DRYING SOYBEAN SEED USING AIR AMBIENT TEMPERATURE AT LOW RELATIVE HUMIDITY[1]

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ABSTRACT - Under subtropical and tropical environments soybean seed (*Glycine max* (L.) *Merrill)* are harvested early to avoid deterioration from weathering. Careful after-harvest drying is required and is an important step in maintaining the physiological quality of the seed. Soybean seed should be harvested when the moisture content is in a range of 16-20%. Traditional drying utilizes a high temperature air stream passed through the seed mass without dehumidification. The drying time is long because the system is inefficient and the high temperature increases the risk of thermal damage to the seed. New technology identified as heat pipe technology (HPT) is available and has the unique feature of removing the moisture from the air stream before it is passed through the seed mass at the same environmental temperature. Two studies were conducted to evaluate the performance of HPT for dry soybean seed. In the first study the seeds were dried from 17.5 to 11.1% in 2 hours and 29 minutes and in the second sudy the seeds were dried from 22.6 to 11.9% in 16 hours and 32 minutes. This drying process caused no reduction in seed quality as measured by the standard germination, tetrazolium-viability, accelerated aging and seedling vigor classification tests. The only parameter that indicated a slight seed quality reduction was tetrazolium vigor in the second study. It was concluded that the HPT system is a promising technology for drying soybean seed when efficiency and maintenance of physiological quality are desired.

Index terms: *Glycine max*, quality, vigor, germination, conditioning.

SECAGEM DE SEMENTES DE SOJA COM AR À TEMPERATURA AMBIENTE E BAIXA UMIDADE RELATIVA

RESUMO **-** Em condições tropicais e subtropicais, a semente de soja [*Glycine max* (L.) Merrill] é colhida antecipadamente para reduzir os efeitos da deterioração por umidade em nível de campo. Nessa situação, a semente de soja deve ser colhida quando o seu grau de umidade está na faixa de 16 a 20%. A secagem cuidadosa da semente após a colheita antecipada é requerida e é uma etapa importante da manutenção da sua qualidade fisiológica. Secadores tradicionais utilizam fluxo de ar ambiente aquecido através da massa de sementes sem desumidificação. O período de secagem é longo porque o sistema tradicional de secagem é ineficiente e a alta temperatura aumenta o risco de dano térmico à semente. Nova tecnologia, identificada como "heat pipe technology" (HPT), está disponível e tem a característica única de remover a umidade do ar antes dele ser passado através da massa de sementes na mesma temperatura ambiente. Dois estudos foram conduzidos para avaliar o desempenho do sistema "HPT" para secar a semente de soja. No primeiro, as sementes foram secadas de 17,5% para 11,1% em duas horas e vinte e nove minutos e, no segundo, as sementes foram secadas de 22,6% para 11,9% em 16 horas e 32 minutos. O processo de secagem

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“HPT” não causou redução na qualidade fisiológica da semente, avaliada pelos testes de germinação, de tetrazólio-viabilidade, de envelhecimento acelerado e de classificação do vigor da plântula. O único parâmetro que indicou pequena redução na qualidade da semente foi o tetrazólio vigor, no segundo estudo. Concluiu-se que o sistema “HPT” é uma tecnologia promissora para a secagem da semente de soja, principalmente quando eficiência e manutenção da qualidade fisiológica são requeridas.

Termos para indexação: *Glycine max,* qualidade, vigor, germinação, condicionamento.

INTRODUCTION

In temperate regions soybean seed are field dried to safe storage moisture content before harvesting. When weather conditions are favourable, this is a satisfactory system for safe storage, however, if conditions are not favourable as frequently in the subtropical and tropical regions (Delouche et al., 1973), the soybean seed will deteriorate and harvest losses will increase (Rojanasaroj and White, 1976; White et al., 1976). Through the use of drying equipment and good management practices, both earlier harvesting and drying of the soybean seeds can minimize storage losses. In early harvest, the moisture content of harvested seed may be above 15 to 16% (Delouche, 1971). Technically it is feasible to dry high moisture soybean seed, even up to 22% moisture content, with heated air and obtain a finished product of acceptable quality (Boyd, 1974; Matthes et al., 1974).

Drying is one of the most critical operations in maintaining soybean seed quality. The drying medium used is moist air, which is a mixture of dry air and water vapour. In a drying operation the air carries heat into the system to evaporate moisture and then carries the evaporated water out of the system (Brooker et al., 1974). This method is inefficient as the hot air contains copious quantities of moisture and also the high temperature required is detrimental to the seed quality. Due to these characteristics the air flow rate must be sufficient to avoid saturation before it leaves the seed mass. The air flow rate can be increased until it is capable of absorbing the moisture liberated by the seeds (Boyd et al., 1975). The seed drying speed is also determined by the rate at which the moisture migrates from inside to the outmost layer of the seed (Brandenburg et al., 1961).

When drying with hot air, the temperature range of 40.5ºC to 43.3ºC is the maximum tolerated by the seeds without causing physical and chemical damage (Brooker et al., 1974). The combination of high temperature, low relative humidity and high air flow rate is detrimental to the physiological quality of the seeds (Esdras, 1993). Moist seeds are more susceptible to thermal damage; so the higher the seed moisture content the lower should be the drying temperature (Harrington, 1972). It is generally accepted that seeds with more than 18% moisture should be dried at 32°C and those with a lower moisture content can be dried at 38ºC. Drying temperature should be adjusted according to the relative humidity of the drying air (França Neto et al., 1994). No reduction in seed physiological quality was observed in soybean seed harvested at 22.3% moisture content and dried to 12% moisture content with an air flow rate of $10m^3.minute^{-1}ton^{-1}$ of the seed volume at temperature of 38ºC (Boyd, 1974) However, drying soybean seed with hot air at a temperature of 54.4ºC and relative humidity below 40% reduced seed germination and increased the amount of cracks in the seed coat (Boyd, 1974). Problems of overdrying may occur if the relative humidity of the air is below 35 to 40 percent. Severe overdrying can cause a decrease in vigor and viability and increase the brittleness of the soybean seed (TeKrony et al., 1987).

New technology is available and a prototype dryer has been developed that has the unique feature of taking the moisture out of the air stream before it is heated and passed through the seed. The heat generated when the water is removed is reintroduced into the air stream and raises its temperature. In contrast to the 43°C temperature required by conventional bin dryers (Brandenburg et al., 1961), the temperature of the air stream in the new method never exceeds 32°C.

The purpose of this research was to evaluate the potential of this new technology for drying soybean seed. The evaluation included measuring the capability of the prototype to deliver temperatures and air flows suitable for efficient and safe drying. The effect of the drying on the physiological quality of soybean seed was evaluated.

MATERIAL AND METHODS

Two studies were conducted. A preliminary test with a small quantity of remoistened seed was to evaluate the prototype dryer. A second and larger trial provided more detailed observations.

Preliminary study

The first study was conducted with soybean seed, breeding line F94-9310, harvested at the Florida Foundation Seed Producers Inc. facility at Greenwood, FL. Since the seed were dry they were remoistened to simulate conditions often experienced at harvest. The seed moisture content (mc) was 10.8% fresh weight and was raised to 18.8% by passing moist air through the seed mass in a bin type container that was part of the dryer equipment. Moist air was obtained by passing the air through a water curtain provided by spraying water over a honeycomb of paper, positioned at the air entrance in the plenum chamber. Upon reaching 18% mc, seeds were removed from the bin and placed in plastic bags, sealed and kept in a room at 10ºC for 24 hours for moisture equilibration. An electrical moisture tester (Dole 400) measured the mc. For the drying trial, 27 kilograms were placed in the bin of the dryer prototype (Figure 1). The seed batch depth was 9cm. An airflow rate of $8m^3.minute^{-1}.m^{-3}$ of seed volume was maintained based on the recommendation of Matthes and Rushing (1972). The prototype dryer utilised the "heat pipe technology" as a source of dry air at ambient temperature, and consisted of a special dehumidification air conditioner. The heat pipes increased the dehumidification efficiency of vapour compression in the air conditioning process. The system relied on two technologies to dry the air and extract heat from the moist air. Dehumidifier heat pipes produced dry air, and a latent heat pump produced low cost heat energy from the ambient air (Dinh, 2000) (Figure 2).

The temperature of the air that passed through the air treatment system during soybean drying was measured and recorded using a series of digital thermometers placed at the air treatment unit entrance (ambient), after the pre-cool device, after the evaporator, after the re-heat device and after the condenser (Table 1). The air temperature and the relative humidity (RH) conditions inside the bin unit dryer at various times were measured and recorded using a clock type sensor device with both scales (temperature and RH). The sensors were installed at the plenum chamber and at the bin dryer exhaust (Table 2).

One kilogram seed samples were removed from the seed batch at each of 4 sampling times during drying using an

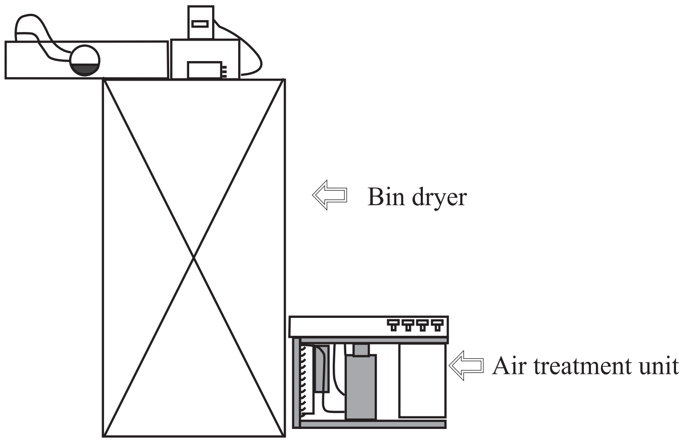

FIGURE 1. Dryer prototype used for the drying trial.

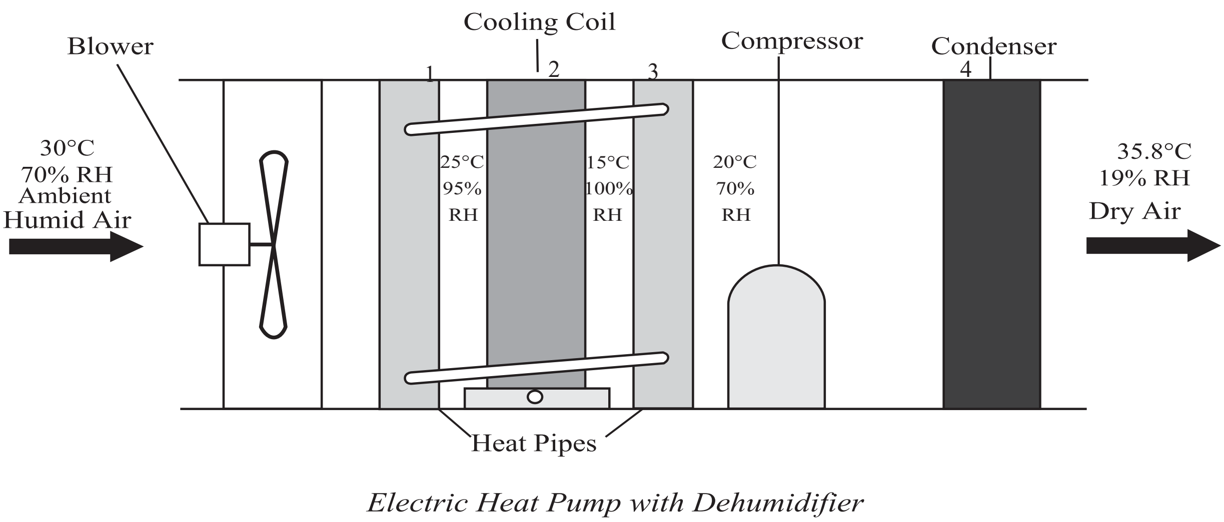

FIGURE 2. Air treatment and examples of typical temperatures and relative humidities at various stages before passing through the seed mass. 1- Pre cool; 2 - Evaporator; 3 - Re-heat and 4 - Condenser.

TABLE 1. Air temperature of ambient and inside the heat pipe system at various times during preliminary test.

Time	Temperature (°C)				
	Ambient	Pre-Cool	Evaporator	Re-Heat	Condenser
08:16 AM	25.8	21.6	10.8	15.9	32.7
08:58 AM			Stop drying		35.0
11:06 AM	28.1	24.1	12.5	18.9	32.7
12:14 PM			Stop drying		37.2
03:33 PM	27.8	22.8	10.5	21.0	35.0
04:12 PM			Stop drying		35.0

TABLE 2. Air temperature and relative humidity (RH) conditions inside the bin at various times during preliminary test.

Time	Plenum		Bin Top	
	T (ºC)	RH(%)	T (ºC)	RH(%)
08:16AM start drying	32.7	27	25.0	61
08:58AM stop drying	35.0	27	28.8	42
11:06AM start drying	32.7	29	30.0	49
12:54PM stop drying	37.2	19	32.7	32
03:33PM start drying	35.0	26	31.1	39
04:12 PM stop drying	35.0	20	32.7	29

official probe of 5cm diameter and 1.5m length. The sample was homogenised using a soil division type homogeniser, after which the seed moisture content was measured (Table 3) by an electrical moisture tester (Dole 400) and oven drying at 105°C (AOSA, 1987). This procedure was followed for subsequent samples until the seeds reached 11% mc. The four seed samples removed during drying plus the control (before hydration) sample were sealed in plastic bags and stored in a room at 10°C for 24 hours before conducting the seed quality tests.

Seed quality tests consisting of the standard germination test (SGT) and accelerated aging test (AAT) were performed as prescribed by AOSA (1987) and (1983), respectively. The experimental design was a completely randomised design (CRD) with three replications, composed of four sub-samples each for SGT and AAT with 50 seeds each.

Second study

A second study was conducted with a soybean breeding line F94-9310, harvested at the Florida Foundation Seed Producers Inc. facility at Greenwood, FL. The seed moisture content (mc) at harvest time was 22.6%. An electrical moisture tester (Dole 400) was used to determine the mc, which was checked by using the oven test, 105ºC during 24 hours, as prescribed by AOSA (1987). For this drying trial 136kg of seed was placed in the bin of the dryer prototype (Figure 1). This seed batch depth was 50cm. An airflow rate of $8m^3.minute^{-1}.m^{-3}$ of seed volume was maintained based on the recommendation of Matthes and Rushing (1972).

Based on preliminary studies of soybean drying, the sampling procedures for the physiological quality evaluation were designed to follow the same procedures adopted in the seed industry. Samples to evaluate seed quality were taken at the beginning and at the end of the drying operation, the seed moisture content was monitored during the process until it reached 11.9%. Samples were removed using an official probe of 5cm diameter and 1.5m length. One kilogram was collected throughout the seed batch depth at each sampling time. The sample was homogenised using a soil division type homogeniser. The first and final seed samples were sealed in plastic bags and stored in a room at 10°C for 24 hours.

A series of seed quality tests consisting of the standard germination test (SGT), accelerated aging test (AAT), seedling vigor classification test (SVCT) and tetrazolium test for viability (Tz-Viab) and vigor (Tz-Vigor) were performed on all samples taken at the beginning and end of the drying trial.

TABLE 3. Soybean seed moisture content at various times during drying in the preliminary test.

Time	Dole 400 MC%	Oven 105 C MC%
07:55 AM	18.8	17.5
08:58 AM	15.2	14.3
12:14 PM	13.2	12.3
04:12 PM	11.8	11.1

The SGT, AAT and SVCT were performed as prescribed by AOSA (1987) and (1983), respectively. The Tz-Viability and Tz-Vigor tests were performed as described by França Neto et al. (1998). The experimental design consisted of a completely randomised design (CRD) with six replications; each one consisting of four sub-samples each for SGT, AAT, SVCT, Tz-Viab. And Tz-Vigor with 50 seeds each.

RESULTS AND DISCUSSION

In the first experiment, the temperature of the air through the heat pipe system and the temperature and the relative humidity of the air that passed through the dryer bin were achieved (Tables 1 and 2) with a 9cm-high seed layer, using an air flow of 8m^3.minute^{-1}.m^{-3} of seed volume at an average temperature of 34.6ºC and a relative humidity of 24.6%. The soybean seed was dried from 17.50% to 11.07% in 2 hours and 29 minutes and the seed moisture content was reduced by 2.67% per hour. The high drying rate value was observed due to a thin layer of seed. A similar result occurred in maize seed with a drying rate of 1.23% water removed per hour in a seed layer one kernel deep (Herter and Burris, 1989). In our study even though the physiological quality of the seed was not high before drying, no further deterioration was observed as a result of the drying process. The slight variation in the SGT data (Table 6) could be related to sampling effect. No reduction in physiological quality was observed either by Boyd (1974) in soybean seed dried from 22.3% to 12% mc with similar parameters of air flow rate and temperature. The results obtained in our study are in accordance with those observed by Matthes et al. (1974) and Boyd (1974) that drying high moisture soybean seed and maintaining acceptable physiological quality is technically feasible.

In the second experiment, soybean seed in a deeper seed layer was dried from 22.56% to 11.88 % in 16 hours and 32 minutes and the moisture content was reduced by 0.65% per hour. The temperature data of the air through the heat pipe system, temperature and the relative humidity of the air that passed through dryer bin (Tables 4 and 5) was achieved with a 50cm-high seed layer, using an air flow of 8m^3.minute^{-1}.m^{-3} of seed volume at an average temperature of 28.33ºC and a relative humidity of 24%. The established rule to be followed in drying is a water removal rate of 0.3% per hour with hot air at 43ºC and a flow rate of 5.5m^3.minute^{-1}ton^{-1} (Brandenburg et al., 1961). This drying rate was less efficient than the 0.65% observed in the present study. By comparison, using a radial air flow dryer, high efficiency was observed with a combination of air flow of 28.4m^3.minute^{-1}ton^{-1} of soybean seed at 46ºC reduced mc from 20% to 9.6% in 12 hours at a drying rate of 0.87% per hour (Miranda et al., 1999). The temperature used in the present study was much lower and safer for preserving seed quality.

The drying process used in this second experiment did not result in seed quality reductions, as measured by standard germination, tetrazolium for viability, seedling vigor classification and accelerated aging test (Table 7). The only reduction observed was in the vigor by the tetrazolium test, which detected a slight reduction in vigor from 87% to 81% which was still considered as highly vigorous seed as determined by França Neto et al. (1998) (Table7). Potts et al.

TABLE 4. Air temperature of ambient and inside the heat pipe system.

Time	Temperature (°C)				
	Ambient	Pre-Cool	Evaporator	Re-Heat	Condenser
03:22 PM	24.61	18.33	10.16	13.78	31.11
06:29 PM	22.77	16.50	5.27	13.33	28.88
11:14 PM	21.16	15.22	3.66	12.22	27.22
07:54 AM	21.35	18.94	8.94	20.00	26.11

TABLE 5. Air temperature and relative humidity (RH) conditions inside the bin.

Time	Plenum		Seed Depth Level -Temperature (°C)					Bin Top	
	T(ºC)	RH(%)	Floor	10cm	20cm	30cm	40cm	T(ºC)	RH(%)
03:22PM	31.11	22	32.55	18.33	18.11	17.61	17.55	17.55	63
06:29PM	28.88	21	30.94	27.40	23.27	17.88	17.88	17.88	67
11:14PM	27.22	22	29.00	27.50	26.00	24.90	24.90	24.90	45
07:54AM	26.11	31	26.55	25.55	24.70	24.50	24.50	24.50	45

(1978) reported that drying temperatures of 30 and 40°C had no effect upon soybean seed viability. Boyd (1974) also reported that no reduction in seed physiological quality was observed in soybean seed harvested at 22.3% moisture content and dried to 12% moisture content with an air flow rate of $10m^3.minute^{-1}.ton^{-1}$ of seed at temperature of 38ºC. However, in the same study, Boyd (1974) using air at high temperature (54.4ºC) and relative humidity below 40% observed a reduction in seed germination and a higher amount of cracks in the seed coat.

TABLE 6. Soybean seed physiological quality as determined by the standard germination test (SGT) and accelerated aging (AA) following drying a moisture contents from 17.5% to 11.1%.

MC% - oven test	SGT (%)	AA (%)
10.8% (initial)	66.0 B[1]	58.5 A
17.5	71.3 A	61.5 A
14.3	71.7 A	62.0 A
12.3	65.0 B	62.0 A
11.1	65.8 B	61.7 A
C.V. (%)	3.85	5.78

[1]Means followed by same letter by column do not differ statistically according to the Duncan's multiple range test at 5.0% probability.

TABLE 7. Soybean seed physiological quality previous and after the drying period.

Drying	Seed Moisture (%)	Germination (%)	Tetrazolium Viability (%)	Tetrazolium Vigour (%)	Seedling Vigour Classif. (%)	Accelerated Ageing Test (%)
Before	22.56	92.0a[1]	93.0a	87.0a	84.0a	85.0a
After	11.88	91.0a	92.0a	81.0b	80.0a	84.0a
	C.V. (%)	2.39	2.81	3.70	2.29	3.48

[1]Means followed by same letter in a column do not differ statistically according to the Duncan's multiple range test at 5.0% probability.

CONCLUSION

Soybean seed drying provided by the heat pipe technology was an efficient process and caused no detrimental effects on seed physiological quality.

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