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EFFECTS OF DRYING AIR TEMPERATURE AND GRAIN INITIAL MOISTURE CONTENT ON SOYBEAN QUALITY (*GLYCINE MAX* (L.) MERRILL)

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ABSTRACT: This study aimed to evaluate the effect of air-drying temperature and initial moisture content on volume shrinkage, physical quality and oil extraction yield of soybean grains. The grains used in this experiment were harvested at two distinct moisture levels of 19 and 25%. Then, these grains were taken to dryness at three different air temperatures of 75 °C, 90 °C and 105 °C, in a forced circulation convection oven of the air. The results showed a drying time reduction with increasing air temperatures. Regarding volume shrinkage, moisture content reductions influenced grain volume and the Rahman's model was the one that best fit the data. Moreover, the higher the air temperature, the greater the effects on soybean grain shrinkage and physical quality. By grain volume reduction effected on oil yield, major impacts were observed when assessing grain initial moisture content were higher. Furthermore, the temperature of 105°C and an initial moisture content of 25% were the factors that most affected soybean grain quality, however not affecting oil extraction yield.

KEY WORDS: extraction, performance, processing.

INTRODUCTION

Brazilian agriculture has a high yield potential that increases each year. In 2012/ 2013, there was a record of 53.27 million hectares being grown. One of the crops that has most contributed to such growing trend is soybean (*Glycine max* (L.) Merrill). The average yield of this crop have increased due to technology breakthroughs and increased acreage. Some areas of the Brazilian Cerrado which have been used for cattle rearing are being converted into soybean fields (CONAB, 2013). Furthermore, soybean yields in 2013/ 2014 season reached 3,056 kg ha^{-1}, being 356 kg ha^{-1} higher than the previous season (2,700 kg ha^{-1}) (CONAB, 2013).

Mostly, soybean grains are harvested at high moisture levels, from 16% to 25%, which becomes inappropriate for storage since such levels make grains most susceptible to infections by fungi or other microorganisms, thereby reducing their quality. For storing and selling, moisture content of soybeans must not exceed 14%, or even 12%, because it would improve storage quality. Therefore, drying process is extremely important; however, it may damage grains for changing their physical properties or even causing direct damage thereto (RESENDE et al., 2010; NIAMNUY et al., 2011; SOUSA et al., 2011; CORADI et al. 2014a). Even though the mechanical drying of soybeans can anticipate harvest, the high air temperatures involved in such process may cause biochemical changes in the product, affecting its quality.

The drying process accelerates the loss of water in grains but may be damaging to the cell structure thereof, leading to a change in shape and decrease in size of the tissue (CORRÊA et al., 2010; GONELI et al., 2011; NIAMNUY et al., 2012; CORADI et al., 2014b). For GONELI et al. (2011), grain volume shrinkage derives from a decrease in tension within the cells as water is removed whilst the drying process continues. On the other side, size reductions of plant products by drying process are not only related to loss of water, the process conditions also have great influence on product size and format (CORRÊA et al., 2010; ULLMANN, et al., 2010; GONELI et al., 2011;

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HEMIS et al., 2012). SIQUEIRA et al. (2011) found smaller geometric mean diameters for seeds with reducing moisture contents, regardless of the drying conditions.

Soybean is an oilseed crop of great importance for agro-industrial, animal feeding and cosmetics companies. Regarding this parameter, air-drying temperatures are extremely important because oil physicochemical properties may undergo significant alterations such as rancidity of fats and pigmental changes as for carotenoids (SANJINEZ-ARGANDONA et al., 2011; CORADI et al., 2014b).

Thus, the objective of this study was to evaluate the effects of drying temperatures and initial moisture content on volume shrinkage, physical quality and oil yield of soybean grains.

MATERIAL AND METHODS

This study was carried out at the Laboratory of Grain Postharvest of the Federal University of Mato Grosso do Sul, in Chapadão do Sul – MS, Brazil. The soybean grains were purchased from private companies located in the cities of Chapadão do Sul (MS) and Chapadão do Céu (GO), both in Brazil, which were harvested at different initial moisture content (19% and 25%).

Samples of these grains were placed into plastic bags and stored in B.O.D. chambers set at 10 °C. Then, these samples were divided into six 25-g sub-samples, which were put into aluminum capsules placed to dry in a forced circulation convection oven at varied temperatures (75 °C, 90 °C and 105 °C).

Every thirty minutes, samples were weighed until reaching moisture balance. During drying process, temperature and relative humidity were monitored by means of a psychrometer. Grain moisture content (%) was determined by mass difference at the beginning and end of the drying process, by weighing 15-g samples. After that, these samples were placed in an oven with air heating and ventilation regulated at 105 °C ± 1°C for 24h (BRASIL, 2009); hereupon, the samples were removed and placed into desiccators for cooling. All tests were performed in three replicates.

During the drying process, the unitary volume shrinkage (Ψ_g) was estimated as being the ratio between final and initial grain volumes (V_g) using a caliper, as proposed by MOSHENIN (1986):

$$V_g = \frac{\pi.a.b.c}{6} \qquad (1)$$

where,

a: major axis of the grain, mm;

b: mean axis of the seed, mm,

c: minor axis of the seed, mm.

The experimental unit shrinkage, expressed by the following mathematical models have been adjusted:

Model reference	Model	
Bala and Woods	$\Psi_g = a.\{1-\exp[b.(U-U_0)]\}$	(2)
Lang and Sokhansanj	$\Psi_g = a+\text{ß}_1.(U-U_0)$	(3)
Rahman	$\Psi_g = a+\text{ß}_2.(U-U_0)$	(4)
CORRÊA et al. (2010)	$\Psi_g = 1/[a+b.\exp(U)]$	(5)
Line	$\Psi_g = a+b.U$	(6)
Exponential	$\Psi_g = a.\exp(b.U)$	(7)

where,

Ψ_g : unit volume shrinkage, decimal;

U : water content of the product, dry base;

U_o : initial water content of the product, dry base;

$ß_1 = a + b(UR) + c(T)$

a, b, c: parameters that depend on the product;

UR : relative humidity (decimal);

T : air temperature (ºC),

$ß_2$: volumetric coefficient, dimensionless contraction.

The samples also underwent electrical conductivity (EC) testing as described by VIEIRA & KRZYZANOWSKI (1999) and oil yield (OY) assessment according to the methodology described by OLIVIERA (2008).

The experiment was arranged in a completely randomized design (CRD) in a two-factor scheme with three drying air temperatures (75°C, 90°C and 105°C) and two initial grain moisture contents (19% and 25%). The OY and EC data underwent variance analysis with means compared by the Tukey's test at 1% and 5% probability.

The mathematical models for Ψ_g were fit by nonlinear regression, using the quasi-Newton method, obtained through Statistica 7.0®. The goodness of each model was evaluated by considering the following parameters: regression coefficient significance at 5% probability, by the t-test; coefficient of determinations (R^2); relative mean errors (P); standard errors (SE); and residue distribution (RD). The P and SE for each model were calculated according to the following expressions:

$$P = \frac{100}{n} \sum \frac{\left|Y - \hat{Y}\right|}{Y} \tag{8}$$

$$SE = \sqrt{\frac{\sum \left(Y - \hat{Y}\right)^2}{GLR}} \tag{9}$$

where,

Y: experimentally observed value;

$\hat{Y}$: value calculated by the model;

n: number of experimental observations,

GLR: degrees of freedom of the model (the number of observations minus the number of model parameters).

RESULTS AND DISCUSSION

The drying process aimed at removing water content from soybeans by simultaneous heat transfer and airflow from water vapor to grains (GONELI et al. 2011; CORADI et al. 2016). Figures 1A and 1B show the drying curves for soybean grains at different air temperatures and with distinct initial moisture contents. For grains dried at 75 ºC, moisture reductions from 0.19 to 0.11 (decimal, db) lasted 2.33 hours, and losses between 0.25 and 0.11 (decimal, db), after 3.7 hours. It is noteworthy mention that increasing air temperatures shortened drying time, showing higher water removal rates. This outcome arouse from an increased energetic availability for water vaporization as well as a growing mass transfer coefficient by rising the drying air temperature.

Figure 1A shows that the drying rates at 105 °C were higher than those observed at 75 °C and at 90 °C were. Nonetheless, throughout the drying process and up to reaching moisture equilibrium, the drying curves became similar, differing only as to time. After 1 hour, grains under 105 °C reached a 12% (wb) moisture content, while those under 75 and 90 °C were still at 17.5 and 16.5% (wb), respectively.

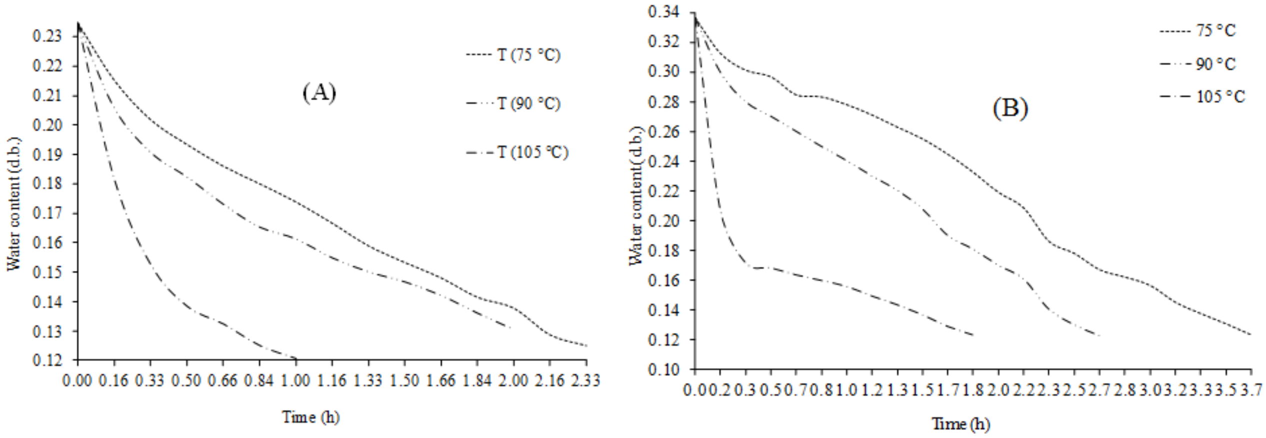

FIGURE 1. Curves of drying of soybeans with initial moisture content of 19% (w.b.) (A), and 25% (w.b.) (B).

Additionally, Figure 1B reveals increased drying rates at 105 °C within the first 0.3 hours compared to those achieved at 75 and at 90 °C. Meanwhile, as the process continues towards equilibrium, the drying curves of grains submitted to 75 and 90°C surpassed those of 105 °C, suggesting a possible change in mechanisms for inner water movement. After 0.3 h, grains at 105 ° C reached a 17% moisture level (wb) for both initial moisture contents, whilst those subjected to 75 and 90 °C were still at 31 and 28% (wb), respectively. From this point on, grains of damper treatment, i.e. soybeans dried at 75 °C, certainly have a greater amount of free water to provide largest drying rates whether compared to those dried at the highest temperature.

Data analysis in Table 1 indicates that Rahman and Correa’s models were the best to represent grain shrinkage, showing less marked trend of residue distribution (random distribution). It was also noted that these models provided the highest coefficient of determination, besides of the lowest estimates and relative errors (Tables 1 and 2). Thus, only these two models may be recommended to predict shrinkage in soybean grains. Conversely, CORRÊA et al. (2010) pointed out Bala and Woods's model as the only one able to predict successfully data regarding grain Ψ_g. Beforehand, RIBEIRO et al. (2005) had recommended a linear model to best represent such variable. Lastly, we chose the Rahman model, because in addition to have been adapted better to the experimental data, it is the simplest one.

TABLE 1. Estimated parameters, coefficient of determination (R^2), standard error (SE), relative error (P) and residue distribution of the mathematical models used to describe shrinkage at different drying air temperatures of soybean grains with an initial moisture content of 19% (wb).

Mathematical models	Estimation of parameters	R^2	SE (decimal)	P (%)	Distribution of residuals
	Temperature 75ºC				
$\Psi_g = a.\{1-exp[b.(U-U_0)]\}$	a= 0.96144 b= -18.32210	5.71	0.035730	1.195070	A
$\Psi_g = a+b.U$	a= 2.14567	8.21	0.046570	2.345619	A
$\Psi_g = a+ß_1.(U-U_0)$	b= 1.34560 a= 0.23450	1.23	0.398233	1.923451	A
$\Psi_g = a+ß_2.(U-U_0)$	a= 0.68100 b= 1.40000	5.85	0.021048	1.100000	A
$\Psi_g = 1/[a+b.exp(U)]$	a= 2.97552 b= -1.59233	7.67	0.026304	1.042430	A
$\Psi_g = a+b.U$	a= 0.69567 b= 1.60571	6.55	0.027392	2.021655	A
	Temperature 90ºC				
$\Psi_g = a.\{1-exp.[b.(U-U_0)]\}$	a= 1.022420 b= -15.5389	4.91	0.014525	1.004364	A
$\Psi_g = a+b.U$	a= 2.13289 b= 1.22181	7.98	0.015672	2.451567	A
$\Psi_g = a+ß_1.(U-U_0)$	a= 0.24123	2.34	0.148912	2.012348	A
$\Psi_g = a+ß_2.(U-U_0)$	a= 0.642703 b= 1.792793	9.40	0.014382	1.000000	A
$\Psi_g = 1/[a+b.exp(U)]$	a= 3.309627 b= -1.89993	7.61	0.014241	1.003675	A
$\Psi_g = a+b.U$	a= 0.675218 b= 1.988907	7.51	0.014525	2.004364	A
	Temperature 105ºC				
$\Psi_g = a.\{1-exp[b.(U-U_0)]\}$	a= 1.055487 b= -13.4491	4.46	0.0249491	1.3962264	A
$\Psi_g = a+b.U$	a= 2.21572 b= 1.41018	0.23	0.0317891	1.4527809	A
$\Psi_g = a+ß_1.(U-U_0)$	a= 0.31017	0.45	0.0261234	1.2345167	A
$\Psi_g = a+ß_2.(U-U_0)$	a= 0.586533 b= 2.12000	9.56	0.0128582	1.1006289	A
$\Psi_g = 1/[a+b.exp(U)]$	a= 3.769244 b= -2.28705	9.13	0.0051166	1.1773585	A
$\Psi_g = a+b.U$	a= 0.631492 b= 2.380158	8.87	0.0113594	2.0207547	A

Figure 2 displays the values of unitary volume shrinkage (Ψ_g) adjusted by the Rahman model. Moisture reductions from 0.19 to 0.11 (db) led to a mass reduction of 23.20% in grains (Figure 2A), and from 0.25 to 0.11 (db) caused a shrinkage of 21.1% (Figure 2B).

Likewise, temperature variation has exerted influence on Ψ_g, and the highest one acted most intensely on reducing the size of soybeans, as highlighted by OLIVEIRA et al. (2013). Similarly, CORADI et al. (2014b) reported a decrease of 39% in volume of coffee berries, by reducing moisture content from 2.27 to 0.11% (db).

TABLE 2. Parameters estimated, coefficient of determination (R^2), estimated average (SE) and relative error (P) and distribution of residues of the mathematical models used to describe the shrinkage of soybeans grains to different drying air temperatures and an initial moisture content of the grains of 25% (w.b.).

Mathematical models	Estimation of parameters	R^2	SE (decimal)	P (%)	Distribution of residuals
	Temperature 75ºC				
Ψ_g = a.{1-exp[b.(U-U_0)]}	a= 0.94693 b= -17.9467	72.21	0.039817	2.275428	A
Ψ_g = a+b.U	a= 2.31625 b= 1.17238	82.12	0.035181	2.136110	A
Ψ_g = a+ß$_1$.(U-U_0)	a= 0.27142	93.22	0.218143	2.125810	A
Ψ_g = a+ß$_2$.(U-U_0)	a= 0.70713 b= 1.05963	90.60	0.024360	1.000093	A
Ψ_g = 1/[a+b.exp(U)]	a= 2.51031 b= -1.16293	92.99	0.021167	1.044430	A
Ψ_g = a+b.U	a= 0.72095 b= 1.21226	91.49	0.023226	2.025056	A
	Temperature 90ºC				
Ψ_g = a.{1-exp.[b.(U-U_0)]}	a= 0.99175 b= -16.9372	98.07	0.011486	1.238779	A
Ψ_g = a+b.U	a= 2.37193 b= 1.21561	81.48	0.012131	2.617105	A
Ψ_g = a+ß$_1$.(U-U_0)	a= 0.27138	92.61	0.167125	2.316241	A
Ψ_g = a+ß$_2$.(U-U_0)	a= 0.72227 b= 1.14054	98.50	0.010429	1.013273	A
Ψ_g = 1/[a+b.exp(U)]	a= 2.41417 b= -1.11077	97.37	0.013501	1.036152	A
Ψ_g = a+b.U	a= 0.74136 b= 1.23357	98.15	0.011486	1.238779	A
	Temperature 105ºC				
Ψ_g = a.{1-exp[b.(U-U_0)]}	a= 1.01154 b=-15.0265	97.92	0.0148753	2.2386286	A
Ψ_g = a+b.U	a= 2.45714 b= 1.36817	82.50	0.0426990	1.5274710	A
Ψ_g = a+ß$_1$.(U-U_0)	a= 0.33148	94.12	0.0342321	1.1046112	A
Ψ_g = a+ß$_2$.(U-U_0)	a= 0.69141 b= 1.29368	97.71	0.0141216	3.3904000	A
Ψ_g = 1/[a+b.exp(U)]	a= 2.56782 b= -1.23388	95.87	0.0194607	1.7385143	A
Ψ_g = a+b.U	a= 0.71758 b= 1.38971	97.09	0.0160931	3.5440000	A

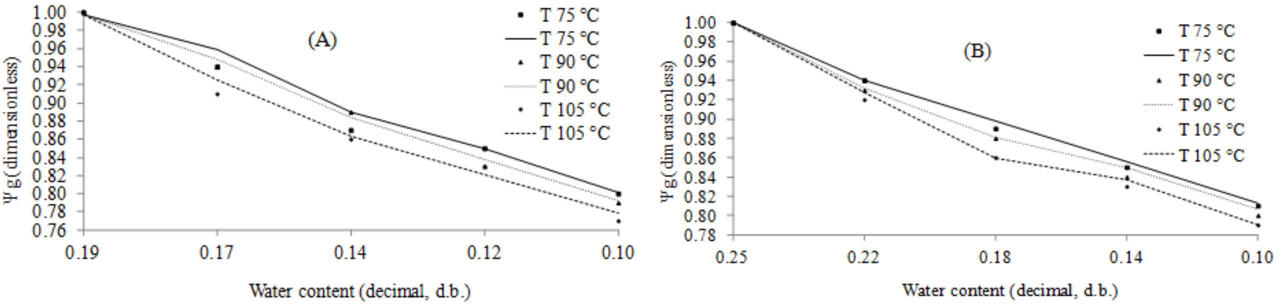

FIGURE 2. Volumetric shrinkage of soybeans during drying at different air temperatures and initial moisture content of 19% (w.b.) (A) and 25% (w.b.) (B) with the model of Rahman.

Table 3 shows the results of EC variance analysis ($p > 0.01$) for the different drying temperatures and initial water levels. These results underscore that the EC variation accompanied the increase in temperature. Such outcome might be due to higher releases of exudates derived from disruption of system cell membranes.

TABLE 3. Analysis of variance to test electrical conductivity (µS cm^{-1} g^{-1}) in soybeans after drying.

FV	DF	SS	AS	FC	PR>FC
Temperature	2	13589.55	6794.77	6.531	0.0044*
Moisture	1	10523.68	10523.68	10.11	0.0034*
Temperature x moisture	2	24123.01	12061.50	11.59	0.0002*
Error	30	31209.66	1040.32		
Total corrected	35	79445.91			

CV (%) = 7.26 General Average: 444.07 *Significant the 1% of probability

As already observed by other authors like CORADI et al. (2014a), EC values (Table 4) increased with worsening of the drying process quality. Therefore, this trait proved to be an efficient parameter in separating soybean samples regarding better and worse physical quality. Perhaps, a higher leaching of potassium with consequent increase in EC might be considered a strong indicator of cell membrane damages.

TABLE 4. Electrical conductivity test (µS cm^{-1}g^{-1}) in soybeans grains with different drying temperatures and initial water content.

Temperature of air drying (^{0}C)	Initial water content (19% w.b.)	Initial water content (25% w.b.)
75	396.17 a A	409.3 b B
90	412.94 a A	423.30 a A
105	471.79 b A	457.96 a b A

Means followed by the lower case letter in the column, for each temperature of the drying air, upper lines for each water content was not significantly different at 1% probability.

The high temperature pre-processing of soybeans have been linked to membrane selectivity; thus, cell ruptures might have promoted extravasations of cellular contents (enzymes, proteins, amino acids, carbohydrates, lipids, ions, etc.), causing a chain of random undesirable reactions. According to CORADI et al. (2014a), once cell disruption is observed, those reactions become irreversible, resulting in a product of poorer quality at the end of the process.

On the other hand, EC testing may lead to different results depending on the grain to which it is applied. For instance, ROSA et al. (2000) evaluated the effectiveness of EC testing on studies of corn grain drying; they noted that air temperatures below 50 °C promoted immediate and severe damages to corn kernels. Differently, RIBEIRO et al. (2003) observed that coffee beans dried at 50 °C had higher values of EC (85.08 µS cm^{-1} g^{-1}), corresponding to greater reductions in moisture content thereof. Similar results were found here when higher EC values were observed for grains dried at higher temperatures.

Table 5 indicates the results of oil content in soybeans for all treatments, which proved to be not significant ($p > 0.05$ and $p > 0.01$). Therefore, through the Tables 6 and 7, it is possible to notice no difference in yield of oil extracted from soybeans at the different temperatures, irrespective of the initial moisture content thereof. Similarly to our results, OLIVEIRA et al. (2013), testing four air temperatures for soybean grain drying (room temperature, 40, 60, 80 and 100°C), reported no difference in OY for values above 40 °C; however, the authors highlighted that this value was more visible for seeds stored for at least eight months. The same was verified by ZENI (2010), who evaluated variable temperatures to dry soybeans (20-25, 35-40, 55-60 and 75-80°C); they found no statistically significant difference in an immediate effect on the OY parameter. In addition, POHNDORF (2012) assessed grains at different initial moisture level (12 and 16% wb) and dried various temperatures (8, 13, 18, 23, 28°C), and found no significant differences among these treatments. Thus, the results obtained here corroborate the above-mentioned ones, showing no immediate effect of the drying methods on soybean OY.

TABLE 5. Analysis of variance of oil yield (%) of soybeans grains after drying.

FV	DF	SS	AS	C	PR>C
Temperature	2	24.78	8.26	0.49	0.2320^{NS}
Moisture	1	4.32	2.16	0.39	0.2785^{NS}
Temperature x moisture	2	4.01	4.01	0.72	0.3993^{NS}
Error	30	193.01	5.51		
Total corrected	35	226.15			

CV (%) = 14.67 General Average: 16.00 ^{NS}Not significant the 1 e 5% of probability

TABLE 6. Oil yield (%) in soybeans grains after drying at different temperatures.

Temperature of air drying (^{0}C)	Average
75	15.37 a
90	15.59 a
105	17.20 a

Means followed by the lower case letter in the column, for each temperature of the drying air was not significantly different at 1% probability.

TABLE 7. Oil yield (%) in soybeans grains with different initial water contents after drying.

Initial water content (% w.b.)	Average
19	15.73 a
25	16.37 a

Means followed by the lower case letter in the column, for each temperature of the drying air was not significantly different at 1% probability.

Figure 3 displays the comparative results among Ψ_g, OY and EC of soybean grains for each treatment. The rate of free fatty acids, as well as the oil content and its quality are the most important factors in purchasing of soybeans for human food and biodiesel industries. Figure 3A emphasizes that the largest OY values were obtained at higher drying air temperatures, given the reduced grain volumes. When the moisture contents were reduced from 25 to 10% (wb) (Figure 3A), grain volumes shrank by 20, 21 and 23% for grains dried at 75, 90 and 105 °C, respectively, whereas the content of oil ranged by 15.68, 17.97 and 16.27%, respectively.

By comparing the Ψ_g and OY results, one can observed that 3% volume shrinking provided 2.29% OY increase. Conversely, Figure 3A stresses that grain cell structures were compromised with increasing drying temperatures, achieving the largest amount of leached ions at 105 °C. On the other hand, even though these cell damages promoted risings in EC values, they did not affect OY.

Similar results are shown in Figure 3B for all variables in grains with initial moisture content of 19%, dried at all air temperatures up to 10% (wb). However, it can be underlined a slight difference in OY, aside from lower physical damages to cell structure, which ranged with initial moisture content of the grain mass, taking them less time to be dried up to a 10% level (wb). It is suggested that soybeans intended for industrial oil extraction can be collected at higher moisture levels, prior to drying treatments, increasing thus oil extraction, preferably, whether drying is carried at temperatures above 90 ºC.

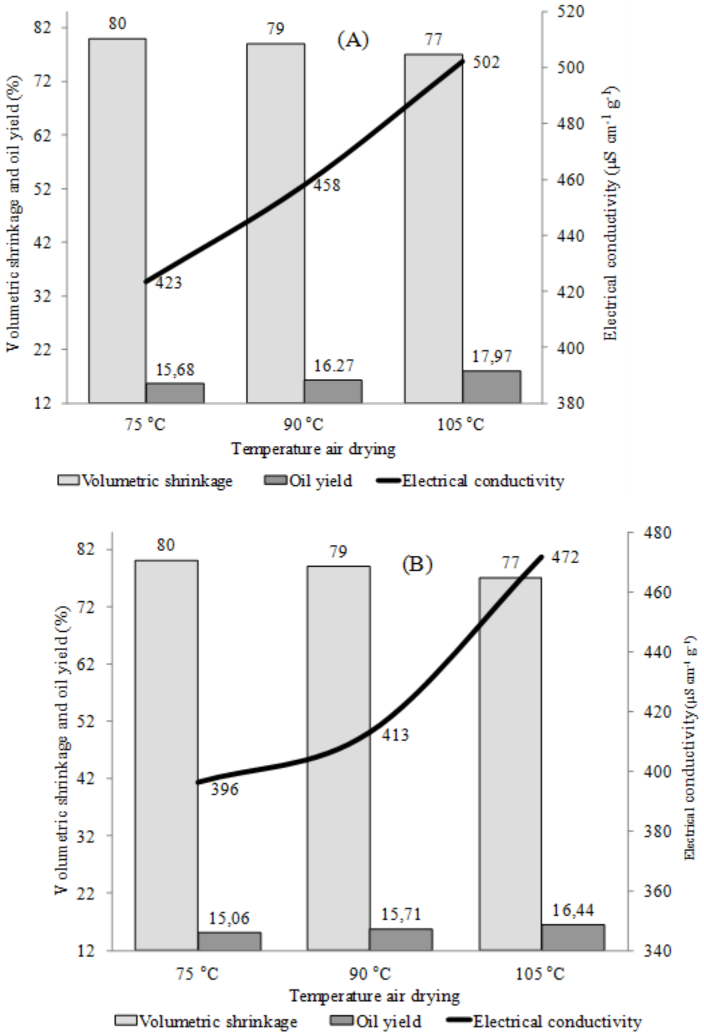

FIGURE 3. Comparison of the effects of air temperature on drying shrinkage, oil yield and electrical conductivity in soybeans with initial water content of 25% (A) and 19% (B).

Conversely, when evaluating drying effects on shrinkage and ion leaching, by means of EC testing, Figure 3 names reductions in grain volume inversely proportional to rises in EC values as drying temperatures increase. These results confirm those obtained by BARBOSA et al. (2012), who claimed that EC gains were influenced by decreasing sizes of soybean grains. Analyzing the aspect of using this plant material for seeds, the results obtained in this work are not favorable. Therefore, elevated values of EC turn up to be a sign of seed physical damage, possibly affecting germination when sown in the field.

CONCLUSIONS

- Reduced initial moisture content and high temperatures of the drying air influenced soybean grain volume.
- Reduced grain volumes influenced the yield of soybean oil.
- Drying air temperature of 105°C and initial moisture level of grains at 25% had an influence on grain quality, however, not affecting yield of extracted oil.

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