: angelofcl@yahoo.com.br - ORCID: 0000-0002-6433-8671

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ABSTRACT
This study aimed to verify the capacity of silo-dryer-aerator prototype equipment operating as a silo-storage-aerator for soybean quality analysis. Soybeans with water content of 17% (wet basis – w.b.) were dried and stored in a silo-dryer-aerator system that was designed using a drying chamber, four independent storage cells, and a static capacity of 164 kg. Another batch of grains was stored in a silo-storage-aerator with a capacity of 1,200 kg. The experiment was set up in a completely randomized factorial 5 × 4 experimental design including five grain batches stored after being dried at 30, 40, and 50 °C (mixed grains were dried at three temperatures) in the silo-dryer-aerator cells and one mixed grain batch stored in the silo-storage-aerator system under ambient air conditions for four storage times (zero, one, two, and three months). There was no difference between the grains stored in the silo-dryer-aerator and silo-storage-aerator at the end of the three-month storage in terms of the physico-chemical quality. The storage time associated with drying at 50 °C caused a reduction in the physical-chemical quality of the grains. The silo-dryer-aerator system was presented as a possible alternative to store soybean (*Glycine max* L.) grains.

Palavras-chave:
Glycine max L.
pós-colheita
processamento
qualidade

Silo-secador-aerador experimental para armazenagem de grãos de soja

RESUMO
Objetivou-se com este estudo verificar a capacidade de um equipamento protótipo silo-secador-aerador, operando como silo-armazenador-aerador para análise da qualidade dos grãos de soja. Os grãos de soja com teores de água de 17% (b.u.) foram submetidos à secagem e armazenagem em um sistema de silo-secador-aerador, projetado com uma câmara de secagem e quatro células independentes de armazenagem, com capacidade estática de 164 kg. Outro lote de grãos foi armazenado em um silo-armazenador-aerador com capacidade de 1.200 kg. O experimento foi montado em um delineamento experimental inteiramente casualizado, fatorial 5 x 4, sendo cinco lotes de grãos armazenados após a secagem com temperaturas do ar de secagem (30, 40, 50 °C, grãos misturados na secagem com as três temperaturas), nas células 1, 2, 3 e 4, respectivamente, do sistema silo-secador-aerador e um lote de grãos misturados e armazenados no sistema silo-armazenador-aerador nas condições do ar ambiente, quatro tempos de armazenamento (zero, um, dois e três meses). Observou-se que não houve diferença entre os grãos armazenados no silo-secador-aerador e no silo-armazenador-aerador quanto à qualidade físico-química ao final dos três meses de armazenamento. O tempo de armazenamento associado à secagem a uma temperatura de 50 °C proporcionou uma redução na qualidade físico-química dos grãos. O sistema silo-secador-aerador apresentou-se como uma alternativa viável para o armazenamento de grãos de soja.

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Introduction

High agricultural technology utilized in Brazil in recent years enabled higher rates of crop growth after harvest, especially in grains. However, improved performance of the crops did not reflect in the post-harvest operations, whereas caused more losses and reduced initial quality of the agricultural products (Quirino et al., 2013; Coradi et al., 2016a).

According to Cardoso et al. (2012), the deterioration of stored grains is unavoidable, but good storage practices may delay this incident. The losses of products during storage mean financial losses for the product holder. Grains can suffer damage during storage period due to external or inherent factors affecting the grain mass which are: physical (humidity and temperature), chemical (oxygen availability), and biological (rodents, insects, fungi, and bacteria) factors (Lopes et al., 2010; Barbosa et al., 2012; Rigo et al., 2012; Quirino et al., 2013; Coradi et al., 2016b).

Grains often arrive at storage stage with physical defects and quality losses caused during reception, transport, and drying processes. The most questioned procedures during drying and storing stage are related to drying air temperature, storage time, and storage conditions. The drying temperature may have an immediate effect on grain quality and storage conditions may accelerate any resulting damage (Deliberali et al., 2010; Schuh et al., 2011). It is essential to keep the temperature of grain mass low to minimize the effects of grain deterioration in storage, and one of the alternatives is to use an aeration system (Surki et al., 2012; Smaniotto et al., 2014). Therefore, the aim of this study was to verify the ability of silo-dryer-aerator prototype equipment to operate as a silo-storage-aerator that evaluates soybean grain quality after drying at different air temperatures and storage over three months with monthly aeration applications.

Material and Methods

The municipality of Chapadão do Sul is located in the south of center-west region of Brazil (18º 47' 39" S and 52º 37" 22" W) in the north of Mato Grosso do Sul (Microregion of Cassilândia).

A silo-dryer-storage system was designed, it composed of a chamber with four independent drying-storage cells that were arranged to separate the grains by water content, impurities, or grain size, or even at species level, and aimed to increase the yield and quality of the grains in drying-storage (Figure 1).

The silo-dryer-aerator grains prototype is indicated in Figure 2. It was built with 14-inch, circular and raised metal plates containing a drying-storage chamber of 2 m height and 1 m in diameter ('e' in the figure), and it has a variable static capacity according to the grain type (average of 164 kg of soybeans and corn). The floor was scaled with 10% of its total perforated area. In the interior, four mobile drying-storage cells were built to store the grain mass during drying-storage. Each cell is 1.5 m in height and 0.2 m in diameter and constructed of 12-inch metal plates with walls including 2-mm-diameter holes and open at the top. The silo-dryer plenum that reduces the drying air velocity or aeration was arranged below the drying-storage chamber ('d'). The plenum has a diameter of 1.5 m and height of 0.30 m. In the center of the plenum, one of the electrical resistors with 4,000 watts of power was installed (only for drying). The other electric resistance of the same power (drying only) was fixed in a front compartment plenum ('b') which is 1.5 m long and 0.5 m high. A centrifugal fan of straight blades consisting 20 m^3 min^{-1} flow and 392 pascals (Pa) static pressure, 0.5 cheval vapeur (cv) power, 220/380 volts tension, has 1750 rpm rotation, single-phase, carbon steel, aluminum alloy rotor 90 a-weighted decibel (DBA) noise, 35 kg weight was coupled to an air expansion chamber ('a') that is 1.5 m long and 0.5 m high interconnected with the silo-dryer-aerator body (Figure 2).

The instrumentation of the silo-dryer-aerator system was performed with the control of the air temperature directly in the electrical resistances through an external controller with dimensions of (500 × 400 × 250 mm), channels with an open cut out for cable housing, circuit breaker protection for 10 A control and 40 A power, 24 VCC switching power supply for solid state relay drive, three 40 A phase solid state relays with heat sinks, N1040-PR temperature controller for system control, input and output terminal strip of control cables and force. Depending on airflow and heating of the silo-dryer, variations in the speed and temperature of the drying air were obtained. The storage silo was constructed by 14-inch metal sheets. For the aeration and cooling of the grain mass in the storage-aerator silo, a centrifugal fan with straight blades consisting 45 m^3 m^{-2} flow rate, 1862 Pa static pressure, 220/380 volts voltage, radial rotor, 3 cv power, has 3500 rpm rotation, 90 DPA noise, 50 kg weight, single-phase, carbon steel, and cast aluminum rotor. The silo-dryer-aerator grains were moved to the silo-storage-aerator by a 4 m long, 0.30 m diameter helical screw made of 14-inch metal sheets. It was made with a single-phase motor, 220 V, 3 HP power with a transmission via a set of pulleys and belt.

Figure 1. Grains drying and storage unit (A), automated drying system (B), heating system with electric resistances (C), and cells inside the drying chamber (D)

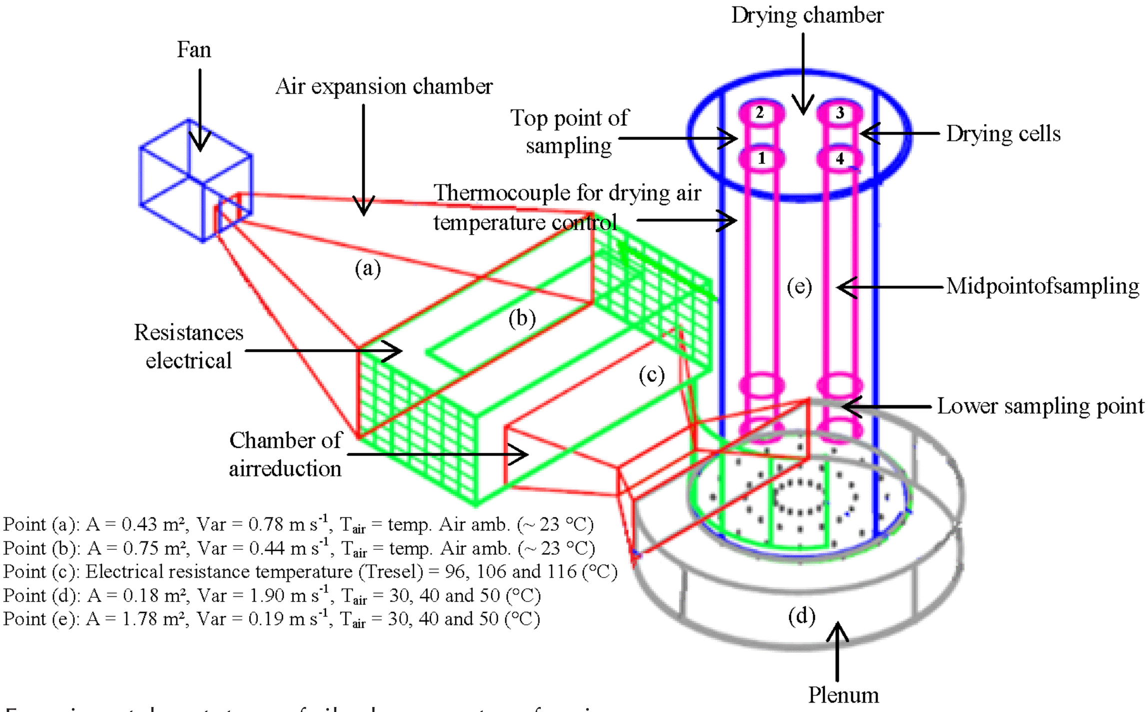

Figure 2. Experimental prototype of silo-dryer-aerator of grains

The silo-dryer-aerator fixed bed with a capacity of 164 kg of soybean was loaded from the top, then the air ventilation system and the heating system with electric resistances was triggered through an external temperature controller to adjust the drying air at 30, 40, and 50 °C. The grain lots were individually dried for each air temperature. During the drying process, the temperature conditions of the grain mass were monitored using mercury thermometers in four drying cells. At 1-hour interval, the grains were sampled throughout the mass profile of four drying cells using a grain-water sampler to determine the water content. At the end of the drying process, top, middle, and lower samples of the four cells were collected and mixed to prepare a single sample for quality assessment. After soybean grains were dried at three different air temperatures (30, 40 and 50 °C), they were stored inside the silo-dryer-aerator equipment and the silo-storage-aerator over three months. Grains dried at 30, 40 and 50 °C were stored in silo-dryer-aerator cell 1, 2 and 3, respectively. Mixed samples of these grains were stored in silo-dryer-aerator cell 4 and the silo-storage-aerator in local ambient air conditions.

In all the storage conditions, the grains exposed to aeration after 15th day for 48 h and during this process temperature of the grain mass was monitored (before and after aeration) using thermometers positioned at the top of silo-dryer-aerator cells and silo-storage-aerator. The aeration operation was repeated monthly for three months from 22nd January to 22nd April 2016.

The experimental design was a completely randomized factorial 5 (grain batches) × 4 (storage times). Five batches of grains stored after drying at drying air temperatures (30, 40 and 50 °C, grains mixed in the drying with the three temperatures) in cells 1, 2, 3, and 4, respectively, of the silo-dryer-aerator system in the air ambient conditions; and a batch of grains mixed and stored in the silo-storage aerator system, four storage times (zero, one, two, and three months). For each drying air temperature, three drying replications were performed. A uniform grain sampling was performed for each cell of the silo-dryer-aerator and silo-storage-aerator each month. Three drying replications were performed for each air temperature, and the samples were evaluated in triplicate. The results were statistically analyzed using SISVAR program, version 5.6 (Ferreira, 2000).

The water content (% w.b.) was determined by the difference between initial and final grain masses dried at 105 ± 1 °C for 24 h, with three replicates of 15 g according to Brasil (2009). The oil yield analysis was completed according to methodology described by IAL (2008). The apparent specific mass of soybean was determined according to Mohsenin (1986). The germination test was conducted with four subsamples of 50 grains for each treatment, placed in rolls of "Germitest" paper towels, and packed in "Mangelsdorf" type germinator at a constant temperature of 25 ± 2 °C. Grain germination results were analyzed on the 5th and 8th days according to the criteria established by Brasil (2009). The electric conductivity test in soybean grains was performed according to a methodology described by Vieira & Krzyzanowski (1999).

Results and Discussion

The mean air temperature was 26 °C, with variations from 22 to 30 °C, and the relative humidity ranged from 47 to 87%, presenting a mean of 67% during January to April 2016 when soybean storage was carried out in Chapadão do Sul city of Mato Grosso do Sul state (Figure 3).

Table 1 presents the results of soybean grain mass temperature before and after application of the aeration performed monthly, for three months, for dry grain conditions at 30, 40, 50 °C, and grain mixed in the silo-dryer-aerator system and mixed grains in the silo-storage-aerator system.

Aeration of the stored grain mass did not significantly reduce the grain mass temperature (0.5 to 1 °C) which

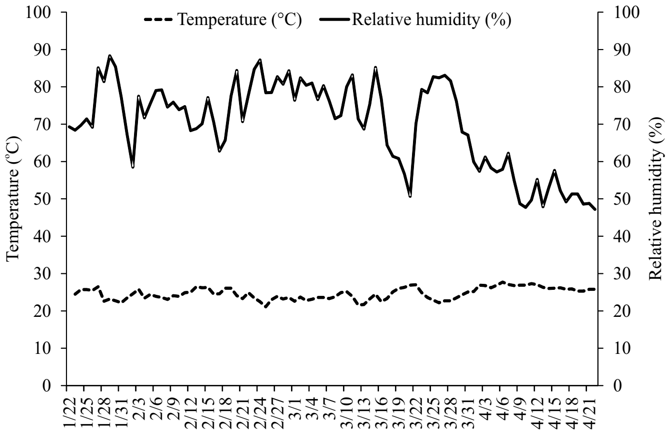

Figure 3. Mean air temperature, and relative humidity in Chapadão do Sul, MS, between January and April 2016

demonstrated that a low efficiency compared to conventional storage system influencing the process of quantitative and qualitative grain losses (Table 1) (Cardoso et al., 2012; Quirino et al., 2013; Coradi et al., 2016b; Nascimento & Queiroz, 2016).

In these conditions, it was observed that the grain deterioration process increased as a function of the water content change after equilibration with the air temperature and relative humidity (Table 3). The increase of the storage time provided a rise in the grain mass temperature regardless of the drying conditions.

Evaluation of the water content, specific mass, electrical conductivity, germination, and oil content of soybean grains stored in silo-dryer-aerator dried at 30, 40, 50 °C, mixed grains and silo storage-aerator with mixed grains in storage time (zero, one, two and three months) was significant at 1% probability (Table 2). The exception occurred for the storage form which was significant only for the variable water content and their interaction (storage form × time) which was not significant for the apparent specific mass variable.

Table 1. Temperature of grain mass stored with aeration application

Points aerated	Period of aeration	Temperature of the grain mass (°C)	
		Before aeration	After aeration
Silo-Dryer-Aerator C1 – TS 30 °C	02/06/2016	25	24.5
	03/08/2016	26	27
	04/07/2016	29	28
Silo-Dryer-Aerator C2 – TS 40 °C	02/06/2016	26	25.5
	03/08/2016	27	29
	04/07/2016	29	29.5
Silo-Dryer-Aerator C3 – TS 50 °C	02/06/2016	26	25.5
	03/08/2016	27	29
	04/07/2016	30	29
Silo-Dryer-Aerator C4 – Mixed Grains (dried at 30, 40 and 50 °C)	02/06/2016	26	26
	03/08/2016	27	29
	04/07/2016	29.5	29
Silo-Storage-Aerator - Mixed Grains (dried at 30, 40 and 50 °C)	02/06/2016	25	24
	03/08/2016	26	25
	04/07/2016	29	28

C - Cell; S - Drying; T - Drying temperature

Table 2. Analysis of variance of water content in stored soybean grains

Source of variation (SV)	Water content (% w.b.)	Specific mass (kg m^{-3})	Electrical conductivity (µSm^{-1} g^{-1})	Germination (%)	Oil content (%)
Time	0.0001*	0.0001*	0.0001*	0.0000*	0.0043*
Storage form	0.0001*	0.1541^{ns}	0.8786^{ns}	0.0000*	0.6842^{ns}
Storage form*time	0.0001*	0.6091^{ns}	0.0418*	0.3659*	0.0012*

*Significant at 0.01 probability; ^{ns} No significant at 0.01 probability

Table 3. Quality analysis in stored soybean grains

Analysis	Forms of storage	Storage time (Months)			
		Zero	One	Two	Three
Water content (% w.b.)	Silo-Dryer-Aerator C1	13.97 Aa	8.63 Ac	9.82 Ab	6.73 Ad
	Silo-Dryer-Aerator C2	13.22 Aa	8.82 Ab	9.28 Ab	6.83 Ac
	Silo-Dryer-Aerator C3	12.36 Aa	8.64 Ac	9.23 Ab	6.93 Ad
	Silo-Dryer-Aerator C4	13.18 Aa	8.94 Ab	9.24 Ab	6.90 Ac
	Silo-Storage-Aerator	13.18 Aa	7.86 Bc	8.51 Bb	6.36 Ad
Specific mass (kg m^{-3})	Silo-Dryer-Aerator C1	872.49 Aa	707.70 Ab	652.00 Ac	663.28 Ac
	Silo-Dryer-Aerator C2	873.16 Aa	689.54 Ab	665.85 Abc	649.33 Ac
	Silo-Dryer-Aerator C3	880.04 Aa	649.68 Ab	667.10 Ab	670.75 Ab
	Silo-Dryer-Aerator C4	875.23 Aa	700.27 Ab	665.43 Ac	649.42 Ac
	Silo-Storage-Aerator	875.23 Aa	708.25 Ab	675.50 Ac	675.02 Ac
Electrical conductivity (µSm^{-1} g^{-1})	Silo-Dryer-Aerator C1	71.99 Bc	112.84 Ab	126.88 Ab	186.84 Aa
	Silo-Dryer-Aerator C2	89.19 Ac	101.74 Aab	130.77 Ab	188.54 Aa
	Silo-Dryer-Aerator C3	88.36 Ac	121.56 Ab	121.11 Ab	172.18 Aa
	Silo-Dryer-Aerator C4	89.85 Ac	111.81 Aab	140.55 Ab	172.19 Aa
	Silo-Storage-Aerator	89.85 Ac	104.78 Aab	147.53 Ab	163.11 Aa
Germination (%)	Silo-Dryer-Aerator C1	85.50 Aa	86.50 Aa	77.25 Aab	68.00 Ab
	Silo-Dryer-Aerator C2	81.50 Aab	87.50 Aa	80.25 Aab	72.00 Ac
	Silo-Dryer-Aerator C3	69.50 Bab	78.00 Aa	61.75 Bc	55.50 Bd
	Silo-Dryer-Aerator C4	82.50 Aa	78.00 Aa	73.00 ABab	67.50 Ac
	Silo-Storage-Aerator	85.00 Aa	85.50 Aa	73.00 ABb	62.50 ABc
Oil content (%)	Silo-Dryer-Aerator C1	9.36 Bb	10.68 Aab	8.22 Ab	14.04 Aa
	Silo-Dryer-Aerator C2	11.48 ABab	7.88 Ab	9.82 Ab	14.24 Aa
	Silo-Dryer-Aerator C3	15.14 Aa	8.00 Ab	11.84 Aab	11.50 ABab
	Silo-Dryer-Aerator C4	11.99 ABa	10.40 Aa	12.44 Aa	8.45 Ba
	Silo-Storage-Aerator	11.99 ABa	11.46 Aa	8.86 Aa	10.97 Aba

Means followed by the same lowercase letter in the line do not differ by Tukey's test at 0.01. Means followed by the same capital letter in the column do not differ by Tukey's test at 0.01

When evaluating the quality of the grains, a significant reduction was detected for the water content, specific mass, and germination at the end of three months of storage in all storage forms (Table 3).

Among the storage systems, there were significant differences in the water contents of the grains in the first two months with lower values for the mixed grain mass in the silo-storage-aerator equipment during three months of storage. However, there were no significant differences in the water contents of the silo-dryer-aerator storage cells and dry grain mass at 30, 40, 50 °C and dry grains mixed (Table 3).

The water content maintenance in the evaluated storage system is in agreement with the recommendations of several authors to guarantee the grain quality in storage. Therefore, the lower grain water contents during the storage, the greater the physical-chemical and microbiological qualities. The grains should be kept at a moisture content of 10 to 12% for six to eight months storage, with the lowest values being indicated for species such as soybean, crambe, and peanuts where lipid reserves predominate (Surki et al., 2012; Lima et al., 2014; Bessa et al., 2015). Regarding the results in Table 3, there was a reduction in grain water contents over storage time, and the apparent specific mass decreased from 880.04 to 649.33 (kg m^{-3}) regardless of the storage form. The drying temperature did not influence the reduction in the specific mass of the grains during storage, and there was no any significant difference between the silo-dryer-aerator storage forms for the four cells and silo-storage-aerator.

The reduction in the grain specific mass indicates a deterioration process which is associated with the dry matter loss. With the influence of storage time, apparent specific mass values tended to decrease because of break down and dry matter consumption most likely by fungi, and total quantitative losses resulted from grain deterioration processes (Demito & Afonso, 2009; Quirino et al., 2013). Alencar et al. (2009) found that regardless of the water content analyzed, the apparent specific mass of the soybeans remained practically constant at 20 °C. They observed a reduction in the apparent specific mass of soybeans stored with a water content of 14.8% in 45 days of storage at 40 °C. This result confirmed an increase in the grain metabolic activity because of the high water content at 40 °C.

The silo-dryer-aerator storage system for the four drying conditions with different temperatures and mixed grains were similar to the storage results of mixed grains in the silo-storage-aerator (Table 3). However, the increase in storage time had a negative effect on grain quality with higher values of electrical conductivity (188.54 μSm^{-1} g^{-1}) regardless of the drying and storage conditions. The cell membrane integrity loss is the first manifestation of reduction or loss in grain quality, and due to the membrane integrity loss, a series of events occur such as protein denaturation. There is a reduction in total carbohydrates, sugars, soluble and phosphate proteins, an increase in free fatty acids, destabilization of enzyme activity, and synthesis of proteins. Increase in electrical conductivity due to a decrease in the grain water content is related to the process of reorganization of cell membranes as a function of grains rehydration (Barbosa et al., 2012; Alves et al., 2016).

Although the germination percentage was higher in some treatments, increased storage time interfered with the grain germination at the beginning of storage and for other treatments at the end of storage (Table 3). In all storage environments, the grains indicated a significant increase in germination potential starting from the 2nd month. However, it was only in the silo-storage-aerator that a significant increase at the end of the third month of storage compared to time zero was observed, but it was not different from other treatments. Differences in the grain germination percentage as a function of the different drying conditions and storage forms were verified. The drying effects of 50 °C (C3) indicated higher grain damage and, consequently, a lower germination percentage independent of the storage time (Smaniotto et al., 2014).

In the conventional silo storage, the percentage of germination was higher with increasing storage time compared to the system silo-dryer-aerator. Grain germination was not very affected by the storage conditions (Table 3) which was observed as an increase in the germination potential. According to Cardoso et al. (2012), this situation can be explained by germination which is an important indicator of the qualitative reduction in a given batch. It is the final consequence of a deterioration process, as verified by a decrease in vigor, or by an increase in electrical conductivity values. Grain germination potential can be explained by the low water content in grains when stored (Alencar et al., 2009; Coradi et al., 2016a).

Although the tests of electrical conductivity and germination are correlated to the water content as indicators of grain quality, the number of leached ions increased as a function of water content reduction. On the other hand, storage at three months with low water contents guaranteed the grain conservation. There was a greater germination potential than at the beginning of storage (time zero) when the effects of drying air temperature on the grain quality had a major impact. The external exposure of soybean embryo allows for major physical damage that is caused by the drying air temperature and, consequently, lower germination potential is observed.

Increase in storage time increased the grain oil content stored at C1 (drying at 30 °C) and C2 (drying at 40 °C) (Table 3). However, for C3 (drying at 50 °C) and C4 (drying at different temperatures with mixed grains), there was a reduction in oil content. The reduction of water content without a change in grain quality over storage may have provided higher oil concentration and increased yield extraction. The increase in oil contents may also result from destruction of phospholipids which constitute the cell membrane, and seen in the extracted oil (Costa et al., 2010; Sampaio et al., 2012).

On the other hand, the oil content reduction verified in C3 and C4 in the final storage (three months) was because of the effects of the drying at a higher temperature (50 °C) due to accelerated deterioration of the grains. Similar results were observed in the soybean grains stored in the silo-storage-aerator (grains that were mixed and dried at different temperatures) in which oil contents were reduced with increasing storage time. However, the stored grains that had undergone drying with higher temperatures indicated a reduction in the oil contents and lessened when the storage was done with mixed grains (C4) and silo-storage-aerator. According to Elias (2008), a loss of lipids may be due to biochemical processes such as the respiration or oxidation of the grains. The authors reported that the oil content reduction of stored grains is attributed to fungal development, the activity of lipase and lipoxygenase enzymes, and auto-oxidation of fats in the presence of oxygen. The reduction in lipid content and increase in the free fatty acids content are directly correlated with the speed and intensity of deteriorative process in the grains.

Conclusions

1. The silo-dryer-aerator system is a viable alternative for the soybean grain storage compared to the conventional silo-storage-aerator system.

2. The grains stored in the silo-dryer-aerator system and conventional model silo-storage-aerator did not indicate differences regarding the grain quality.

3. The storage time associated with drying at a temperature of 50 °C caused a reduction in the grain physico-chemical quality.

Acknowledgements

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