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Storage of Soybeans and Its Effects on Quality of Soybean Sub-Products

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1. Introduction

World soybean production in the 2009/2010 harvest was roughly 260 million tons, and the major producers were the United States, Brazil and Argentina, producing 91.4, 69.0 and 57.0 million tons, respectively (USDA, 2011). Given the significant world production of soybeans, quality is essential for the sectors involved in production and/or processing of this commodity. Quality is an important parameter for commercialization and processing of the grains and can affect the value of the product and its derivatives.

During post-harvest stages, soybeans are subjected to qualitative and quantitative losses due to several external factors. These factors may be physical, such as temperature and humidity; chemical, such as oxygen supply; and biological, such as bacteria, fungi, insects and rodents (BROOKER et al., 1992). According to BAILEY (1974), secure storage retains the qualitative and quantitative aspects of the grains, creating conditions unfavorable to the development of insects, rodents and microorganisms. Grain storage in the natural environment of tropical regions, according to ABBA & LOVATO (1999), presents major problems as a result of the temperature and relative humidity when compared with temperate or cold climates.

Soybeans are composed of roughly 20% lipids and are susceptible to qualitative deterioration processes via degradation of these compounds when stored improperly and can result in serious damage to the food industry. According to NARAYAN et al. (1988a), physical, chemical and biochemical alterations may occur in soybeans, depending on conditions and storage time. The qualitative changes of soybeans during storage contribute to the loss of oil and meal quality (ORTHOEFER, 1978), as well as other derivatives such as tofu and soymilk (NARAYAN et al. 1988b; LIU, 1997; HOU & CHANG, 1998; KONG et al., 2008).

2. Soybean storage

The objective of storage is to preserve the characteristics that grains present after harvest, therefore it is possible to obtain and market sub-products with satisfactory quality. Vitality of the grains can be preserved and the grinding quality and nutritive properties of the food can be maintained (BROOKER et al., 1992).

2.1 Soybean quality during storage

The pursuit of quality grain and sub-products should be a priority for producers, processors and for distributors of these products. According to BROOKER et al. (1992), the main characteristics that determine soybean quality are: low and uniform moisture content; low percentage of foreign material, discoloration, susceptibility to breakage, damage by heat (internal cracks), insect and fungal damage, elevated values of density, oils and protein concentration, and seed viability. Some factors can affect these characteristics such as the environmental conditions during grain formation on plants, season and harvesting system, drying system, techniques of storage, transport and characteristics of the species, and the variety.
The grain mass is an ecological system in which deterioration is the result of interaction between physical, chemical and biological variables (internal and external). The rate of deterioration during storage depends on the rates of change of these variables, which are directly affected by temperature and water content, and also by their inter-relationship with the grain and the storage structure (SINHA & MUIR, 1973). Insects, mites, rodents and fungi are the main biological factors responsible for qualitative and quantitative losses in stored grains, where development of these organisms is influenced by environmental factors such as temperature and relative humidity (PADIN et al., 2002).

2.2 Principal variations which affect quality of stored grains

Among the many variables that affect the storability of grains and their sub-products, moisture content and temperature are highlighted, associated with the storage time. Moisture content can be considered the most important factor on the quality of stored grain. ACASIO (1997) suggested that grains with moisture contents greater than 13% w.b. must be dried to reduce risk of deterioration in the form of dry matter loss by respiration, fungi attack, spontaneous heat production and reduction of germination percentage. Table 1 shows periods of safe storage for soybean with different moisture contents (BARRE, 1976 as cited in ACASIO, 1997).

Moisture content (%) w.b.	Safe storage period
10.0 – 11.0	4 years
10.0 –12.5	1-3 years
12.5 – 14.0	6-9 months
14.0 – 15.0	6 months

Source: BARRE (1976) as cited in ACASIO (1997)

Table 1. Safe storage period for soybeans.

Another determinant variable in the quality of stored products is temperature. When it comes to storage of soybeans, temperature not only affects the development of fungi but can promote chemical changes such as hydrolytic and oxidative rancidity. This physical variable also affects the development and reproduction of insect pests, where the optimum temperature for most species is between 27 and 35 ºC. Soybeans with water contents between 14 and 14.3% w.b. and maintained at a temperature of between 5 and 8 °C can be stored for two years without development of fungi, while grain stored at 30 °C can be infected by fungi within a few weeks and severely damaged after six months of storage (ACASIO, 1997). It is emphasized that decision making must take into consideration the ideal conditions for grain storage, analyzing the combination of the variables of moisture and temperature, and not each one separately.

2.3 Qualitative parameters of soybeans and alterations during storage

2.3.1 Bulk density

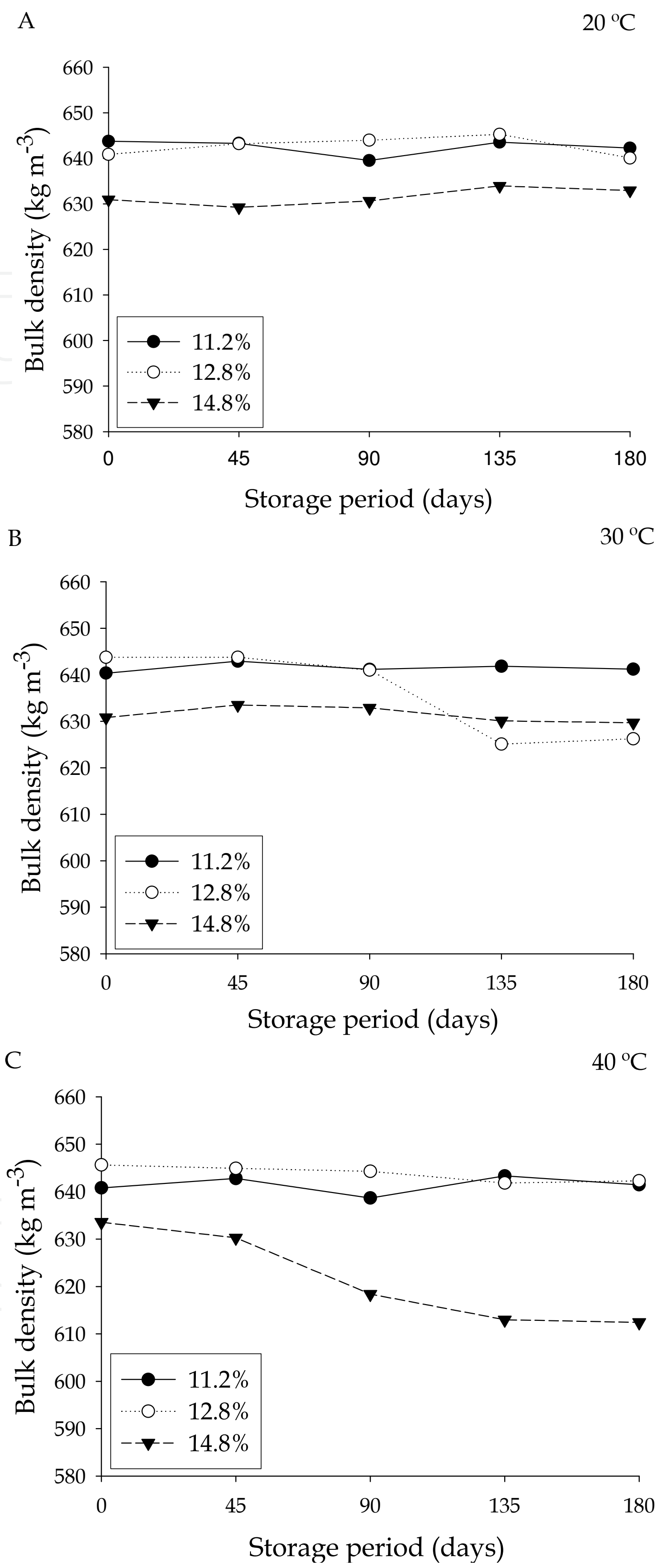
Bulk density of grains is defined as the ratio between mass and volume (kg m^{-3}). This parameter generally increases with the decrease in moisture content of the product, except for coffee, paddy rice and barley (SILVA et al. 2009). It is emphasized that this trend depends on the percentage of damaged grains, initial moisture content, temperature reached during drying, final moisture content and the grain variety (BROOKER et al., 1992). Bulk density can be used as a qualitative indicator and the decrease in its value during storage may be associated with quality losses.

ALENCAR et al. (2009) studied the effect of different combinations of moisture contents and temperatures on the quality of stored soybeans (Fig. 1). The authors observed that the bulk density remained almost constant at different combinations of moisture content and temperature, except for grains stored with 12.8 and 14.8% moisture content and temperature of 30 and 40 °C, respectively. According to the authors, the decrease in bulk density of stored grain with 12.8% moisture content at the temperature of 30 °C (Fig. 1A), was due to infestation by *Plodia interpunctela* and *Sitotroga cerealella* whose optimum conditions of temperature and relative humidity are 30 ºC and 75%, respectively (MBATA & OSUJI, 1983, MASON, 2006, HANSEN et al., 2004). On the other hand, the decrease in grains stored at 14.8% moisture content and temperature of 40 °C (Fig. 1B), was attributed to the development of fungi, where a high incidence (87%) of *Aspergillus glaucus* was verified.

2.3.2 Germination

Germination can be defined as the appearance of the first visible signs of growth or root protrusion, and is affected by several factors, including attack by insects, fungal infection, temperature, moisture and damage to the grains or seeds (BLACK, 1970, as cited in AL-YAHYA, 2001). The germination percentage has been used as an indicator of deterioration in different types of grains during storage.

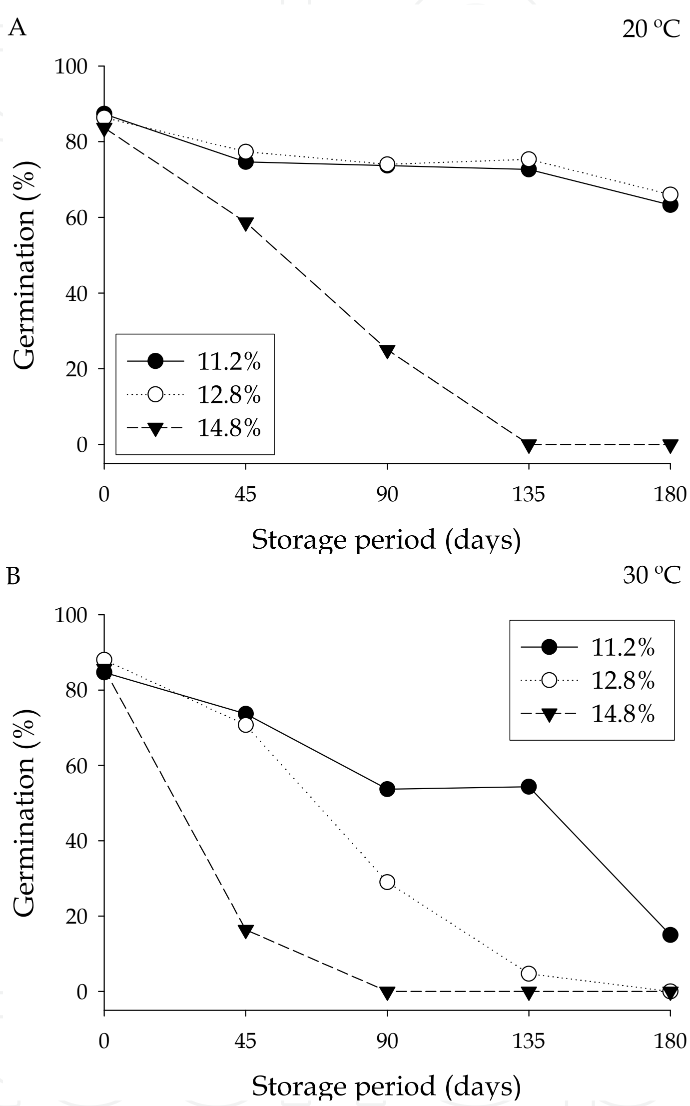
HUMMIL et al. (1954) studied the qualitative deterioration of wheat grain stored with different moisture contents and inoculated or not with fungi at different temperatures. These authors observed a rapid deterioration of the wheat grains stored at 18% w.b. They verified that the process was more pronounced at a temperature of 35 ºC. KARUNAKARAN et al. (2001) stored wheat with moisture contents between 15 and 19% w.b. at different temperatures in order to verify the time of safe storage, using the germination percentage as a quality standard. Results obtained for the water content of 17% w.b. at temperatures of 25, 30 and 35 °C were equal to 15, 7 and 5 days, respectively. Qualitative deterioration of soybeans stored with initial moisture contents between 9.8 and 13.8% w.b. in tropical conditions (30 ºC and 82% RH) was simulated by Locher & Bucheli (1998). These authors confirmed a marked decrease in the germination percentage between 5 and 9 months of storage, where this behavior was more pronounced in seeds with greater initial moisture contents. Bhattacharya & Raha (2002) studied alterations in soybeans stored with moisture content of 14.0%, in the presence of different fungi species. The germination percentage of soybeans after 10 months of storage was zero. GUNGADURDOSS (2003), when studying the viability of soybean seeds under different storage conditions concluded that temperature



Source: ALENCAR et al. (2009)

Fig. 1. Average measurements of bulk density for soybeans stored with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at the temperatures of 20, 30 and 40 ºC.

was the predominant factor in maintaining the viability of soybean seeds. The effect of different combinations of moisture content and temperature on germination percentage of soybeans was evaluated by ALENCAR et al. (2008), during 180 days of storage (Fig. 2). It was verified that there was a decrease in the percentage of germinated grains, where this trend was less pronounced in grains stored with 11.2 and 12.8% moisture contents and temperatures of 20 °C (Fig. 2B).



Source: ALENCAR et al. (2008)

Fig. 2. Average values of germination percentage of the soybeans with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at the temperature of 20 and 30 ºC, along the period of storage.

2.3.3 Electrical conductivity

According to SANTOS et al. (2004), the deterioration of grain is considered all and any degenerative change after the grain has reached its maximum quality, as evidenced by genetic damage, loss of integrity of system membranes, selective reduction of capacity, lipid peroxidation, leaching of solutes, changes in respiratory activity of the grains and seeds, changes in enzyme activity and protein synthesis, the inability to maintain the electrochemical gradient and loss of cellular compartmentalization and accumulation of toxic substances. Membrane damage is the initial event of degenerative changes in grains and seeds (DELOUCHE, 2006). According to HESLEHURST (1988), determination of electrical conductivity can be used to evaluate vigor, since the value of the conductivity is related to the amount of ions leached into solution, which is directly associated with cell membrane integrity. Poorly structured membranes and damaged cells are usually associated with the deterioration process of grains and seeds. Losses in germination and vigor in aged grains and seeds, according to LIN (1990), are correlated with increased electrolyte leaching, which increases with the decrease of membrane phospholipids. The lowest values corresponding to the lower release of exudates, indicate a high physiological potential (greater vigor), revealing a lower intensity of disorganization of cell membrane systems (VIEIRA et al., 2002).

ALENCAR et al. (2008) used electrical conductivity as a qualitative parameter for soybeans stored with moisture contents of 11.2, 12.8 and 14.8%, at temperatures of 20, 30 and 40 °C for 180 days (Table 2 and Fig. 3). In general, the authors observed a tendency for increased electrical conductivity during storage, where this trend was more pronounced as the moisture content and temperature were increased. It is reinforced that for the soybeans stored with 11.2 and 12.8% moisture content and temperature of 20 °C, electrical conductivity remained almost constant.

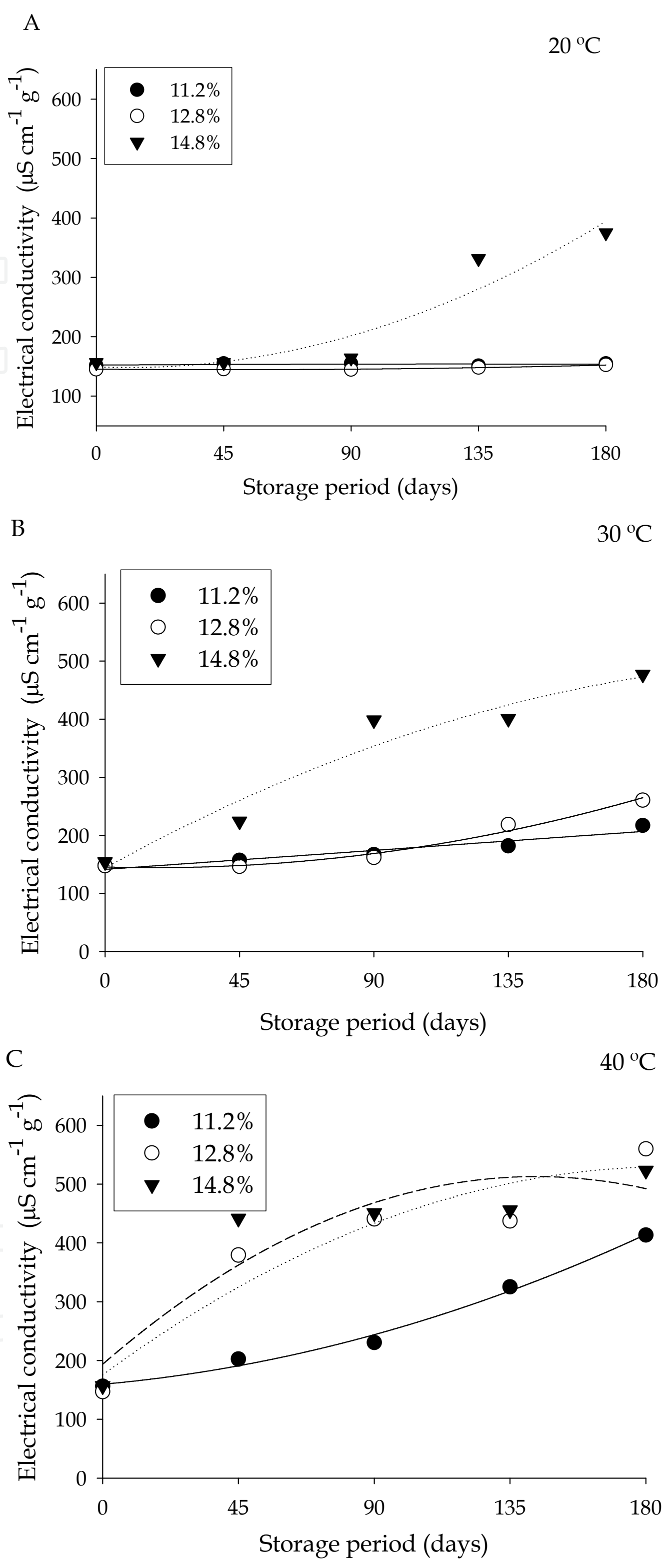
Temperature (ºC)	Moisture content (%)	**Regression equation adjusted**	R^2
20	11.2	$\hat{y} = 153.4$	
	12.8	$\hat{y} = 147.1$	
	14.8	$\hat{y} = 149.4 - 0.2029X + 0.0087X^2$	0.89
30	11.2	$\hat{y} = 145.4 - 0.0403X$	0.91
	12.8	$\hat{y} = 145.5 - 0.1477 + 0.0045X^2$	0.87
	14.8	$\hat{y} = 143.7 + 2.8360X - 0.0056X^2$	0.94
40	11.2	$\hat{y} = 159.6 - 0.4581X + 0.0053X^2$	0.97
	12.8	$\hat{y} = 175.5 + 3.768X - 1.002X^2$	0.88
	14.8	$\hat{y} = 194.2 + 4.403X - 1.530X^2$	0.84

Source: ALENCAR et al. (2008)

Table 2. Regression equations adjusted for electrical conductivity of the solution containing the soybeans with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at temperatures of 20, 30 and 40 ºC along the storage period (X), and respective coefficients of determination.

2.3.4 Color of the grains

Appearance of the grains is considered a critical and decisive factor in the commercialization process. The color of soybeans, according to SINCLAIR (1992), has been used as an indicator of quality, and discoloration is indicative of physical or chemical alterations, presence of metabolites or other unfavorable characteristics. According to this author, changes in color of the soybeans are caused mainly by microorganisms, although changes in climatic conditions can enhance or affect color of the grain, but is not the main cause of the problem. In the United States upper limits are established for the classification of soybeans with distinct colors of yellow that is predominant, but may be green, black,



Source: ALENCAR et al. (2008)

Fig. 3. Regression curves of electrical conductivity (µS cm^{-1} g^{-1}) of the solution which contains soybeans stored with moisture contents of 11.2, 12.8 and 14.8% w.b. at the temperatures of 20, 30 and 40 ºC.

brown or bicolored (USDA, 2006). The percentage limits of grain characterized as other colors for soybeans in types 1, 2, 3 and 4 are 1.0, 2.0, 5.0 and 10.0%, respectively. These values indicate that product is of very poor quality.
The darkening of soybeans, according to SAIO et al. (1980), is an important qualitative indicator of deterioration during storage, and for LIU (1997), the variation in color characterizes the aging of the grains and is associated with qualitative changes such as reducing the germination percentage. HOU & CHANG (2004) evaluated alterations in the color of soybeans stored with 5.4% moisture content in different conditions of temperature and relative humidity. These authors observed a significant darkening, according to variation of the Hunter coordinates, for the soybeans only when stored at 30 °C and 84% relative humidity (Table 3). ALENCAR et al. (2009) studied the change in color of the soybeans stored with moisture contents of 11.2, 12.8 and 14.8% at temperatures of 20, 30 and 40 °C for 180 days. The authors evaluated the color difference (ΔE), from values of Hunter L, a and b coordinates, and found a significant increase, where this increase is more pronounced when grains are stored with elevated moisture content and under increased temperature (Fig. 4 and Table 4). This trend of increasing color difference is directly related to the increase in the percentage of damaged grains, which are considered by Brazilian law as serious defects. The damaged grains are defined as grains or pieces of grain that present visible damage and have an accentuated dark brown color, affecting the cotyledon (MAPA, 2007). Alterations in the color of soybeans can also be viewed from the aspect of soybean flour obtained from these grains (Fig. 5).

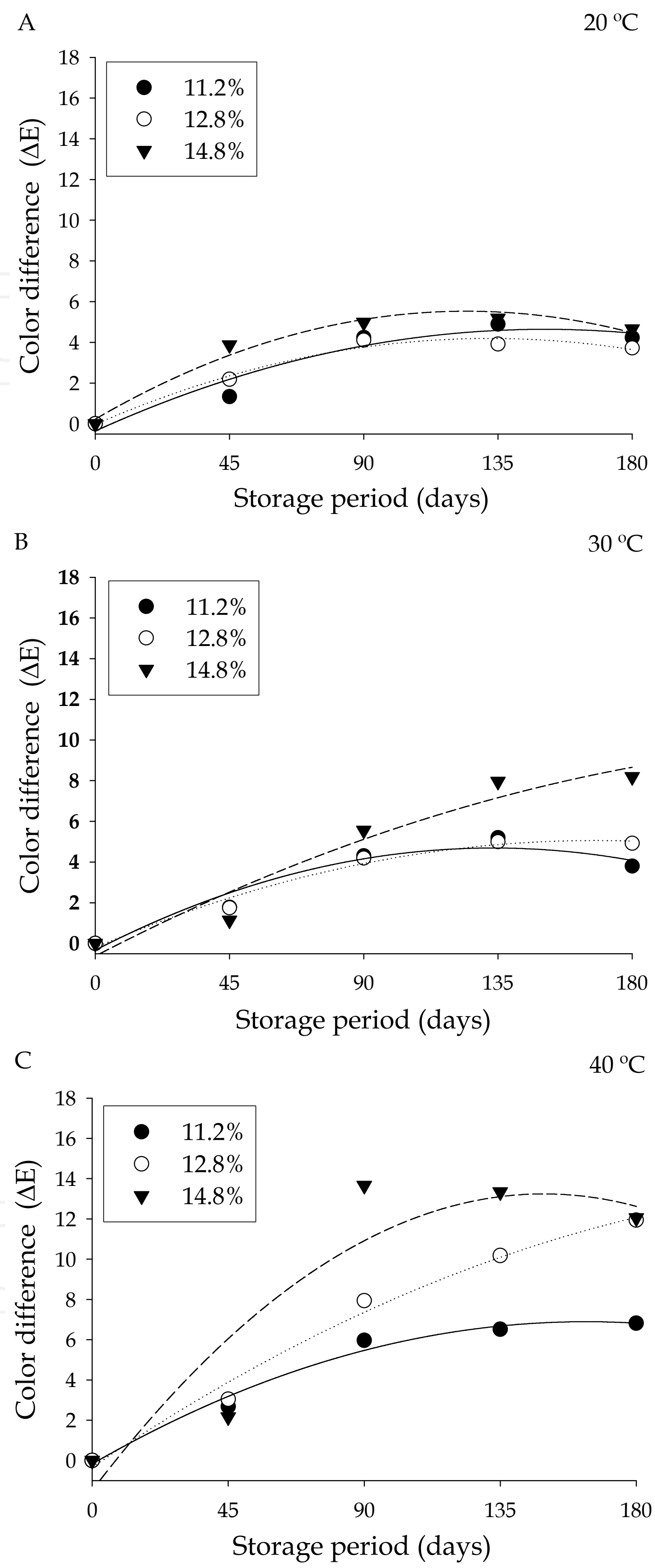
Period (month)	Hunter L value	**Hunter a value**	Hunter b value
0	51.04±0.51[a]	4.05±0.04[g]	15.58±0.09[a]
1	49.56±0.55[c]	4.22±0.15[f]	15.33±0.11[a]
2	50.34±0.37[b]	4.58±0.06[e]	15.38±0.11[a]
3	48.67±0.40[d]	4.83±0.16[d]	14.59±0.25[b]
4	48.38±0.09[d]	5.19±0.06[b]	14.76±0.03[b]
5	45.14±0.44[e]	5.53±0.07[a]	12.87±0.13[c]
6	43.37±0.18[f]	4.81±0.07[d]	11.19±0.13[e]
7	45.37±0.59[e]	5.05±0.15[c]	12.53±0.22[d]
8	41.99±0.55[g]	4.28±0.09[f]	10.57±0.28[f]
9	38.97±0.94[h]	3.87±0.18[h]	8.75±0.58[g]

Values followed by the same letter in the column are not statistically different at 5% probability
Source: HOU & CHANG (2004)

Table 3. Color of soybeans stored at 30 ºC and 84% relative humidity.

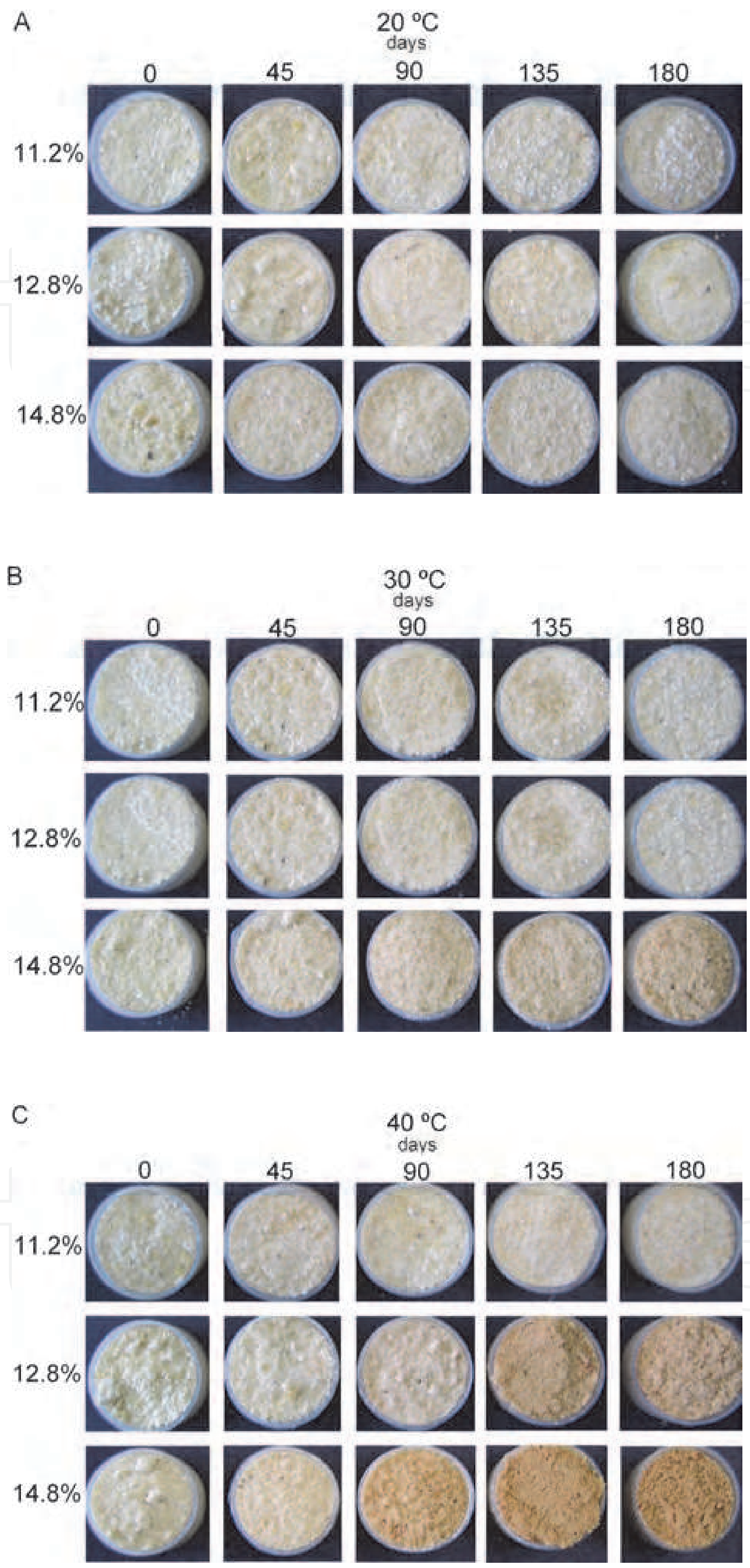
2.4 Soybean oil

Soybean oil has emerged as one of the products obtained from processing of the grain, being one of the major products of this nature in the world market. It is most utilized to prepare food for humans and pets. Because of its properties it is suitable for a wide range of applications including use in margarines, salad oil, mayonnaise, and other food products (MORETTO & FETT, 1998). Virtually all soybean oil is extracted by solvent and commercial extraction techniques have remained unaltered since the early nineteenth century (ERICKSON & WIEDERMANN, 2006). Table 5 shows the main components of crude and refined soy oil, according to ERICKSON & WIEDERMANN (2006).



Source: ALENCAR et al. (2009)

Fig. 4. Regression curves of the color difference of the soybeans stored with moisture contents of 11.2. 12.8 and 14.8% (w.b.) at the temperatures of 20, 30 and 40 ºC.



Source: ALENCAR (2006)

Fig. 5. Visual aspect of whole soybean flour obtained from soybeans with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at the temperatures of 20, 30 and 40 ºC, during storage.

Temperature (ºC)	Moisture content (%)	**Regression equation adjusted**	R^2
20	11.2	$\hat{y} = -0.358 + 0.0663X - 0.0002X^2$	0.91
	12.8	$\hat{y} = -0.031 + 0.0639X - 0.0002X^2$	0.78
	14.8	$\hat{y} = 0.227 + 0.0852X - 0.0003X^2$	0.78
30	11.2	$\hat{y} = -0.329 + 0.0753X - 0.0003X^2$	0.86
	12.8	$\hat{y} = -0.202 + 0.0627X - 0.0002X^2$	0.91
	14.8	$\hat{y} = -0.619 + 0.0759X - 0.0001X^2$	0.92
40	11.2	$\hat{y} = -0.169 + 0.0864X - 0.0003X^2$	0.95
	12.8	$\hat{y} = -0.330 + 0.1020X - 0.0002X^2$	0.96
	14.8	$\hat{y} = -1.488 + 0.1972X - 0.0007X^2$	0.82

Source: ALENCAR et al. (2009)

Table 4. Regression equations adjusted for the color difference of the soybeans with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at 20, 30 and 40 ºC during the storage period (X), and respective coefficients of determination.

Component	Crude oil	Refined oil
Triglycerides (%)	95.0 – 97.0	99.0
Phosphatides (%)	1.5 – 2.5	0.003 – 0.045
Unsaponifiable matter (%)	1.6	0.3
Sterols (%)	0.33	0.13
Tocopherols (%)	0.15 – 0.21	0.11 – 0.18
Hydrocarbons (squalene) (%)	0.014	0.01
Free fatty acids (%)	0.3 – 0.7	< 0.05
Trace metals		
Iron (ppm)	1.0 – 3.0	0.1 – 0.3
Copper (ppm)	0.03 – 0.05	0.02 – 0.06

Source: ERICKSON & WIEDERMANN (1989)

Table 5. Principal components of crude and refined soy oil.

2.4.1 Qualitative parameters of oils and alterations resulting from storage conditions of the grains

In all stages of oil and fat processing various analysis are needed for quality control. In the refining process, for example, determining the percentage of free fatty acids is necessary in the neutralization step, or as a qualitative indicator (O'BRIEN, 2004). Other widely used analyses as quantitative indices of oils and fats are: peroxide value, iodine value, color, saponification number, water content and others.

2.4.1.1 Free fatty acids

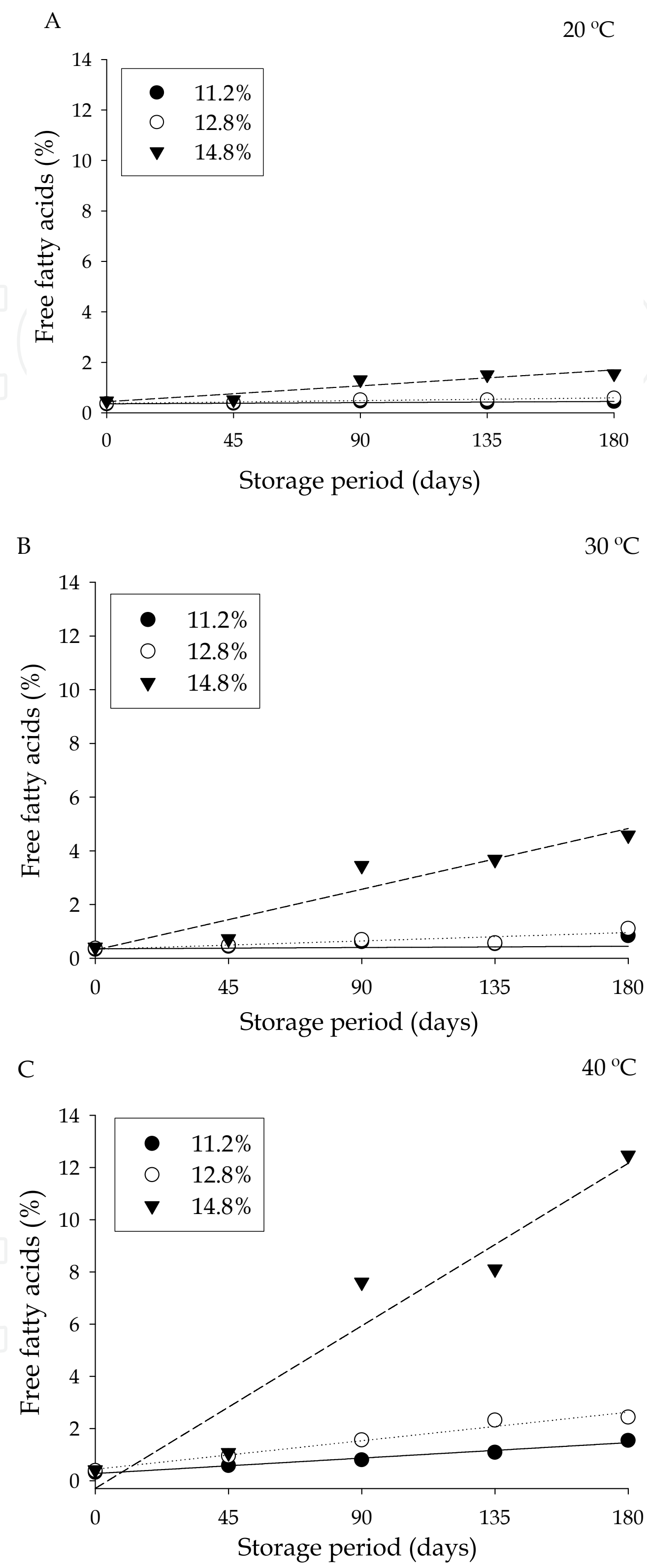
During the storage of grains, the lipid fraction is slowly hydrolyzed by water at high temperature (physical process) or by natural lipolytic enzymes or those produced by bacteria and/or fungi, contributing to the hydrolytic rancidity of the product (ARAÚJO, 2004). Increase in the content of free fatty acids from lipids occurs by the action of lipase and phospholipase enzymes present in the soybeans or produced by the associated microflora, which contribute to the breaking of ester linkages of triglycerides (ZADERNOWSKI et al., 1999). Thus, the percentage of free fatty acids is an important indicator of quality throughout the processing of oils and fats. O'BRIEN (2004) stated that hydrolytic rancidity can affect taste, odor and other characteristics of oil. This author stresses that vegetable oils may present relatively high contents of free fatty acids if the grains or seeds present damages due to procedures in the field or incorrect storage practices, being that high values of free fatty acids can cause excessive losses in refining. WILSON et al. (1995) claimed the refining losses between 1 and 1.5% are considered normal; however, such losses may reach 4% or more for greater levels of free fatty acids.

Many authors have related the increase in free fatty acid percentages to storage conditions. The variation in percent free fatty acids in crude oil extracted from soybeans stored with different moisture contents was observed by FRANKEL et al. (1987). Soybeans stored with 13% (w.b.) resulted in lower increases in the percentage of free fatty acids when compared with the values obtained by grains stored with 16 and 20% (w.b.) moisture content. With regards to the crude oil extracted from the soybeans stored at 13% (w.b.), it was verified that the increase in the free fatty acid percentage was from 0.2 to 1.25% after 49 days of storage; in the crude oil obtained from the grains stored with moisture contents of 16 and 20% w.b., increase was from 0.5 to 2.0% after 27 days and from 0.6 to 2.3% after 28 days, respectively. NARAYAN et al. (1988a) verified the increase in free fatty acid percentage in soybeans stored at different temperature conditions (between 16 and 40 ºC) and relative humidity (between 50 and 90%), obtaining average values equal to 0.69, 4.32, 5.37 and 9.85% after 12, 24, 36 and 108 months of storage. ALENCAR et al. (2010) evaluated the effect of different combinations of temperature and moisture content on the percentage of free fatty acids of crude oil extracted from soybeans stored for 180 days. The authors adopted the grain moisture contents of 11.2, 12.8 and 14.8% and temperatures of 20, 30 and 40 °C (Fig. 6 and Table 6), and generally observed a significant increase in free fatty acid content of crude oil, except for the grains with moisture content of 11.2% at 20 ºC. The increasing trend in the percentage of free fatty acids was more pronounced as water content and temperature increased, and the greatest percentage of free fatty acids from crude oil was 12.5% for grain stored at 14 8% moisture content after 180 days.

Temperature (ºC)	Moisture content (%)	**Regression equation adjusted**	R^2
20	11.2	$\hat{y} = 0.41$	
	12.8	$\hat{y} = 0.370 + 0.0012X$	0.85
	14.8	$\hat{y} = 0.438 + 0.0069X$	0.80
30	11.2	$\hat{y} = 0.352 + 0.025X$	0.82
	12.8	$\hat{y} = 0.332 + 0.035X$	0.72
	14.8	$\hat{y} = 0.307 + 0.0251X$	0.86
40	11.2	$\hat{y} = 0.277 + 0.0066X$	0.96
	12.8	$\hat{y} = 0.440 + 0.0121X$	0.87
	14.8	$\hat{y} = -0.294 + 0.0692X$	0.84

Source: ALENCAR et al. (2010)

Table 6. Regression equations adjusted for free fatty acids of oil extracted from soybeans with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at the temperatures of 20, 30 and 40 ºC along the storage period (X), and respective coefficients of determination.



Source: ALENCAR et al. (2010)

Fig. 6. Regression curves of the percentage of free fatty acids (%) of crude oil extracted from soybeans stored with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at temperatures of 20, 30 and 40 ºC.

2.4.1.2 Peroxide index

Lipid oxidation is a spontaneous and inevitable phenomenon, according to SILVA et al. (1999), with direct implications on the market value of either the fatty bodies, or of all the products formulated from them, and peroxidation is the main cause of deterioration of fatty bodies (lipid materials and greases). It is the main cause of deterioration of oils and fats, and the hydroperoxides formed from the reaction between oxygen and unsaturated fatty acids are the primary products. Although these compounds do not exhibit taste or odor, they are rapidly decomposed even at room temperature into aldehydes, ketones, alcohols, hydrocarbons, esters, lactones and furans, causing unpleasant taste and odor in oils and fats (O'BRIEN, 2004; EYS et al., 2006). Other consequences of lipid oxidation in foods are changes in nutritional value, functionality, and also in the integrity and safety of the product via the formation of potentially toxic polymer compounds (SILVA et al., 1999; ARAÚJO, 2004; NAZ et al., 2004; RAMALHO & JORGE, 2006). According to HOU & CHANG (2004), the appearance of off-flavors (unpleasant aroma and taste) in soybean products can be partially attributed to lipid peroxidation.
One of the methods used to determine the degree of oxidation in fats and oils is the peroxide index. The peroxide index (PI) is a measure of oxidation or rancidity in its initial phase, as shown in Table 7 and measures the concentration of substances (in terms of milliequivalents of peroxide per thousand grams of sample) which oxidize potassium iodide to iodine is widely used in determining the quality of oils and fats, showing good correlation with taste (O'BRIEN, 2004).

Range	Degree of oxidation
<1	Freshness
1< PI<5	Low oxidation
5<PI<10	Moderate oxidation
10<PI<20	High oxidation
>20	Poor flavor

Source: O'BRIEN (2004)

Table 7. Classification of the degree of oxidation of soybean oil in accordance with the peroxide index (PI, meq kg^{-1}).

Works are encountered in literature that report the effect of different soybean storage conditions on the peroxide index of crude oil. NARAYAN et al. (1988a) studied the evolution of the peroxide index of crude oil extracted from soybeans stored at different temperatures and humidities. Average values observed for the peroxide index were 18, 40, 65 and 98 meq kg^{-1} after 12, 24, 36 and 108 months. ALENCAR et al. (2010) evaluated the peroxide value in crude oil obtained from soybeans stored with moisture contents of 11.2, 12.8 and 14.8%, at the temperatures of 20, 30 and 40 °C for 180 days. The authors verified an increase for all combinations of water content and temperature, where the highest values were obtained as the water content and temperature were increased (Table 8).

2.4.1.3 Color of the oil

The color and appearance of oils and fats, according to O'BRIEN (2004), are not monitored only due to the visual character, but also because they are related to the cost of processing and quality of the final product. Most oils present a reddish-yellow color as the result of the

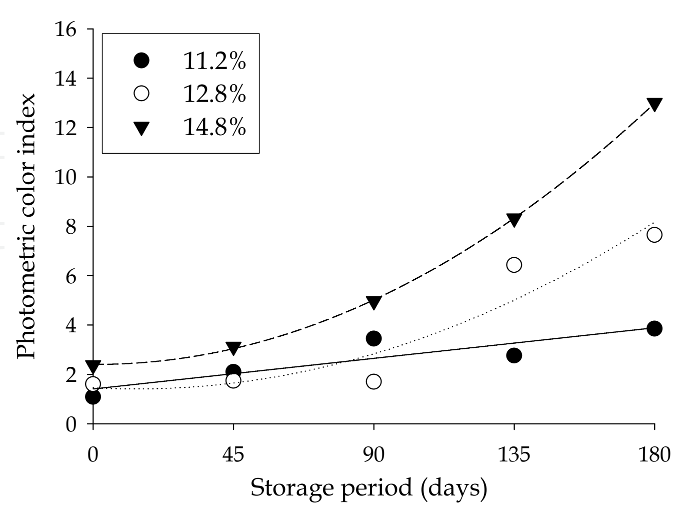
Temperature (ºC)	Moisture content (%)	Storage period (days)				
		0	45	90	135	180
	11.2	1.51	2.17	2.87	2.81	2.68
20	12.8	1.45	2.09	3.29	3.57	2.76
	14.8	1.52	3.58	4.33	3.62	7.84
	11.2	1.34	2.57	2.80	3.14	2.79
30	12.8	1.52	2.66	2.75	3.52	2.96
	14.8	1.48	4.25	3.51	5.89	8.09
	11.2	1.87	2.73	3.64	6.60	7.64
40	12.8	1.48	2.58	8.37	9.85	14.54
	14.8	1.30	4.47	11.77	13.88	14.76

Source: ALENCAR (2006)

Table 8. Average values of the peroxide index of crude oil extracted from soybeans stored at 20, 30 and 40 ºC and moisture contents of 11.2, 12.8 and 14.8% (w.b.) during storage.

presence of carotenoids and chlorophyll. However, some crude oils may present a relatively high pigmentation due to damage of the raw material in the field, storage or processing failures; alterations in color indicate qualitative deterioration of the oil.

Alterations in color of the crude oil obtained from soybeans stored under different conditions were evaluated by ALENCAR et al. (2010). In this study different combinations of water content (11.2, 12.8 and 14.8%) and temperature (20, 30 and 40 ºC) were obtained for the grains stored for 180 days, and the qualitative photometric index of the oil was analyzed. The authors observed a significant increase in the photometric color index for all combinations of water content and temperature, as for the temperature of 30 °C (Fig. 7 and Table 9). WILSON et al. (1995) associated an increase in the photometric color index to the percentage of grains damaged by fungi. It is emphasized that the degumming of crude oil extracted from seriously damaged grains is hampered and the refined oil is darker than that obtained from healthy kernels, as well as greater losses in refining (LIST et al., 1977).



Source: ALENCAR et al. (2010)

Fig. 7. Regression curve of the photometric color index of crude oil extracted from soybeans stored with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at the temperature of 30 ºC.

Temperature (ºC)	Moisture content (%)	**Regression equation adjusted**	R^2
30	11.2	$\hat{y} = 1.41 + 0.0138X$	0.46
	12.8	$\hat{y} = 1.46 - 0.0067X + 0.00024X^2$	0.74
	14.8	$\hat{y} = 2.40 - 0.0007X + 0.00033X^2$	0.85

Source: ALENCAR et al. (2010)

Table 9. Regression equations adjusted for the photometric color index of the oil extracted from the soybeans with moisture contents of 11.2, 12.8 and 14.8% (w.b.) at the temperature of 30 ºC during the storage period (X), and respective coefficients of determination.

2.5 Effects of different storage conditions on the quality of other sub-products derived from soybeans

The quality of soybeans can also influence the qualitative parameters of other sub-products, including soymilk and tofu. SAIO et al. (1980) evaluated qualitative parameters of soymilk and tofu made from soybeans stored with a moisture content of 10.61%, and different combinations of temperature (15, 25 and 35 ºC) and relative humidity (60 and 90%) during 180 days. The authors verified, resulting from the storage conditions adopted, significant changes in color and pH of the soymilk and hardness of tofu. The physicochemical quality of tofu, obtained from soybeans stored at temperatures of 3-4, 20 and 30 ºC and relative humidities of 86.0, 57.0 and 84.0%, respectively, was assessed by HOU & CHANG (2004). For grains stored at 30 ºC and relative humidity of 84.0%, the authors observed a reduction in yield (512g/100g of grains at time zero to 71g/100 g of grains after 7 months of storage) and alterations in texture with increasing hardness and color (Table 10). ACHOURI et al. (2008) evaluated the quality of the soymilk obtained from soybeans stored for 10 months at 18 ºC and 50% relative humidity. Under these storage conditions the authors observed no significant change in the water uptake factor and pH of the soymilk, but there was significant variation in color and total volatiles. KONG et al. (2008) evaluated the physicochemical quality of soymilk and tofu made from soybeans stored with moisture contents between 6 and 14% in different combinations of temperature (40 to 50 °C) and humidity (55 to 80%). For the soymilk a decrease in pH and protein content was verified, this tendency being more accentuated as temperature and relative humidity increased. Reduction in the pH of the soymilk was observed for the soybeans stored under temperatures between 22 and 50 ºC and relative humidity between 55.0 and 80.0%. It is highlighted that the protein content of the soymilk reduced by 24.0% in grains stored for 10 months at 40 ºC. With regards to tofu, KONG et al. (2008) observed a significant reduction in yield for grains stored at 30 and 40 °C, as well as alterations in texture and color of the product. Also according to these authors, there is a strong relationship between the color of the grains and tofu, with respect to the Hunter (L, a and b) coordinates, as shown in Table 11.

3. Conclusion

The combination of high grain moisture and temperature during soybean storage accelerates the deterioration process of the sub-products of soybean. Proposed preventive measures of post-harvest handling to reduce risks of quality loss in soybean grains and sub-products are: store soybean grains with moisture content up to 15% (w.b.) at 20 ºC without

Period (month)	Hunter L value	**Hunter a value**	Hunter b value
0	87.13±0.37[a]	-0.50±0.17[e]	13.57±0.26[b]
1	87.30±0.05[a]	-0.31±0.03[e]	13.57±0.09[b]
2	85.20±0.18[b]	0.50±0.25[d]	13.36±0.09[b]
3	85.13±0.12[b]	0.71±0.10[d]	13.95±0.13[b]
4	84.09±0.41[c]	1.06±0.17[c]	13.11±0.23[b]
5	83.60±0.41[d]	1.04±0.04c	12.63±0.25[c]
6	82.30±0.22[e]	1.71±0.06[b]	12.97±0.23[bc]
7	70.14±0.49[f]	4.56±0.12[a]	15.90±0.04[a]

Values followed by the same letter in the column do not differ statistically at 5% probability
Source: HOU & CHANG (2004)

Table 10. Tofu color obtained from soybeans stored at 30 ºC and 84% relative humidity.

Coordinate	**Adjusted equations**	**R^2**
L	$\hat{y} = 19.275 + 1.1084X$	0.623
a	$\hat{y} = 9.0894 + 1.3217X$	0.546
b	$\hat{y} = 9.929 + 0.4453X$	0.125

Source: KONG et al. (2008)

Table 11. Regression equations which relate the Hunter L, a and b coordinates of tofu (y) and soybean grains (X).

risk of deterioration up to 180 days; in regions with temperatures around 30 ºC, store soybean with moisture content up to 13% (w.b.); do not store soybean with moisture content above 11% (w.b.) in regions where the grain mass temperature can reach 40 ºC with the risk of accelerating deterioration of grains and sub-products.

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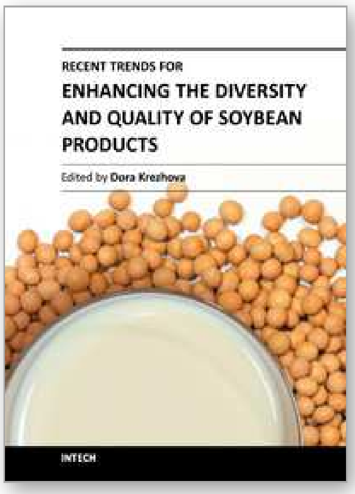

Recent Trends for Enhancing the Diversity and Quality of Soybean Products
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This book presents new aspects and technologies for the applicability of soybean and soybean products in industry (human food, livestock feed, oil and biodiesel production, textile, medicine) as well as for future uses of some soybean sub-products. The contributions are organized in two sections considering soybean in aspects of food, nutrition and health and modern processing technologies. Each of the sections covers a wide range of topics. The authors are from many countries all over the world and this clearly shows that the soybean research and applications are of global significance.