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Immediate and latent effects of drying soybeans with dehydrated air

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ABSTRACT. New grain drying techniques have been improved to reduce post-harvest losses. The electric air dehumidifier (UTA 60®) is an example; it was installed at the ELLITT Seed Company for drying soybean seeds (TEC 7849) with random sample collection (DIC). Our objective was to evaluate the immediate and latent effects of the dehumidified air on the vigour of the seeds. Our vigour analysis method was based on the Rules for Seed Analysis (RAS), and our results showed an immediate significant difference in seedling percentage, but the germination level did not have an effect at 5% (Dunnett's test). In latent effects, at 5% (Tukey test), there was a reduction in the germination percentage and emergence rate, but it was not possible link such variations to the drying process. The germination potential was classified as "highest vigour", and it was possible to conclude that dehydrating drying air with UTA constituted a method capable of maintaining seed quality and germinative vigour.

Keywords: air dehumidification; air handling unit; electricity; germinative vigour; *Glycine max*.

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Introduction

The world population grows daily, currently standing at 7 billion. Wang et al. (2017) estimates 9.6 billion people by 2050. This scenario assumes a growing demand for food. In this context, the 2016/2017 world harvest was estimated at 348.04 billion kg of grain (USDA, 2016), of which 102.00 billion kg were Brazilian-produced. This production is expected to double by 2050 (Foley et al., 2011; Tilman, Balzer, Hill & Befort, 2011) to meet population growth (Wang et al., 2017).

To increase demand, new studies should be directed at increasing productivity and reducing agricultural losses, as well as logistical planning of planting and adequate supply of the raw material - be it seeds, fertilizers or insecticides. Drastig, Palhares, Karbach and Prochnow (2016) and Cunha and Spíndola (2015) argue that there will be increased demand for seeds in a proportion similar to the increase in grain demand boosted by population growth.

Therefore, it is necessary that all stages of the soybean production process occur as efficiently as possible. One step that exerts a great influence on the germinative vigour of seeds is the drying and storage process (Ferreira, Araujo, Tabosa & Lima, 2016).

In grain production, the sowing operation represents one of the crucial points for the success of the crop (Ferreira, Dias, Oliveira, Alonço & Baumhardt, 2010 and Melo, Dias, Oliveira, Alonço & Baumhardt, 2013), since it is done only once per crop, concentrating most of the investments. Seed costs correspond to 12% of the plantation (Oliveira, Lazarini, Tarsitano, Pinto & Sá, 2015). Among the factors related to sowing, the germinative vigour of the seeds is highlighted by Scheeren, Peske, Schuch and Barros (2010).

The germinative vigour of soybean seeds is maximum at the end of the mature stage, while seeds are still in the plant, with humidity of approximately 1.00 (decimal b.s.). From this stage, the seeds begin their natural drying process, aiming to reduce metabolic reactions to avoid germination in the plant itself.

Seed dryers receive the seeds from the field (0.25) and dehydrate at the nearest 0.14, seeking their hibernation to maintain the physiological quality through the storage period (Smaniotto, Resende, Marçal, Oliveira & Simon, 2014).

The most common form of seed drying is the desorption of water by the passage of air with high vapor pressure and, for this to occur properly to the harvest flow, the air is heated with firewood, wood chips, liquefied petroleum gas (LPG) or electricity (Campos et al., 2016).

Electricity can be used for air heating, but it is more efficient to reduce the rate of mixing of air by dewatering before heating, which increases its enthalpy and the difference in vapor pressure between drying air and seed mass.

This work aimed to analyse the technical viability of drying soybean seeds with dehydrated air in an electric air treatment unit, evaluating the immediate and latent germinative quality of these seeds.

Material and methods

In this experiment, three lots from the 2014-15 and 2015-16 crops were observed with 20,000 ± 1,000 kg of *Glycine max* (soybean) of the cultivar TEC 7849 IPRO. The lots were named in this study as A-1, A-2, and A-3. They were received and dried at the Seed Processing Unit (UBS) of the company Elitt Seeds, in Cruzália, São Paulo State, Brazil.

The seeds were processed immediately after harvesting with pre-cleaning using the fraction retained between the 4 x 10^{-3} and 8 x 10^{-3} m circular sieves; then the seeds were transported to the cross-flow dryer with static capacity of 20 x 10^{3} kg, and the drying process was started.

From each lot, seven samples were obtained in triplicate. The first one was collected on the conveyor belt carrying the seeds from the cleaning machine to the dryer, just before drying (here named AS). The second was made shortly after reaching the desired humidity (0.14), collected on the conveyor belt that transported the seeds from the dryer to the bagger, called DS in this study. The other five samples were randomly collected from the pile of seeds bagged and deposited in the company shed, made in the range of 30, 60, 90, 120, and 150 days after drying. In this work, they are referred to as D30, D60, D90, D120, and D150, respectively.

In this way, the samples were characterized as follows: A-1-AS as the sample of lot 1 analysed immediately before drying, A-1-DS as the sample from lot 1 analysed immediately after drying, A-1-D30 as the sample from lot 1 analysed 30 days after drying and so on, up to A-3-D150 as the sample from lot 3 analysed 150 days after drying.

A control treatment from each lot was obtained with natural drying of 4 ± 0.5 kg of seeds (not submitted to the drying process in the dryer), deposited in a concrete base near the drying shed. The humidity of the control treatments was monitored every 2 h, and the seeds were collected with humidity of 0.14 ± 0.02. The mean of the control treatments was presented in this study as C.

Similar to the samples, the analyses made for the control treatment were characterized as: C-AS as the control sample analysed immediately before drying, and so on, up to C-150 as the control sample analysed 150 days after drying.

The vigour evaluation data of the seeds of the different lots and tests used in this study was submitted to analysis of variance, and the means were compared with the control treatment by the Dunnett test at 5% probability.

The means of the treatments were also compared by the Tukey test at 5% probability.

Air Treatment Units (UTA)

The air dehumidifier unit (model UTA 60) used in this study was developed by the Coolseed Company (Figure 1), installed in Santa Tereza do Oeste, Paraná State, Brazil.

Figure 1. Air dehumidifier unit used (Image: Coolseed, 2015).

This UTA has electrical power of 74 kW and is connected with line voltage of 380 Vca to a diesel generator. This UTA has a cooling capacity of 181,818 kcal h^{-1} and a ratio of 8.3 [kWh (t % bu)$^{-1}$] (Coolseed, 2015).

To promote air dehydration, the UTA has an evaporator unit composed of two independent refrigeration circuits, thermostatic expansion valves and ball valves with oil equalization, and two finned aluminium coils with an independent stage, thermostatic expansion valve and refrigeration circuits and copper pipe collectors (Coolseed, 2015).

Once dehumidified, the air passes through the condenser unit to be preheated. This unit has two independent refrigeration circuits with dryers and ball valves with oil equalization, as well as six compressors of the armoured type, alternating or rotary, 10 HP each with R-22 gas (Coolseed, 2015).

Figure 2 below shows the seed flow in the cross-flow dryer and the air used to dry the seeds, delimiting the UTA and illustrating its function in the drying process.

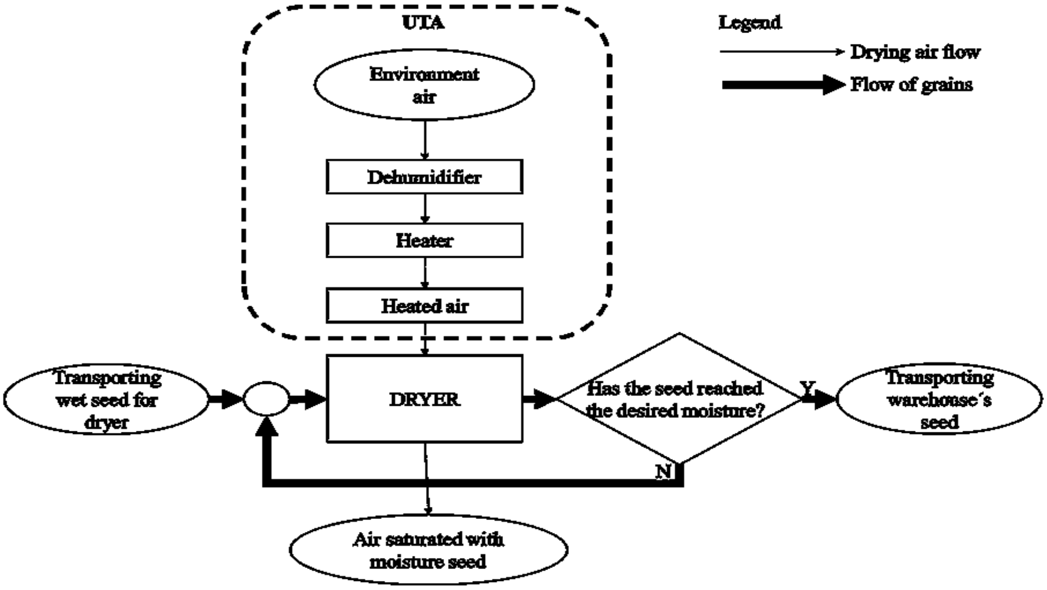

Figure 2. Seed drying scheme by dehumidifying and heating the air.

It follows from this scheme that the UTA has the function of dehumidifying and heating the air that will pass through the dryer. Additionally, this system is easily adaptable in existing plants and can be coupled to the air inlet pipe in the dryer.

Germination quality analysis

The analysis of the weight of one thousand seeds was performed using four replicates of 1000 seeds, randomly counted, for each treatment, weighed on a scale to an accuracy of 0.001 x 10^{-3} kg, with the results presented in grams.

The purity analysis was obtained from a homogenized working sample for each replicate in which the intact (or pure) seeds were quantified; cracked, shelled, wrinkled, stained, or inert materials and others not listed were avoided by counting 100 seeds in. All components were weighed on a precision scale accurate to 0.001 x 10^{-3} kg, and percentages were calculated to two decimal places, according to the Rules for Seed Analysis (RAS) proposed by Brasil (2009).

In the germination test, four replicates of 50 seeds of each treatment were used. They were seeded on Germitest® paper previously moistened with water in a proportion 2.5 times larger than the dry substrate mass (Figure 3).

Figure 3. Germitest® paper moistened with water in a ratio of 1:2.5.

These papers were placed in a germinator with a constant temperature of 25°C. Evaluations were performed on the seventh day, and the results were presented as percentage of normal seedlings.

In the emergence sand test, four replications of 50 seeds per treatment were seeded in plastic boxes, containing a substrate sand of medium texture, moistened and rinsed (when necessary) with water, as shown in Figure 4. The boxes were kept under laboratory conditions at room temperature for eight days, and then the seedlings were counted (Brasil, 2009).

(a) (b)

Figure 4. Emergence sand test (a) seed placement and (b) preparation of the carton.

To obtain the rate of emergency (IVE), the data of the emergence tests in sand were used, adding the number of emerged seedlings divided by the number of days elapsed from sowing.

Tetrazolium tests were also performed to classify germination potential. For the tetrazolium test, a 1.0% stock solution was prepared by mixing 10.0 x 10^{-3} kg of the tetrazolium salt in 1.0 L of distilled water. To obtain the 0.075% solution, 0.75 x 10^{-3} L of stock solution was used in 0.925 L of distilled water. From the samples, 100 seeds of each treatment were separated into two replicates of 50 seeds each.

These seeds were packed in moist germination paper, as shown in Figure 5, and then held under these conditions for 16h at 25°C.

Figure 5. Seeds were packed in moist germination paper.

After this period, the seeds were placed in plastic containers to be submerged in 0.075% tetrazolium solution. The seeds were then brought to the germinator at 35 to 40°C for a range of 2.5 to 3h. After the seeds were removed from the germinator, they were washed with water and then kept submerged in water until the moment of the evaluation (Brasil, 2009).

The seed germination potentials were classified at levels from 1 to 5, according to Table 1.

Table 1. Classification of seed germination potential.

Potential germinative	Rating
Highest vigour	1
High vigour	2
Medium vigour	3
Low vigour	4
Very low vigour	5

Font: Adapted by França Neto, Krzyzanowski and Costa (1998).

The moisture content in two subsamples of each replicate was determined using a UBS proprietary measuring device, and the difference between results did not exceed 0.5%, according to RAS.

Results and discussion

The dried seeds with dehydrated air presented significant variation compared to the control treatment for the variables percent of seeds and IVE. The data obtained during the drying process and during the 150 days of storage are shown in Table 2.

Table 2. Comparison of means of the treatments with the control for the variables: Weight of 1,000 seeds, percentage of seeds sequestered, percentage of germination, sand emergence and index emergence speed (IVE) of dried soybean seeds with dehydrated air.

		AS	DS	30 D	60 D	90 D	120 D	150 D
Weight of 1,000 seeds (g)	A-1	13.7 ns A	12.7 ns B	12.4 ns BC	12.4 ns BC	12.3 ns C	12.3 ns C	12.3 ns C
	A-2	13.7 ns A	12.6 ns B	12.5 ns BC	12.5 ns BC	12.4 ns BC	12.3 ns C	12.3 ns C
	A-3	13.8 ns A	12.8 ns B	12.6 ns B	12.5 ns B	12.4 ns B	12.4 ns B	12.4 ns B
	C	13.8 ns A	12.7 ns B	12.5 ns B	12.5 ns B	12.4 ns B	12.4 ns B	12.4 ns B
Seeds sequestered (%)	A-1	4 a B	6 b A	3 b B	6 b A	3 b B	4 a B	7 a A
	A-2	2 ab B	5 b A	4 b A	5 b A	5 ab A	6 a A	5 a A
	A-3	3 ab B	10 a A	8 a A	10 a A	6 a A	6 a A	7 a A
	C	1 b NS	1 c NS	1 c NS	1 c NS	0 c NS	1 b NS	0 c NS
Germination (%)	A-1	99.4 ns A	99.1 ns A	98.9 ns A	98.9 ns A	98.6 ns A	98.5 ns AB	98.1 ns B
	A-2	98.8 ns A	98.8 ns A	98.6 ns A	98.6 ns A	98.6 ns A	98.5 ns A	98.4 ns A
	A-3	99.2 ns A	98.8 ns A	98.8 ns A	98.7 ns A	98.3 ns AB	98.3 ns AB	98.2 ns B
	C	99.1 ns A	99.1 ns A	98.9 ns A	98.9 ns A	98.2 ns B	98 ns B	97.9 ns B
Sand emergence (%)	A-1	99.0 ns NS	98.7 ns NS	98.0 ns NS	98.0 ns NS	97.7 ns NS	97.7 ns NS	96.7 ns NS
	A-2	98.0 ns NS	98.0 ns NS	97.3 ns NS	96.7 ns NS	97.0 ns NS	96.7 ns NS	96.3 ns NS
	A-3	98.7 ns NS	98.3 ns NS	98.0 ns NS	97.7 ns NS	97.3 ns NS	97.0 ns NS	97.0 ns NS
	C	98.6 ns NS	98.0 ns NS	98.0 ns NS	98.0 ns NS	97.0 ns NS	97.0 ns NS	97.0 ns NS
IVE (adimens)	A-1	3.1 ns A	3.1 ns A	3 ns A	2.7 ns B	2.6 ns B	2.5 a B	2.4 ns C
	A-2	3.1 ns A	3.1 ns A	3.1 ns A	2.6 ns B	2.6 ns B	2.4 ab C	2.3 ns C
	A-3	3.2 ns A	3.1 ns A	3.1 ns A	2.7 ns B	2.6 ns B	2.4 ab C	2.4 ns C
	C	3.1 ns A	3.1 ns A	3.1 ns A	2.7 ns B	2.6 ns B	2.3 b C	2.3 ns C

Notes: AS: Data collection occurred just before drying; DS: Collection of data occurring immediately after drying; ns: Comparison of the mean of the treatment with the control variable showed no possibility of rejection of the null hypothesis (H_0), at the 5% significance level of Dunnett's test. Lowercase letters: Comparison of mean treatment with control variable (column) had null hypothesis (H_0) rejected at the 5% significance level of Dunnett's test. Upper case letters: Latent comparison between treatment averages as a function of storage time (line) had null hypothesis (H_0) rejected at the 5% significance level of the Tukey test.

There was an immediate, significant variation in the weight of 1,000 seeds caused by the removal of water during the drying process, while there was no significant variation between the dry mass of the seeds in the AS and DS samples.

The weight of 1,000 seeds underwent a significant latent change at the 5%significance level of the Tukey test in samples A-1 and A-2; such changes occurred from 90 days and 120 days, respectively. There was no latent weight loss for the control or for sample A-3.

Regarding the latent variation of the weight of 1,000 seeds, it is estimated to be related to seed water loss, since no correlation was identified between the weight loss of samples A-1 and A-2 with the percentage of germination, sand emergence or IVE. To evaluate the size and development of seedlings, Pádua, Zito, Arantes, and França Neto (2010), Pereira, Pereira, and Dias (2013) and Pereira, Pereira, and Dias (2015) pointed to be directly proportional to size with the development of seedlings, understood here as the bond of the dry mass with the germination.

In the evaluation of the percentage of pre-dried seeds, a significant difference was observed between sample A-3 and control C, while all samples differed from the control after drying. Oliveira, Sader, and

Krzyzanowski (1999) state that mainly mechanical damages can occur during processing, which influences the physical and physiological quality of the seeds, since the falls, transport, mats, elevators and other equipment can cause damage to the seeds.

Pinto, Mondo, Gomes-Júnior, and Cicero (2012) and Neve et al. (2016) argue that mechanical damage is caused by collisions between seeds or on hard surfaces and that such conditions reduce germination and vigour, which may result in a reduction in their sanitary quality. The results of this study converge to suggest that the cracks arising in the seeds come from the transport of seed mass during the drying and later processing, independent of the physical conditions of the air used in the drying process.

As for the percentage of cracks, the A-1 treatment differed from the control, both immediately and in latent measurements, whereas the treatments A-2 and A-3 differed only in the latent value, which indicates that the drying process with dehydrated air can present cracks in the seeds and that the processes adopted after drying (processing) led to an increase of cracks. Being transported in mats and lifts is the likely cause of this mechanical damage.

In this study, no statistical correlation was found, at the level of 5% (Tukey test), between the cracks and reduction in the percentage of emergence or IVE.

Similarly, Souza, Albuquerque, Zorato and Carvalho (2009), analysing mechanical damages and quality of cotton seeds, found that the cuts and deep fissures, including those that reach the embryo, lead to reductions in seed germination and vigour. Still, Pacheco et al. (2015), studying physiological quality of soybean seeds under mechanical injuries caused by combines, have realized that the mechanical injury has most affected seed quality reductions.

However, França Neto et al. (1998) note that mechanical damages in seeds can occur in the teguments, cotyledons or embryo and may be imperceptible in causing germination loss but may negatively affect the vigour and performance of the seed.

In this sense, Wagner Junior, Negreiros, Alexandre, Pimentel and Bruckner (2007) evaluated the effect of soaking water pH and the cracking of yellow passion fruit seeds on initial germination and development, in which the unsealed seeds presented the best results, thus discouraging seed cracking in germination and early development processes.

Still, Moreano et al. (2013), searching the physical and physiological qualities of soybean seed affected by processing and handling, found that there was no significant difference in the viability and vigour affected by mechanical damages.

As for germination percentage, a significant reduction (at 5% level in a Tukey test) was observed at 150 days for samples A-1 and A-3 and at 90 days for control-dried seeds in a concrete base. There is a longer shelf life of those dried seeds with dehydrated air, although the Dunnett tests (at 5%) showed no significant variations in the comparison of the samples with the control, which represent an excellent index of seed germination in the two drying processes (with dehydrated air and in the concrete base).

The germination percentage was higher than 97% for all the analysed samples, a factor well above the minimum germination index of 80% determined by Law No. 10,711 of August 5, 2003 (Brasil, 2003).

Sand emergence tests showed an excellent percentage of germination without drying with dehydrated air causing significant immediate or latent differences. In the sand emergence tests, more than 96% of the seeds emerged, showing excellent quality of the lots obtained by the UBS.

Regarding IVE, sample A-1 showed differences of the control for storage periods of 120 days and higher, maintaining the same index of the other two samples. This did not show significant variation in relation to the control, since IVE is the relation between the sum of the data collected in the sand emergence test with the number of emerged seedlings and the number of days elapsed from sowing. The individual variations of each of these factors led the samples to a progressive temporal reduction.

The IVE of the treatments of the control presented a reduction in the emergence speed of all the analysed samples from 60 days and from 120 days. In the case of soybean seeds treated with insecticides under the effect of storage, its observed a decrease in the IVE index as the storage period increased.

The authors noted that vigour, determined by the rate of emergence, characterizes the ability of seedlings to withstand stress in real field conditions.

According to Marcos Filho, Cicero, and Silva (1987), IVE can be influenced by management, temperature and soil water content. The environmental temperature varied greatly during the 150 days of observation, varying between 5 and 37°C. The weather may be interfering with the results presented here.

By the tetrazolium test, it was verified that the average vigour of the seeds, both after drying and throughout the storage period, remained in classification 1, which suggests the excellent quality of the analysed seeds and the maintenance of quality characteristics of immediate and latent forms in the evaluated drying process.

With the dehumidification of air resulting in greater potential for withdrawal of water from the seeds, this technique can accelerate the drying process, correlating with an energy savings. Avelar, Levien, Peske, Villela, and Baudet (2011) analysed the efficiency of stationary drying of soybean seeds with an apparatus similar to that used in this study and found it possible to dry soybean seeds on a commercial scale.

Conclusion

The soybean seeds of the cultivar TEC 7849 IPRO, dried in a continuous stream with UTA 60, showed no significant difference related to the weight factors of 1,000 seeds, percentage of germination, emergence in sand and emergence speed index. The seed drying with dehydrated air is a method able to maintain the quality of the seeds.

The prototype was used with temperature controlled at 48 ± 5°C, and dehydrated drying air was kept at 12 ± 0.7%. Its energy source was electric power and can be used on commercial scale to dry soybeans while maintaining highest vigour and germination potential.

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