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Yield and acidity indices of sunflower and soybean oils in function of grain drying and storage

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ABSTRACT. The aim of this study was to identify the best conditions for drying and storing soybeans and sunflower grains to maintain their quality. In the first experiment, the soybeans were found to have initial moisture contents of 25 and 19% (w.b.) at different drying air temperatures (75, 90, 105, and 120°C). In the second step, the soybeans were evaluated after they were stored in paper bags and plastic polyethylene at temperatures of 3, 10 and 23°C for six months. In the third experiment, sunflower grains were tested after exposure to drying air temperatures of 45, 55, 65, and 75°C, and under storage conditions of 25°C and 50%, 20°C and 60%, 30°C and 40% RH over six months in paper bags and raffia. Drying the sunflower seeds at 45°C and storing them at 30°C and 40% RH led to higher oil yields and lower acid numbers. The oil that was extracted from the acid number was higher for soybean grains that were dried down from initial concentrations of 25% water at a drying air temperature of 120°C. The air temperature in storage at 3°C favored for yield and reduction of the soybean oil acidity.

Keywords: postharvest, processing and quality.

Rendimento e índice de acidez do óleo de girassol e soja em função da secagem e armazenamento dos grãos

RESUMO. Este estudo teve como objetivo identificar as melhores condições para secagem e armazenamento de grãos de soja e de girassol para a qualidade. No primeiro experimento, avaliou-se grãos de soja com umidades iniciais de 25 e 19% (b.u.) em diferentes temperaturas do ar de secagem (75, 90, 105 e 120°C). Na segundo etapa, avaliou-se grãos de soja armazenadas em sacos de papel e de plástico polietileno nas temperaturas de 3, 10 e 23°C, durante seis meses. No terceiro experimento, testaram-se grãos de girassol na secagem com temperaturas do ar de 45, 55, 65 e 75°C e condições de armazenagem de 25°C e 50%, 20°C e 60%, 30°C e 40% de UR do ar, ao longo de seis meses, usando sacos de papel e ráfia. A secagem de grãos de girassol a 45°C e o armazenamento na condição de 30°C e 40% UR forneceu maior rendimento do óleo e menores índice de acidez. O índice de acidez do óleo extraído da soja foi maior para os grãos submetidos à secagem com teores iniciais de água de 25% e na temperatura do ar de secagem de 120°C. O armazenamento na temperatura do ar a 3°C foi favorável ao rendimento e a redução do índice de acidez do óleo de soja.

Palavras-chave: pós-colheita, processamento e qualidade.

Introduction

Soybeans are the primary oilseed crop of the world, and they have a prominent place as a protein source for humans and animals (Companhia Nacional de Abastecimento [CONAB], 2015). Soy accounts for approximately 90% of vegetable oil production and more than 80% of biodiesel production in Brazil. Soybeans are one of the primary cereals in the world, and Brazil accounts for 40% of the total grain produced; it is responsible for 27% of the global market. Brazil is the second-largest soybean producer and the largest exporter (CONAB, 2015). Sunflower grains constitute the second-largest source of edible vegetable oil (CONAB, 2015). The sunflower crop is being expanded into different regions of Brazil for its positive features such as its short growth cycle, cross-pollination, and increased resistance to drought, cold and heat relative to most cultivated species, in addition to having extensive adaptability to different environmental conditions and different altitudes and photoperiods (Freitas, Dias, Dias, Oliveira, & Josse, 2006).

Soybeans and sunflower grains are harvested at high moisture contents and are not ready to be stored at that point because high moisture can cause grain infection by fungi and other microorganisms, which will reduce the product quality. Soybeans for storage or sale should not contain more than 14% moisture, which can be reduced to 12% (w.b.) for soybeans and 9% (w.b.) for sunflower grains. Thus, there is concern about drying the product, although this technique may cause some type of damage, altering the physical properties and even causing damage to the grains (Coradi, Melo, & Rocha, 2014a; Resende, Rodrigues, Siqueira, & Arcanjo, 2010; Sousa, Resende, Chaves, & Costa, 2011).

Information about the heat and mass transfers that occur between biological material and its drying elements are essential for grain quality systems (Corrêa, Goneli, Afonso Júnior, Oliveira, & Valente, 2010; Dalpasquale, Sperandio, & Kolling, 2009). The temperature that is used for drying is very important because it can change the physicochemical properties of the oil, leading to the rancidity of fats and changes in pigments such as carotenoids (Borém, Coradi, Saath, & Oliveira, 2008; Coradi, Borém, & Reinato, 2014b).

To produce biodiesel and edible oils, soybeans and sunflower grains must be stored for longer periods. However, the existing traditional storage techniques do not guarantee total control over the environment in terms of grain storage (Lacerda Filho, Souza, & Resende, 2000). Grain quality losses occur mostly in storage because of insect infestations and fungal decay, which accelerate the mass of beans that are subject to the respiration process (Elias, Oliveira, & Schiavon, 2010). The combined effects of humidity and temperature in the storage location determines the activity of all the biotic components of the system, which lead to either safe storage or product loss (Elias et al., 2010; Sousa et al., 2011). Depending on the grain storage conditions, metabolic activity can be delayed or accelerated, triggering a series of biochemical reactions that quantitatively and qualitatively affect the components of the grains as well as their technological properties. Grain degradation during storage can be indicated by increased levels of acidity and peroxides for grain reduction darkening and grain oil content (Elias et al., 2010; Faroni, Alencar, Paes, Costa, & Roma, 2009).

In view of the various ways in which grain quality is observed in the field, soybeans are harvested close to a water content of 19% (w.b.). However, given the existing technology, these grains could be harvested at 25% (w.b.) water content, and the practice of drying the soybeans would vary principally in relation to the temperature used in mechanical dryers (75 to 120°C). Soybeans are then placed in bulk storage in metal silos, remaining there over a period in which the temperature of the grain mass is monitored for quality assurance.

However, sunflower cultures with grains that contain high oil contents are pre-processed in the same storage units as those used for soy or corn, and they are subjected to the same drying apparatus that is used for soybeans. However, with different dryers that have temperatures ranging between 45 to 75°C, their temperatures were similar to those used in the seed dryers. Sunflower kernels are stored, but because of their lower volume and low static storage capacity, these grains are stored in bags, and the temperature and the relative humidity are monitored to minimize the grain quality loss. Depending on the variation in the technology used post-harvest, the temperature ranges used in dryers and storage systems as well as the form of storage, the aim of this study was to identify the best conditions for drying and storing quality soybeans and sunflower grains for use in the oil production industry. Thus, the drying air temperature, which is associated with the moisture content of the soybeans and sunflower seeds, and the storage conditions, may affect the yield and the oil acidity index. The aim of this study was to evaluate the different temperatures of the drying air (75, 90, 105, and 120°C) and initial moisture contents (25 and 19% (w.b.)) of soybeans, the drying air temperatures (45, 55, 65, and 75°C) and the storage conditions of sunflower grains (25°C and 50%, 20°C and 60%, and 30°C and 40% air RH) over six months in paper bags and in raffia bags to evaluate the yield and acidity index of the oils.

Material and methods

This experiment was conducted at the Federal University of Mato Grosso do Sul (UFMS), at the Campus of Chapadão do Sul (CPCS), in the Postharvest of Agricultural Products Laboratory. For the first experiment, sunflower grains were harvested by hand, and they had a moisture content of approximately 46.64% (w.b.). The initial procedure for the selection of the material was to take sunflower seed samples at random and perform a manual separation of impurities (straw and bagasse) and damaged grains. To avoid the effects on the studied phenomena from the variability of the particle sizes, the material was classified and homogenized. The soybeans were then collected to complete their drying tests in a convection oven with forced air ventilation at temperatures of 45, 55, 65, and 75°C. Drying was performed until the beans reached moisture content equilibrium. For each drying air temperature, three tests were performed, and 5 kg of pellets were used for each test. The beans were weighed every five minutes to describe the drying kinetics. The relative humidity and temperature monitors were checked throughout the drying process with the aid of a psychrometer. After they were dried, the pellets were stored in three different environments, namely, a natural environment (25°C and 50%) and two climate chambers (20°C and 60%, and 30°C and 40% RH air), and two types of packaging (paper bag and raffia bag) were used for a period of six months. Over time, the stored grain, together with the storage environment, were monitored for their temperatures and relative humidity values with a psychrometer. The experiment was conducted in a completely randomized design (CRD), with factors (4 x 3 x 2 x 2) and treatments, four drying air temperatures (45, 55, 65 and 75°C), three storage conditions (25°C and 50%, 20°C and 60%, and 30°C and 40% of RH air), two containers (a paper bag and a raffia bag) and two storage times.

In the second experiment, the soybean grains were harvested at random with 25 and 19% (w.b.) moisture contents, and a manual separation of impurities from the specimens was performed to remove damaged grains. The grains were dried in a convection oven with forced air ventilation at temperatures of 75, 90, 105, and 120°C. Drying was performed until the grains reached hygroscopic moisture balance. Three tests were performed for each drying air temperature, and 5 kg of soybean grains were used for each test. The temperature and relative humidity were checked with studio monitors, with the aid of a psychrometer. The experiment was arranged in a completely randomized design that was factorial (4x2), with four drying air temperatures (75, 90, 105, and 120°C) and two initial moisture contents for the soybean grains (19 and 25% w.b.).

In the third experiment, the soybeans were dried in a continuous mixed flow dryer with a nominal capacity of 50 ton h^{-1}, and the temperature of the drying air was 90°C. Three tests were performed during the drying process, and test samples were collected to measure their moisture contents. Drying was performed until the beans reached a moisture content of 11.5% (w.b.), which is recommended for storage. The temperature and relative humidity were monitored throughout the process with the aid of a psychrometer. During drying, the temperature of the grain mass was monitored using thermocouple sensors that were installed in the drying chamber. After they dried, ten kilograms of soybeans were randomly collected for storage. These soybeans were then stored under the following three controlled environments: in a room at 23°C in climatic chambers with a B.O.D. temperature of 10°C and in freezers at 3°C. The soybeans were stored in two types of packaging (paper bags and polyethylene plastic bags) for six months. During storage, the temperature of the grain mass was monitored with the aid of thermocouple type J. Throughout the storage period, the ambient temperature and humidity were also monitored using a psychrometer. The experimental design was completely randomized and factorial (3 x 2 x 2), with three storage temperatures (3, 10 and 23°C), two types of packaging (paper bags and polyethylene plastic bags), and two storage periods (zero and six months). The data for the oil yield and acidity index were analyzed by an analysis of variance e regression, with Tukey's test at 1 and 5% probabilities.

The moisture contents of the grains (% w.b.) were determined by weighing 15 g of sample. The samples were then placed in an oven with air heating and ventilation regulated at 105 ± 1°C for 24h, according to the recommendations of (Brasil, 2009). Afterwards, the samples were removed and placed in desiccators to cool. The moisture contents (% w.b.) were determined by taking the mass difference between the initial and final sample weights. Tests were performed in three replicates. After drying and storing the grains, soybeans and sunflower oil were extracted to determine their yield and acid number. The Soxhlet extraction method was used to extract the oil (Coradi, Fernandes, Peralta, & Pereira, 2015). To analyze the oil yield, sunflower grains were ground with the aid of a domestic multiprocessor (model Pro Arno). After extraction, 5 g of the sample was weighed and then the entire mass was transferred to a paper cartridge. The cartridges were placed in metallic baskets, after which they were mixed with 150 mL of hexane PA and connected to a capsule extraction apparatus. The Soxhlet method was used to extract sunflower oil. For this purpose, the solvent and oil extraction drip was monitored for 4 hours. After the extraction, the flow valve was closed and the solvent was recovered. The beaker containing the micelle was decoupled from the system and taken to an oven with air renewal and circulation to evaporate the solvent until the pair (beaker + oil) maintained a constant weight. The oil content was determined gravimetrically. According to the methodology described by Association of Official Analytical Chemists (AOAC, 2000), we determined the acid number of the product that was sampled over three replications. The procedure was performed by placing 5 g of sample in a 250 mL beaker, adding 150 mL of ethanol, and leaving the mixture to stand for approximately 30 minutes, with agitation every 5 minutes. The supernatant was then filtered through filter paper (0.5 mm) by passing it into an Erlenmeyer flask. Another 100 mL of ethanol was then added to the Erlenmeyer, which was left to rest for 15 minutes with agitation every 5 minutes. It was filtered again and 4 to 5 drops of phenolphthalein indicator solution (1%) were added to the solution in the Erlenmeyer, and then the filtrate was titrated with NaOH 0.1 N until it displayed a pink color.

Results and discussion

Drying and storage of sunflower grains

Figure 1 shows the influence of the air temperature on the drying kinetics of sunflower grains. The initial moisture content of the sunflower grains was approximately 46.64 ± 1% (w.b.), and the final moisture contents were 7.62, 7.76, 6.7, and 7.03% (w.b.) at 45, 55, 65, and 75°C, respectively. At ambient air conditions of 23°C and 60% relative humidity, the drying times needed to reach the ultimate moisture content for the sunflower grain samples were 7.5, 6.0, 5.0 and 4.0 hours at 45, 55, 65, and 75°C, respectively.

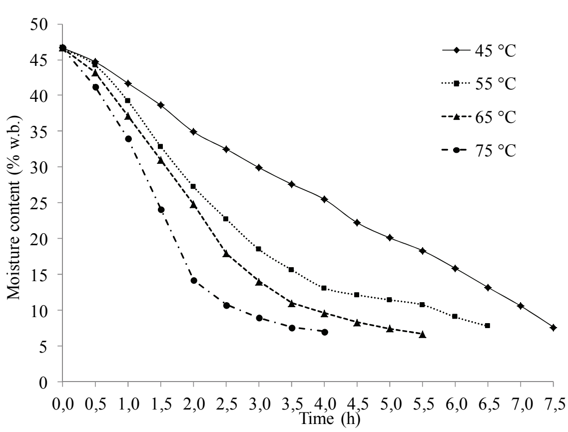

Figure 1. Drying curves of sunflower grains.

As expected, the drying time decreases with the increasing air temperature, so there is a greater rate of water removal from the grain because of the increased moisture gradient between the grain and the air, decreasing the time required to reduce the moisture content to the desired value for storage. This finding was noted by several researchers in other agricultural products, namely parboiled wheat (Mohapatra & Rao, 2005); adzuki beans (Almeida, Resende, Costa, Mendes, & Sales, 2009) and jatropha (Ullmann, Resende, Sales, & Chaves, 2010). For each equally increased temperature interval of 10°C, the drying time decreased by 13.33% (45 to 55°C), 15.38% (55 to 65°C), and 27.27% (65 to 75°C). The increased temperature interval of 10°C from 65 to 75°C has a greater effect on the decreasing drying time.

Moreover, the use of higher temperatures allows for quicker drying, resulting in a very high humidity difference between the periphery and the center of the grain, generating super drying and problems such as deterioration during the acceleration process. The moisture ratio decreases continuously during the drying progress (Figure 1). Therefore, half of the total drying process was required to remove the residual moisture because of slower diffusion. These observations are consistent with previous results on the drying of biological products (Coradi et al., 2014a; Coradi et al., 2014b; Resende, Corrêa, Goneli, Botelho, & Rodrigues, 2008, Ullmann et al., 2010). Figure 1 shows that a constant rate period was not present during sunflower grain drying.

The drying process took place over a falling rate period, except for a very short accelerating period at the beginning. At the higher moisture content, the increase in temperature has a more considerable effect on the drying rates than at lower moisture contents, which was almost negligible at the end. Moisture loss was found to occur more quickly at the start of drying than at the end. The reduction in drying that occurs at that point is primarily caused by a reduction in the moisture content as drying advances. The rate of moisture migration from the inner surface to the outer surface decreases at the final stage of drying and hence leads to lower drying rates (Rajkumar, Kailappan, Viswanathan, & Raghavan, 2007). In practice, when the heating temperature is higher, a loss of quality will occur in the sunflower grains (Almeida et al., 2009). Therefore, in the interest of optimizing the energy efficiency and the product quality, the heating temperature zone between 65 and 75°C is a better option for drying sunflower grains. The storage of agricultural products is a great alternative to meeting the logistical requirements for the production and marketing of food. Thus, understanding the behavior of the grains under different conditions and storage times is important for management. Table 1 shows the moisture content results of sunflower grains after drying and storage under different temperature and relative humidity conditions, packaging and storage times. At low temperatures and high relative air humidities, and also with increasing storage time, there was a significant increase in the moisture content ($p < 0.05$) of the sunflower grains. The drying air temperature significantly influenced the moisture content of grains that were stored for six months.

Table 1. Moisture content of sunflower grains (%) in function of the drying air temperature and storage conditions for each type of packaging and storage time.

Storage time (months)	Packing	Storage conditions	Temperature of the drying air 45°C	55°C	65°C	75°C
0	-	-	10.34 a	10.67 a	10.45 a	10.32 a
3	Raffia bag	20°C / 60%	19.56 Aa	20.42 Aa	20.36 Aa	20.25 Aa
		25°C / 50%	19.90 Aa	19.95 Aa	20.31 Aa	20.21 Aa
		30°C / 40%	16.38 Bc	19.77 Ab	17.51 Bc	21.99 Aa
	Paper bag	20°C / 60%	18.74 Aa	19.65 Aa	19.39 Aa	19.82 Aa
		25°C / 50%	19.14 Aa	18.76 Aa	19.14 Aa	19.71 Aa
		30°C / 40%	18.54 Aa	18.38 Aa	17.31 Ba	17.83 Ba
6	Raffia bag	20°C / 60%	19.82 Ac	38.56 Aa	33.45 Ab	31.36 Ab
		25°C / 50%	16.60 Ba	15.80 Ba	16.43 Ba	16.46 Ba
		30°C / 40%	14.85 Ca	15.09 Ba	14.36 Ca	16.55 Ba
	Paper bag	20°C / 60%	14.17 Ab	15.91 Aa	13.55 Bb	12.76 Cc
		25°C / 50%	15.54 Aa	15.91 Aa	16.55 Aa	14.56 Ab
		30°C / 40%	12.87 Ba	12.38 Ba	12.87 Ba	13.06 Ba

Means followed by the capital letter in the column for each storage condition and lower lines for each temperature of the drying air, do not differ at 5% probability. Coefficient of variation (CV) = 5.40%.

Among the different packaging types, the raffia bags were associated with higher grain moisture contents during storage, regardless of the initial conditions of the grains. When grains are stored at a low temperature the possibility of deterioration is lower and can counteract the effect of the moisture content in relation to the development of the microorganisms that attack stored grains. When the vital activity (respiration) of grains is controlled by the water content, then the conservation during the storage period will be good (Chaves, Resende, Siqueira, & Ullman, 2012). When quantities of stored grains are heated, they become moldy; the grains will sprout at the surface and ultimately give way to rot. Grains can be stored for years, even under unsuitable conditions, if low moisture contents are maintained, minimizing losses. Grains can be stored in warm areas, but they must be dry (Borba Filho & Perez, 2009). Grains are hygroscopic; in other words, their moisture contents are always in equilibrium with the relative humidity.

High moisture contents combined with high temperatures accelerate degeneration processes in biological systems, leading to heavy respiration and the consumption of reserved materials; under these conditions, the grains lose their vigor, and, sometime after, their ability to germinate. The maximum recommended moisture percentage for the safe storage of sunflower grains is 9.5%, with a relative humidity of approximately 75%. With the growth of microflora, weight loss and increased moisture content and temperature will occur in stored grains (Toledo et al., 2009). Fungi will begin to develop in sunflower grains that are stored at a humidity of approximately 11%. In stored sunflower grains with initial moisture contents of 10, 12, and 14% at temperatures of 3-5, 8-10 and 27-28°C, the fungal incidence and germination decrease were proportionally related to the increase in the initial moisture content, the temperature and the storage period (Bajehbaj, 2010). The results in Table 2 for the oil yield of sunflower grains shows a significant difference ($p < 0.05$) between treatments and no significant storage differences for the given drying air temperatures. It was observed that the oil yield was higher for grains that were stored in airtight containers at a lower temperature and higher relative humidity, which was consistent with the grain emergence and electrical conductivity results.

During storage, there were also greater reductions in the oil contents with increasing storage temperatures of 20 to 30°C and a reduced relative humidity from 60 to 40%. Under these conditions, the oil yield decreased from 65 to 17% on average, depending on the type of treatment. Among the evaluated systems, a drying temperature of 45°C, the raffia bag and storage conditions of 25°C and 50% RH led to better results with respect to the oil percentage. When compared with other grain cultures, sunflower seeds are relatively easy to store, and they have a low density. A feature of the sunflower grains during storage is the acidification of their oils, which occurs gradually. This acidification occurs faster when the grains are kept at higher humidities and temperatures, and it depends on the environmental conditions of the site, the amount of foreign material, stones, crushed and peeled grains. Another important factor to consider during storage that is associated with the oil yield is changes in the lipids, which are attributed to enzymatic hydrolysis, peroxidation and autoxidation (Freitas et al., 2006).

Table 2. Oil yield in sunflower grains (%) in function of the time storage, type of packaging, drying air temperature and storage conditions.

Drying air temperature	Storage conditions	Packing	Time of storage (months) 0	3	6
45°C	20°C / 60%	Raffia bag	45.00 Ab	46.95 Ab	51.04 Aa
		Paper bag	45.00 Ab	48.24 Aa	41.91Bc
	25°C / 50%	Raffia bag	45.00 Ab	61.30 Aa	44.85 Ab
		Paper bag	45.00 Aa	45.16 Ba	34.62 Bb
	30°C / 40%	Raffia bag	45.00 Ac	54.34 Aa	49.72 Ab
		Paper bag	45.00 Aa	35.73 Bb	19.21 Bb
55°C	20°C / 60%	Raffia bag	40.93 Ab	51.23 Aa	29.81 Ab
		Paper bag	40.93 Ab	45.21 Ba	25.98 Bc
	25°C / 50%	Raffia bag	40.93 Ab	65.79 Aa	65.44 Aa
		Paper bag	40.93 Ab	49.00 Aa	43.60 Ab
	30°C / 40%	Raffia bag	40.93 Ab	62.25 Aa	35.24 Ac
		Paper bag	40.93 Aa	27.57 Ab	20.32 Bb
65°C	20°C / 60%	Raffia bag	44.07 Ab	52.94 Aa	37.26 Ac
		Paper bag	44.07 Ab	50.07 Aa	39.84 Ac
	25°C / 50%	Raffia bag	44.07 Ab	47.57 Aa	42.20 Ab
		Paper bag	44.07 Aa	46.60 Aa	36.46 Ab
	30°C / 40%	Raffia bag	44.07 Aa	43.86 Aa	44.24 Aa
		Paper bag	44.07 Aa	18.12 Bc	27.71 Bb
75°C	20°C / 60%	Raffia bag	45.46 Ab	50.95 Aa	50.51 Aa
		Paper bag	45.46 Ab	51.48 Aa	40.12 Bc
	25°C / 50%	Raffia bag	45.46 Aa	42.34 Bb	42.84 Ab
		Paper bag	45.46 Ab	64.22 Aa	44.14 Ab
	30°C / 40%	Raffia bag	45.46 Ab	58.41 Aa	46.54 Ab
		Paper bag	45.46 Aa	20.36 Bb	20.07 Bb

Means followed by the capital letter in the column for each package and lower lines for each storage time, do not differ at 5% probability. Coefficient of variation (CV) = 5.30%.

Oil grains should be stored at moisture contents that are lower than those recommended for starch. Accordingly, an increase in the temperature as a result of the respiration process is sufficient for the decomposition of lipids, and it increases the deterioration rate (Rodrigues, 2011). As shown in Figure 2, drying sunflower grains at different air temperatures affect the acidity index of the extracted oil substantially, at 5% probability. However, increasing the grain-drying air temperature increased the acid value of the oil, impairing its quality. However, the oil quality was not found to be significantly different when the sunflower grains were dried at temperatures of 45°C, 55, 65, and 75°C.

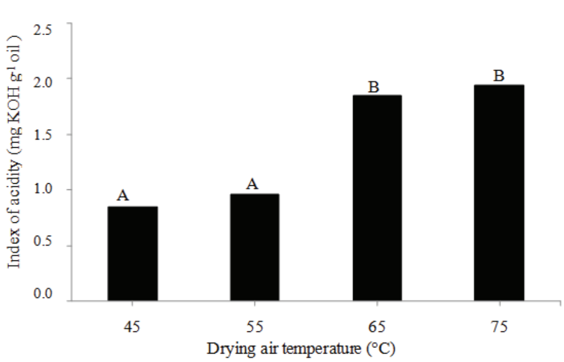

Figure 2. Evaluation of oil extracted from the acid value of sunflower grains after drying with different air temperatures.

When analyzing the acidity of the oil as a function of the storage conditions, the packaging types and storage times exhibited significant differences at 5% probability (Table 3). The increase in the sunflower grain storage time increased the acid value of the extracted oil, regardless of the storage conditions and the type of packaging. Among the grain storage conditions, 20°C and 60% RH had the most negative effects; they affected the quality of the sunflower grains and increasing the acid value of the extracted oil. Among the types of sunflower grain storage packages, the paper bags were found to affect the quality of the beans, increasing the acidity index of the extracted oil. The increase in the storage time by six months adversely changed the oil quality and increased the acidity index (Table 3).

These results confirm the observations of Martins, Melo, Almeida, Santos, and Machado (2002), who found that the deteriorative changes that take place during storage are expressed primarily as rising levels of free fatty acids. Modification spoilage in grains and oils can be oxidative, resulting in a rancid taste and odor, and it can hydrolytic, with the production of free fatty acids. In grains, hydrolytic rancidity can occur during storage, processing operations and in the final product. Typically, this rancidity is caused by the lipase enzyme activity that is present in grain, which can act during storage, thus affecting the quality of the grain as much as in oil, as noted by Araujo, Goneli, Souza, Gonçalves, and Vilhasanti (2014).

Table 3. Oil extracted from the acid value of sunflower grains after drying and storage.

Drying air temperature	Storage conditions	Packages	Storage time (months) 0	3	6
45°C	20°C / 60%	Raffia bag	0.846 Aa	0.964 Aa	3.123 Ab
		Paper bag	0.846 Aa	1.040 Aa	3.563 Bb
	25°C / 50%	Raffia bag	0.846 Aa	1.016 Aa	1.756 Ab
		Paper bag	0.846 Aa	1.018 Aa	1.923 Bb
	30°C / 40%	Raffia bag	0.846 Aa	1.021 Aa	1.234 Ab
		Paper bag	0.846 Aa	1.017 Aa	1.543 Bb
55°C	20°C / 60%	Raffia bag	0.957 Aa	1.107 Aa	3.456 Ab
		Paper bag	0.957 Aa	1.031 Aa	5.164 Bb
	25°C / 50%	Raffia bag	0.957 Aa	1.052 Aa	1.876 Ab
		Paper bag	0.957 Aa	1.021 Aa	2.012 Bb
	30°C / 40%	Raffia bag	0.957 Aa	1.113 Aa	1.345 Ab
		Paper bag	0.957 Aa	1.122 Aa	1.756 Bb
65°C	20°C / 60%	Raffia bag	1.846 Aa	1.936 Aa	4.151 Ab
		Paper bag	1.846 Aa	2.010 Aa	6.523 Bb
	25°C / 50%	Raffia bag	1.846 Aa	2.001 Aa	2.234 Ab
		Paper bag	1.846 Aa	1.921 Aa	2.234 Ab
	30°C / 40%	Raffia bag	1.846 Aa	1.996 Aa	1.867 Aa
		Paper bag	1.846 Aa	2.112 Aa	1.867 Ba
75°C	20°C / 60%	Raffia bag	1.946 Aa	1.967 Aa	5.093 Ab
		Paper bag	1.946 Aa	1.993 Aa	7.456 Bb
	25°C / 50%	Raffia bag	1.946 Aa	2.187 Aa	1.978 Aa
		Paper bag	1.946 Aa	2.122 Aa	2.486 Bb
	30°C / 40%	Raffia bag	1.946 Aa	2.098 Aa	1.978 Aa
		Paper bag	1.946 Aa	2.115 Aa	1.987 Ba

Means followed by the capital letter in the column for each package and lower in lines for each storage time, not different at 5% probability.

Similar behavior was observed by Rupollo, Gutkoski, Marini, and Elias (2004), who studied oat storage. In their study, the increase in the free fatty acid contents and the peroxides in lipids was attributed to the actions of lipase enzymes, peroxidases and phospholipases that were present in the grains themselves or that were produced by the associated microflora by mites or insects, which contributed to the breakdown of ester connections and the triglyceride oxidation of unsaturated carbon chains in the fatty acids.

Drying of soybean grains

The drying process was aimed at the partial removal of water from the grains, through the simultaneous transfer of heat from the grains and air mass flow through the water vapor in the air of the grains (Coradi et al., 2014a; Goneli, Corrêa, Magalhães, & Baptestini, 2011). The soybean drying curves show the moisture data in comparison with the settled time (Mohler, 2010). Figure 3 shows the soybean drying curves under different conditions with respect to the temperatures and initial moisture contents. In considering the reduction of the moisture content from 19 to 11% (w.b.), the drying time of the soybeans was found to be 2.33 hours for the 75°C temperature. Figure 3A shows that the rate for the 120°C treatment is greater than that observed at 75, 90, and 105°C. However, as the drying process continues towards moisture content equilibrium, the representative drying curves are similar, but they differ in their drying times. After 0.5 hour of drying, the product was subjected to a temperature of 120°C, the moisture content reached 10% (w.b.) when drying at 75, 90, and 105°C and the moisture contents were 16.5, 16, and 12% (w.b.), respectively. Figure 3B shows the first 0.3 hours of the process, and the drying rates at 120 and 105°C are greater than those observed at 75 and 90°C. However, as the drying process continues toward moisture content equilibrium, the representative drying curves at 75 and 90°C were above the curve at 120 and 105°C, indicating a possible change in the mechanisms that govern the internal movement of moisture. In any event, after 0.3h of drying, the products that were subjected to temperatures of 105 and 120°C had reached a moisture content of 14% (w.b.), and those that were dried at 75 to 90°C reached moisture contents of 23 and 22% (w.b.), respectively.

The oil contents at different temperatures and initial moisture contents were not significant at 1 and 5% probabilities (Table 4). Thus, Table 4 shows that there were no differences in the grain yields of soybean oils that were extracted after they were dried at different temperatures, regardless of the initial moisture contents of the grains when they began drying.

The results obtained in this study (Table 4) confirm those reported in the literature, and no immediate effects of the drying methods were detected in relation to the soybean oil yields. Similar results were observed by Hartmann Filho et al. (2016), who studied the effects of five drying temperatures on soybeans (in ambient air at 40, 60, 80, and 100°C) when the soybean oil yields with drying temperatures below 40°C were significant; however, this value was more visible following a storage period of more than eight months.

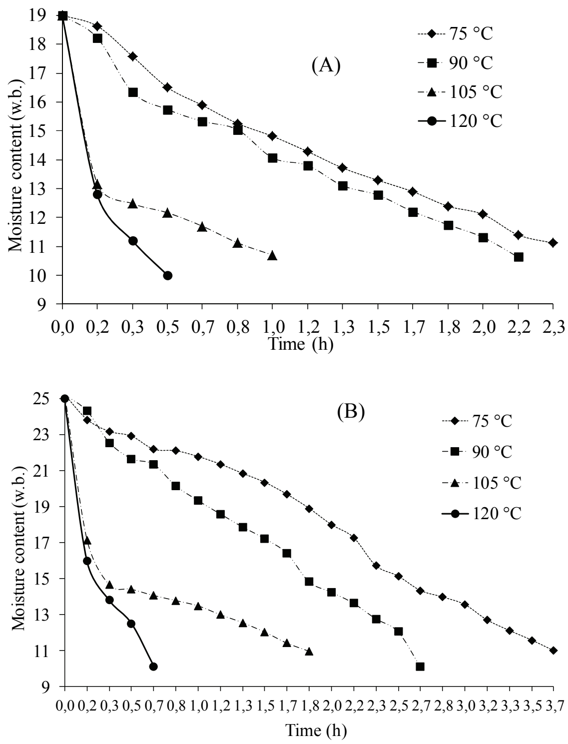

Figure 3. Curves soybean drying with initial moisture contents of 19% (w.b.) (A). Curves soybean drying with initial moisture content of 25% (w.b.) (B).

Table 4. Average results for oil yield (%) in soybean after drying (12% w.b.) at different temperatures

Temperature air drying (°C) NS	Initial moisture content (19% w.b.) NS	Initial moisture content (25% w.b.) NS
75	15.37	15.73
90	15.59	15.41
105	15.20	15.25
120	15.69	15.37

Coefficient variation (%) = 14.67, NS = not significative.

When evaluating the effect of the temperature on grain drying (20-25, 35-40, 55-60, and 75-80°C), Hemis et al. (2016) also found no statistically significant difference in an immediate effect of the drying process. Hemis et al. (2016) studied the soybean oil yield when it was extracted from grain stored at different humidities (12 and 16% w.b.) and temperatures (8, 13, 18, 23, and 28°C), and there was no statistically significant difference between the treatments. According to Figure 4A, the oil acidity index changed regardless of the drying condition and moisture content of the grain.

The increased moisture content of the grains and consequently the longer time required to dry the grain, regardless of the drying air temperature, led to an increase in the oil acidity indices. The highest drying air temperatures also influenced the acidity increase in the oil content. However, when compared with the moisture content, the drying temperature was found to have less impact on the increase in the oil acidity. Figure 4B shows that the acidity index indicates that the oil acidity is most affected when different grain moisture contents are analyzed for the drying temperature treatments (Figure 4), and they showed higher values with higher humidity higher.

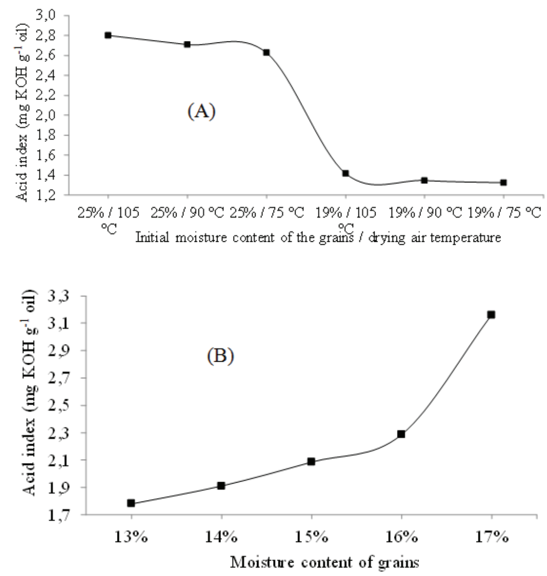

Figure 4. Extracted oil acid value of soybeans after the drying process in different initial moisture content of the grains and drying air temperature (A). Extracted oil acid value of soybeans, along the process for drying air temperature of 120°C (B).

Storage of soybean grains

The analysis of variance indicated that there were significant interactions between the packaging, storage time and temperature of the storage environment ($p < 0.05$) for soybeans. The influence of the grain storage time reduced a moisture content of 10 to 9% (w.b.), under storage temperatures of 3 and 10°C (Table 5). These changes occurred because of the low relative humidity (30 to 40% RH, respectively) and the storage environment, and the grain that was stored at an air temperature of 23 °C exhibited an increase in its moisture content from 10 to 11% (w.b.) because of the high relative humidity of the ambient air (80% RH). During the storage period, the percentage of oil was found to diminish regardless of the air temperature storage conditions and the type of packaging.

Negative effects were found for the paper bags, which led to a greater reduction in oil production, regardless of the storage temperature. However, among the storage conditions, the oil yield was lower at temperatures of 23 to 10°C and did not differ statistically between them during storage in water vapor-permeable containers. For the grain stored in polyethylene plastic bags, storage at 10°C was as favorable as that of the 3°C temperature, matching the statistical oil yield values. During this evaluation, a storage temperature of 23°C was the one that most affected the oil yields of soybeans (Figure 5).

Table 5. Moisture content soybean stored in different storage containers, and air conditions

Storage conditions		10°C		23°C		3°C	
Analysis	Times (months)	P	PL	P	PL	P	PL
Moisture content	0	10.31 Aa	10.31 Ba	10.31 Ba	10.31 Ba	10.31 Aa	10.31 Aa
(% w.b.)	3	10.20 Aa	10.28 Ba	10.24 Ba	10.22 Ba	10.27 Aa	10.20 Aa
	6	9.20 Bb	11.00 Aa	11.20 Ab	12.00 Aa	9.90 Bb	10.50 Aa

Means followed by the capital letter in the column for each time of storage and lower lines for each temperature of storage, do not differ at 1 and 5% probability. PL - polyethylene plastic bag, P – paper bag.

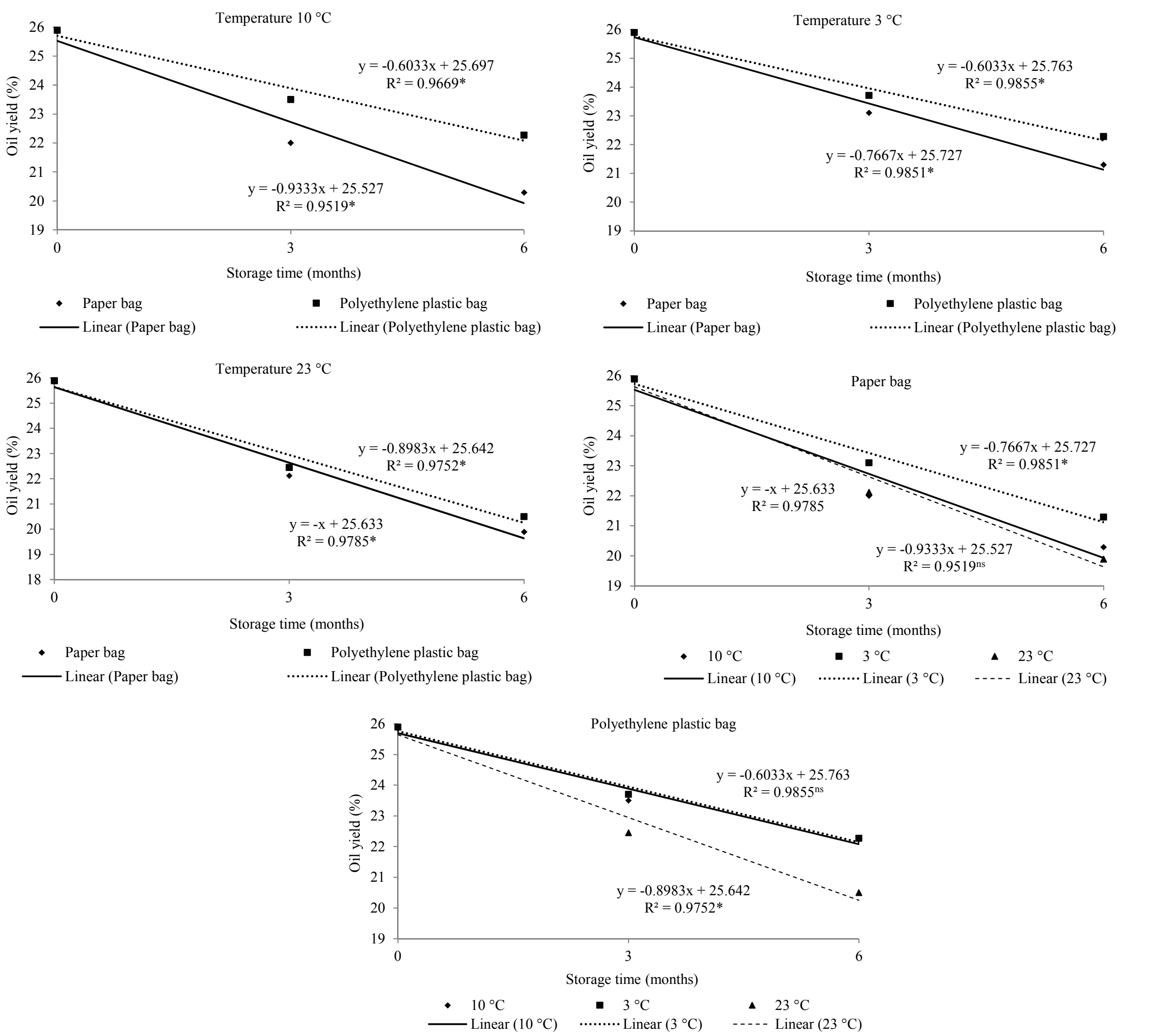

Figure 5. Evaluation of the oil percentage (%) on soybean stored at different temperatures of the air and packaging, over six months. *Significant 5% probability, nsNot Significant.

In evaluating the acidity indices, as shown in Figure 6, the results showed further grain deterioration with increasing storage time and air temperature ($p < 0.05$). The grain that was stored in paper bags had higher acid numbers, and storage at 23°C had a greater influence on the increase in the acid value; at temperatures from 3 to 10°C, the acid values were not significantly different, regardless of the packaging. Park et al. (2012) reported increases in the soybean acid value for all storage conditions; however, increases in temperature and air humidity led to further grain deterioration.

Conclusion

Increasing the storage time reduced the yields and increased the acid values of sunflower and soybean oils. Drying sunflower grains at 45°C and storing them at 30°C and 40% RH provided better oil yields and lower acid values. The oil acidity value in soybeans was higher in grain that was subjected to drying to a moisture content of 25% and an air temperature of 120°C. The paper bags have a direct influence on the yield and they increase the acid value of the soybean oil. Storage an air temperature of 3°C was favorable to the yield and oil acidity index of extracted soybeans.

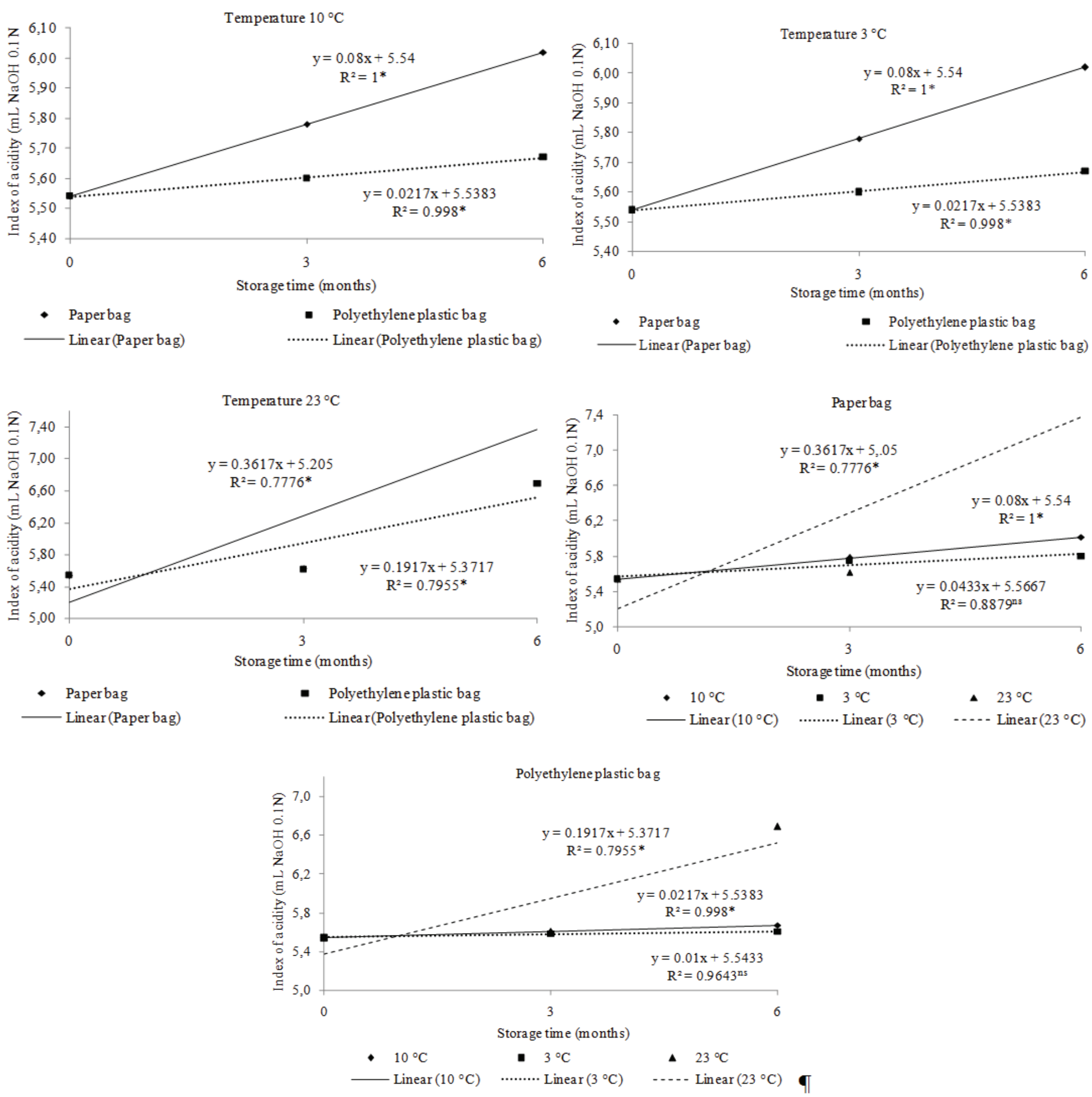

Figure 6. Evaluation of the acid value (mL NaOH 0.1N) in soybeans stored at different temperatures of the air and packaging, over six months. *Significant 5% probability, nsNot Significant.

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