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Optimization of Processing Parameters of Soybean Seeds Dried in a Constant-bed Dryer Using Response Surface Methodology

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ABSTRACT

In some conditions, to avoid deterioration and field losses of soybean seeds (*Glycine max* Merr.) from weathering at end of the season, farmers start to harvest seeds with a high moisture content and so, careful post-harvest drying would be required to maintain the physiological quality of seeds. Response Surface Methodology (RSM) was used to optimize the operating conditions of soybean seed drying. The study was performed using a three-level, four-factor fractional factorial design and aimed at determining the optimum combination of initial moisture content (X_1), drying air temperature (X_2), air velocity (X_3), and depth of loading (X_4) that could result in high germination, vigor and field emergence. The seeds of two soybean cultivars (*Clark* and *Sahar*) with initial moisture content of 15 to 45% dry weight basis (d.w.b), were dried in different drying air temperatures from 35 to 55°C, air velocity ranging from 0.5 to 1.5 m s^{-1} and a loading depth of 0.5 to 10 cm. According to the results of germination and vigor tests, the optimum drying conditions for seeds of *cv. Clark* were obtained at an air temperature of 52ºC, which needs to be decreased with higher initial moisture content. Harvesting can start at about 30% d.w.b initial seed moisture content, if drying is done carefully, but *cv. Sahar* was more susceptible and the drying air temperature should not exceed 41ºC and harvesting should take place when seeds reach an initial moisture content of below 32%. Moreover, it is strongly recommended to use moderate depths of loading because of best aeration and air circulation and to avoid overdrying. The seed quality indices in this experiment were more sensitive to both air temperature and initial moisture content than air velocity and depth of loading.

Keywords: Drying, Germination, Response Surface Methodology, Seed quality.

INTRODUCTION

Soybean seeds are field dried to a safe storage moisture content before harvesting in temperate regions. When weather conditions are favorable, this is a satisfactory system for safe storage. However, if conditions are not favorable as is frequently the case in subtropical and tropical regions (Delouche *et al.,* 1973), the soybean seeds will deteriorate and harvest losses will increase (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 seeds may be high. Technically it is feasible to dry high moisture soybean seeds, even for seeds up to 22% d.w.b moisture content, with heated air and obtain a finished product of acceptable quality (Matthes *et al.,* 1974). Harvesting time is one of the critical steps in soybean

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seed production that can affect seed quality (Rahman *et al.,* 2004; Peske *et al.* 2004). Soybean seeds mature at the time they reach maximum dry weight. At this point, they are at 40 to 50% d.w.b moisture content and have maximum germination and vigor. Soybeans should be harvested promptly when they are mature to reduce field losses and lessen chances of damage from bad weather (Sumner and Clark, 2006). With adequate drying methods, soybeans can be harvested at a moisture content as high as 30-45% d.w.b. Under good field drying conditions, seed moisture will decrease to 13-15% d.w.b moisture content. It is necessary to harvest at a time as close as possible to the physiological maturity, that is, after the stabilization of dry matter translocation to the seeds, when they reach the maximum germination and vigor potential (Marcos-Filho *et al.,* 1994). Because of unfavorable weather conditions as frequently occur in the harvest season in the main center of the soybean seed production area of Iran, the soybean seeds will deteriorate and harvest losses will increase, so the farmers should harvest seeds as soon as possible and dry them. Drying permits harvesting the grain as soon as it is ripe and mature to avoid field losses and it places the grain in a condition for safe storage, reducing storage losses from heat damage and molds. Drying is an important postharvest operation for prolonging the storage life of a product by slowing down respiration and hence preventing deterioration (Henderson and Perry, 1976). Efficiency of other processing operations in the seed industry and final usage of seeds depends on the quality of the dried product. At present, the drying process is one of the major methods of agricultural product preservation and an important unit operation in a wide variety of industries such as the seed industry (Crapiste and Rotstein, 1997). A mechanical dryer employs a container to hold the seed, a blower to force air through the grain mass, and a heating system to increase the water holding capacity of the air. It can be operated anytime and its high capacity enables more seed to be dried in a short period of time. It is, however, an expensive process. The factors most affecting the rate and quality of drying are the drying air temperature, the drying air relative humidity and the drying air velocity, in addition to the initial seed moisture content (Amer *et al.,* 2003). Other factors like type of grain, variety, drying method, dryer type and efficiency of the dryer can also affect the rate of drying. Faster drying rates are desirable but may lead to undesirable grain cracking.

Optimization of the drying process is performed to recommend rapid processing conditions yielding an acceptable quality product and a high throughput capacity *via* manipulation of the amount of independent variables (Madamba, 2002). For example, percentage of germination, normal seedling, vigor indices and other vigor traits are important seed quality factors for soybean seeds and the experiment is performed to optimize these. Response surface methodology (RSM) is a statistical procedure frequently used for a wide range of optimization studies (Madamba, 2002). RSM allows us to find the optimal working conditions by combining a small number of variables, resulting in fewer experiments (Mullen and Ennis, 1979). RSM was employed in optimizing drying operations and techniques (Barrozo *et al.,* 2006 and 2005, Madamba and Liboon, 2001; Madamba, 2002; Madamba and Lopez, 2002; Zhang *et al.,* 2003). It uses quantitative data from an appropriate experimental design to determine and simultaneously solve multivariate problems. The equations describe the effect of the test variables on the responses, determine interrelationships among test variables and represent the combined effects of all test variables in the response. This approach enables us to make efficient exploration of a process or system (Madamba, 2002).

Drying conditions for soybean with different initial moisture contents were evaluated in literature but its effects on the seed quality were not well analyzed especially in different cultivars. For example, Overhults *et al.* (1973) studied soybean drying from moisture contents of 25-30% d.w.b. to 11%, in a thin bed, at drying temperatures of 38-104°C. At high drying temperatures, the physical surfaces of the soybeans were damaged, with cracks appearing. Hirunlabh *et al.* (1992) studied strategies for the batch drying of soybeans at temperatures of 44-75°C, from moisture contents of 25-11% (d.b.), finding that cracking increased with both drying time and temperature. Zeng *et al.* (1996) studied soybean cracking using air temperatures of 37, 49 and 60°C, from 19, 25 and 32% d.w.b. to a final moisture content of 12% d.w.b, finding that cracking increased with both temperature and initial moisture content. Recently, Barrozo *et al.* (2005; 2006) showed that for a Brazilian cultivar of soybean at a temperature of below 45°C, a low air flow rate and high air humidity are essential to seed drying. They showed that the air velocity has to be lower than 1.5 m s^{-1}. Therefore, overdrying in soybean seeds causes excessive seed coat cracking. The air flow rate also, must be sufficient to avoid saturation before it leaves the seed mass. It can be increased until it is capable of absorbing the moisture liberated by the seeds (Boyd *et al.,* 1975). Depth of loading in the dryer has to be adjusted adequately to permit a cycling movement of air and water and avoid overdrying. Anyway, the seed quality of different soybean cultivars was not optimized properly. Hence the specific objectives of this study were: (1) modeling the influence of the initial moisture content, air temperature, air velocity and loading depth on the soybean seed quality *cv. Clark* and *Sahar*, and (2) to obtain an experimental region for the four factors in which the drying achieves high seed quality in mentioned cultivars.

MATERIALS AND METHODS

Sample Preparation

Soybean seeds *cv. Clark* and *Sahar* were hand harvested at three initial seed moisture contents of 45, 30 and 15% d.w.b. in 2007. The seed samples obtained from the University of Tehran Farm were then sealed in plastic bags and stored in a cold place (4°C) for less than one week. Equilibration with ambient air was performed for at least 60 minutes prior to the drying treatments.

Seed Moisture Content Determination

Two 20-seed sub-samples from each lot were weighed to the nearest 0.01 g and oven dried for 24 hours at 105±3°C (ISTA, 1999). Moisture content was determined before and after each treatment.

Drying Methodology

Drying experiments were carried out using a laboratory dryer (Figure 1) consisting of a centrifugal fan that forces heated air from the heating elements to the sampling drum. The temperature and air velocity of inlet air were controlled by a digital thermometer (1°C accuracy) and an air velocity meter (Lotron model AM 4205) with 0.1 m s^{-1}

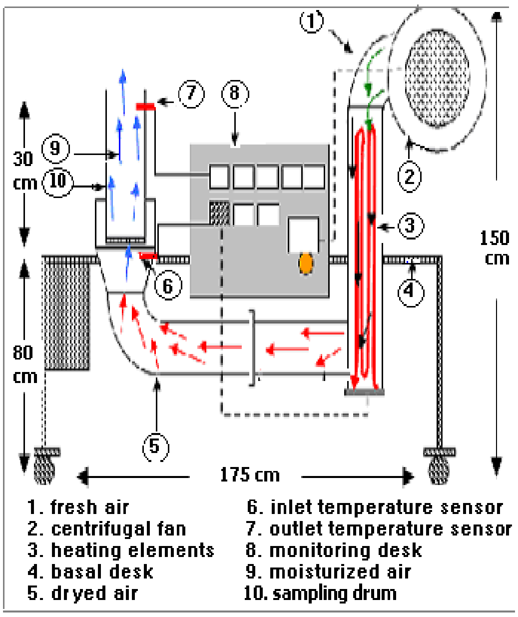

Figure 1. Schematic diagram of the laboratory dryer used in this study (Gazor and Hoseinkhah, 2006).

accuracy, respectively. The sample was weighed using an electronic balance with a 1 g accuracy in every 15 minutes until the desired weight corresponding to moisture content of 12±1% d.w.b. was reached.

Cracked Grain Ratio (CGR)

Three 100-seed samples were selected after drying. Each sample was observed using a box with a magnifying glass and a light source. The percentage of cracked grains was recorded.

Standard Germination Test (GR)

Germination tests were performed with four 50-seed samples from each lot, in rolled papers (sandwich). Germination proceeded in a germinator at 25°C for eight days. On the final day, numbers of normal seedlings were counted and normal seedling ratio (NSR) were assessed (ISTA, 1999).

Rate of Germination (RG)

Rate of germination was calculated as described in the following Formula (1) (ISTA, 1999):

$$RG = \frac{No.of\ \ germinated\, seed\, at\ first\, count}{Days\, of\ \ first\, count} + \text{---} \text{-------} + \frac{No.\ of\ \ germinated\ \ seed\ at\ final\ count}{Days\ of\ \ final\ count} \quad (1)$$

Vigor Indices I and II (VI I) (VI II)

On the final germination day, the lengths of seedlings were measured. The vigor index I was calculated as follows (2):

$$VI\ I = \frac{Germination\ percentage\,(\%) \times Mean\ seedling\ length\,(cm)}{100} \quad (2)$$

Also the weights of germinated seedlings were measured in grams. The vigor index II was calculated as:

$$VI\ II = \frac{Germination\ percentage\,(\%) \times Mean\ seedling\ weight\,(g)}{100} \quad (3)$$

Accelerated Ageing Test (AA)

The accelerated ageing test was performed on 42 g of seeds placed on a wire mesh screen and suspended over 40 mL of distilled water inside plastic boxes (15.0×11.0×6 cm), held at 41°C and near 100% air relative humidity for 72 hours (Hampton and Tekrony, 1995). After the ageing period, seeds were tested for standard germination, and the number of normal, five day-old seedlings was evaluated.

Electrical Conductivity Test (EC)

Three 50-seed samples were weighed and immersed in 75 mL of deionized water within plastic cups and kept in a germinator at 25°C, for 24 hours. Thus EC was determined in the solution with a conductivity meter (Inolab model Listed 8F93), and results expressed as $\mu S\ cm^{-1} g^{-1}$ (Hampton and TeKrony, 1995).

Field Emergence (FE)

Field emergence was carried out using four replications of 50-seed samples, uniformly sown in 2 m long and 0.5 m spaced rows. The field was irrigated to provide sufficient water to allow seedling emergence. The number of emerged seedlings was evaluated 14 days after sowing and the results were expressed in terms of percentage (Egli and Tekrony, 1995); the rate of field emergence (RFE) was also calculated as described for the rate of germination.

Experimental Design and Statistical Analysis

A three-level four-factor (initial moisture, drying air temperature, air velocity and depth of loading) fractional factorial design can be used to evaluate the optimum drying conditions. In the following case, four mathematical functions of f_k are assumed to exist for Y_k:

$Y_k = f_k$ (initial moisture, drying air temperature, air velocity and depth of loading).

A second-degree polynomial equation in the following form can be used to approximate the function f_k:

$$Y_k = \beta_{k0} + \sum_{i=1}^{4} \beta_{ki} X_i + \sum_{i=1}^{4} \beta_{kii} X_i^2 + \sum_{i=1}^{3} \sum_{j=i+1}^{4} \beta_{kij} X_i X_j \quad (4)$$

Where β_{k0}, β_{ki}, β_{kii}, and β_{kij} are regression coefficients and X_i's are the coded independent variables of initial moisture, drying air temperature, air velocity and depth of loading while Y_k is the dependent variable or the measured response.

This experiment was carried out using the Box and Behnken (1960) three-level, four-factor fractional factorial design and coded as -1, 0 and +1. Seeds containing an initial moisture content of 15 to 45% d.w.b, were dried at different drying air temperatures varied from 35 to 55°C, air velocity ranging from 0.5 to 1.5 m s^{-1} and different loading depth of 0.5 to 10 cm, resulting a total of 28 runs. The coding of the independent variables is presented in Table 1 and the experimental design in Table 2.

Response surface regression (Minitab 14 software) was performed on the collected data. The analysis included fitting a full second-order response surface, analyzing the spectral properties of the fit surface and calculating the ridge of optimum response. Equations were formulated by response surface regression using initial moisture (X_1), drying air temperature (X_2), air velocity (X_3) and depth of loading (X_4) as independent variables while the cracked grains ratio (CGR), germination ratio (GR), rate of germination (RG), normal seedling ratio (NSR), vigor index I (VI I), vigor index II (VI II), electrical conductivity (EC), accelerated ageing (AA), field emergence ratio (FE) and rate of field emergence (RFE) were all considered as responses. The results were averages of three replications. Using RSM, an optimum combination of initial moisture, drying air temperature, air velocity and depth of loading that will yield a low cracked grain ratio, high values for germination ratio, rate of germination, normal seedling, vigor indices, accelerated ageing, field emergence ratio and rate of field emergence and low electrical conductivity was determined. Contour plots for each response were obtained. The contour plots of main responses with the same parameters were overlaid to find an optimum region. Germination ratio, normal seedling, vigor indices, accelerated ageing and field emergence were the major factors in determining soybean seed grade and quality that were finally overlaid to obtain optimum region for soybean seed drying.

RESULTS

Analysis of variance, using Minitab (Ver. 14) was performed to determine the lack of fit and the significance of the linear, quadratic, and cross-product effects of the independent variables on the quality attributes. An ANOVA (Tables 3 and 4) for the response models of the form of Equation (4) was developed when the experimental

Table 1. Coded levels of treatment variables used in developing experimental data for optimization of the drying process.

Independent variables	Symbol	Coded values		
		-1	0	+1
Initial moisture (%)	X_1	15	30	45
Drying air temperature (°C)	X_2	35	45	55
Air velocity (m s^{-1})	X_3	0.5	1	1.5
Depth of loading (cm)	X_4	0.5 (Monolayer)	5.25	10

Table 2. Combination of parameters used to acquire experimental data for optimization of the drying process experimental design.

Run No.	Pt type	Block	Initial moisture (%)	Drying air temperature (°C)	Air velocity (m s^{-1})	Depth of loading (cm)
1	2	1	-1	0	1	0
2	2	1	1	1	0	0
3	2	1	0	1	1	0
4	0	1	0	0	0	0
5	2	1	0	0	1	-1
6	0	1	0	0	0	0
7	0	1	0	0	0	0
8	2	1	1	0	-1	0
9	2	1	-1	0	0	-1
10	2	1	0	0	1	1
11	2	1	0	1	-1	0
12	0	1	0	0	0	0
13	2	1	0	1	0	1
14	2	1	-1	-1	0	0
15	2	1	1	0	1	0
16	2	1	-1	0	-1	0
17	2	1	1	0	0	1
18	2	1	1	0	0	-1
19	2	1	-1	0	0	1
20	2	1	0	1	0	-1
21	2	1	0	-1	1	0
22	2	1	0	-1	-1	0
23	2	1	0	0	-1	-1
24	2	1	0	-1	0	-1
25	2	1	0	0	-1	1
26	2	1	1	-1	0	0
27	2	1	0	-1	0	1
28	2	1	-1	1	0	0

data were fitted to the response surface. Statistically significant response models for all terms (linear, quadratic, and interaction) and the residual variances for all the responses are shown. The residual variance actually represents contributions from two factors, namely: lack-of-fit and pure experimental error. The lack-of-fit test is a measure of failure of the model to represent the data in the experimental domain at which points were not included in the regression or variations in the models can not be accounted for by random error. Indeed it represents other than contributions from the first order terms, while the pure experimental error variance is calculated by considering the variation between observations at the same experimental conditions run in a random sequence (Myers and Montgomery, 2002). In the case of lack-of-fit, F-ratio was calculated in this way:

$$F= \frac{\textit{Mean square for lack - of - fit}}{\textit{Mean square for experimental error}}$$

And if *F* is not significant, the conclusion is made that the errors about the fitted model (lack-of-fit) are on the same order of magnitude as those accounted for by errors of observation (experimental error) and the model is an adequate representation of the data.

For *cv. Clark* significant second-order polynomial (SOP) models resulted for all traits except EC (Table 3). This shows that Most of the values were affected by the process variables in which the product was exposed. The linear term contributed substantially to the significance of the generated SOP models for all traits except for rate of germination. For the latest case the quadratic term played a role in the significance of the model. All SOP models

Table 3. The ANOVA table showing the independent variables as a linear, quadratic or interaction terms on each of the responses for soybean (*cv. Clark*).

	Ms									
Regression	CGR	GR	RG	NSR	VI I	VI II	EC	AA	FE	RFE
Model	49.5^{**}	271^{**}	380.3^{**}	352^{**}	3.9^{**}	0.007^{**}	253.8^{ns}	508.2^{**}	1748^{**}	346.5^{**}
Linear	21.2^{**}	131.2^{**}	197.6^{ns}	100.9^{*}	3.9^{**}	0.007^{**}	452.9^{ns}	181.9^{**}	74.5^{**}	55.2^{**}
Square	21.9^{**}	204.4^{**}	332^{*}	211^{**}	4.13^{**}	0.004^{*}	496.7^{ns}	306.7^{**}	1569.6^{**}	143.8^{**}
Interaction	-	233.7^{**}	-	156.2^{*}	4.28^{**}	-	-	-	120.3^{**}	-
Total error	1.54	21.5	53.4	23.6	0.4	0.001	154.1	22.83	11.1	5.12
Lack of fit	1.22^{ns}	18.7^{ns}	-	13.52^{ns}	0.31^{ns}	0.002^{ns}	-	14.52^{ns}	11.2^{ns}	-
Pure error	1.61	37.2	53.4	38.1	0.51	0.0008	154.1	24.579	10.9	5.12
Total										
s	1.24	4.63	7.30	4.85	0.63	0.03	12.42	4.77	3.33	2.26
r^2	0.85	0.81	0.37	0.80	0.74	0.46	0.12	0.81	0.98	0.85

and ** : Significant at p=0.05 and p=0.01, respectively.
ns: Non Significant.

except for the rate of germination and EC showed insignificant lack-of-fit, which means that these SOP models represented the experimental data adequately. On the other hand, the coefficient of determination (r^2) is defined as the ratio of the explained variation to the total variation and is a measure of the degree of fit (Haber and Runyon, 1977). It is also the proportion of the variability in the response variable, which is accounted for by the regression analysis (Mclaren *et al.,* 1977). A reasonably high proportion of the variability ($r^2 > 0.80$) was explained for the response surface models for cracked grain ratio, germination ratio, normal seedling ratio, accelerated aging, field emergence ratio and rate of field emergence, showing that the models developed for these responses appeared to be adequate. This outcome reinforced the earlier notion on the significance of these models, with insignificant lack-of-fit. On the other hand, other polynomial models gave lower r^2 values indicating that the experimental data was not satisfactorily explained (Table 3). For *cv. Sahar*, resulting SOP models were significant for all traits and values were affected by the process variables (Table 4). The linear term contributed substantially to the significance of all generated SOP models. All SOP models showed insignificant lack-of-fit,

Table 4. The ANOVA table showing the independent variables on each of the responses as a linear, quadratic or interaction terms for soybean (*cv. Sahar*).

	Ms									
Regression	CGR	GR	RG	NSR	VI I	VI II	EC	AA	FE	RFE
model	108.2^{**}	1890.9^{**}	6675.1^{**}	1127.6^{**}	24.1^{**}	0.02^{**}	1819.8^{**}	2370.9^{**}	3219.9^{**}	120.3^{**}
Linear	28.8^{**}	2423.5^{**}	191.4^{**}	1624.9^{**}	9.2^{**}	0.02^{*}	1250.7^{**}	2323.6^{**}	1739.2^{**}	16.5^{**}
Square	433.3^{**}	364.1^{**}	239.1^{**}	454.2^{**}	7.9^{**}	-	1520.4^{**}	1369.5^{**}	3427.8^{**}	81.5^{**}
Interaction	-	-	-	-	7.1^{**}	0.004^{*}	1943.8^{**}	-	375.5^{**}	27.1^{**}
Total error	3.6	18.3	31.4	26.2	0.4	0.0004	148.3	27	30.7	1.4
Lack of fit	3.58	11.1^{ns}	37.9^{ns}	17.8^{ns}	0.5^{ns}	0.0005	131.5^{ns}	34^{ns}	53.7^{ns}	1.5^{ns}
Pure error	3.68	20.2	22.1	38.3	0.09	0.0004	172.6	25.2	25.8	0.7
Total										
s	1.91	4.28	5.61	5.12	0.69	0.02	12.18	5.2	5.53	1.18
r^2	0.84	0.93	0.83	0.91	0.96	0.87	0.73	0.92	0.95	0.98

and ** : Significant at p=0.05 and p=0.01, respectively.
ns: Non Significant.

Table 5. Equations derived using RSM for the prediction of the dependent variables for soybean (*cv. Clark*).

Dependent variable	Equation
CGR	$16.79+0.53\ X_1-1.1\ X_2-0.008\ X^2_1+0.01\ X^2_2$
GR	$-17.49+0.82\ X_1+5.46X_2-17.36\ X_3-3.47\ X_4-0.02\ X^2_1-0.066\ X^2_2+3.21X_3X_4$
RG	$36.05+1.45\ X_1-0.03\ X^2_1$
NSR	$20.49+3.92\ X_2-14.64\ X_3-2.87\ X_4-0.05\ X^2_2+2.63\ X_3X_4$
VI I	$1.67+0.72\ X_2-2.19\ X_3-0.71\ X_4-0.01\ X^2_2+0.02\ X^2_4+0.43\ X_3X_4$
VI II	$0.05-0.002\ X_1+0.02\ X_2-0.0002\ X^2_2$
EC	$48.37+2.2\ X_1-0.03\ X^2_1$
AA	$-44.72+1.62\ X_1+4.73\ X_2-0.03\ X^2_1-0.05\ X^2_2$
FE	$39.45+2.08\ X_1+1.87X_2-4.38X_4-0.09\ X^2_1-0.05\ X^2_2+0.04\ X_1X_2+0.08\ X_2X_4$
RFE	$7.41+0.77\ X_1-0.02\ X^2_1$

which means that these SOP models represented the experimental data adequately. High r^2 value of response surface models for all models (except for EC) showed that the models developed for these responses appeared to be adequate. This outcome reinforced the earlier notion on the significance of these models, with insignificant lack-of-fit (Table 4).

Tables 5 and 6 show the regression response SOP models used by Equation (1) for predicting the values at optimum conditions for soybeans *cv. Clark* and *Sahar*, respectively. According to this equation, for *cv. Clark* most of the responses were influenced by the drying air temperature except for the rate of germination, EC and the rate of field emergence. Initial moisture affects all responses except for the number of normal seedlings and the vigor index I. These two traits plus the germination ratio were influenced by air velocity and depth of loading. For *cv. Sahar* initial moisture affects all traits, this means that this cultivar is more susceptible to the date of harvesting. Effects of drying air temperature on the responses were significant too. Effects of air velocity on the number of normal seedlings, vigor index I and EC were significant while the depth of loading only affected vigor index I and rate of field emergence (Table 6). The equations and the coefficients were different for the two cultivars, which show that they have structural, physical or perhaps genetical differences that affect these traits and determine seed quality (Ma *et al.,* 2004).

Contour plots were generated using significant parameters for each response. Optimization of the drying process presents us with the conditions necessary to yield a high quality product. To determine the optimum drying conditions, the graphical

Table 6. Equations derived using RSM for the prediction of the dependent variables for soybean (*cv. Sahar*)

Dependent variable	Equation
CGR	$58.71-0.44\ X_1-2.41\ X_2+.0009\ X^2_1+0.03\ X^2_2$
GR	$142.95+1.45\ X_1-1.96\ X_2-0.03\ X^2_1$
RG	$175.7+1.46\ X_1-5.28\ X_2+0.51\ X_4-0.02\ X^2_1+0.04\ X^2_2$
NSR	$144.61+1.96\ X_1-1.86\ X_2-48.65\ X_3-0.04\ X^2_1+23.10\ X^2_3$
VI I	$31.75+0.25\ X_1-0.86\ X_2-4.76\ X_3+2.30\ X_4-0.0055\ X^2_1+0.006\ X^2_2+0.17\ X_2X_3-0.04\ X_2X_4-0.39\ X_3X_4$
VI II	$0.92—0.01\ X_1-0.01\ X_2+0.001\ X_1X_2$
EC	$-57.2+5.7\ X_1+2.74\ X_2+113.46\ X_3-59.56\ X_3^2+0.1\ X_1X_2$
AA	$114.53+2.93\ X_1-1.79\ X_2-0.06\ X^2_1$
FE	$151.13\ X_1+1.39\ X_1-3.1\ X_2-0.09\ X^2_1+0.06\ X_1X_2$
RFE	$83.81+0.29\ X_1-2.38\ X_2-11.68\ X_3-0.73\ X_4-0.02\ X^2_1+0.01\ X^2_2+6.08\ X^2_3+0.06\ X^2_4+0.01\ X_1X_2$

overlaying method was used. The contour plots of the responses as a function of the independent variables show lines of constant value. Figure 2 shows the contour plots for cracked grain ratio as a function of the significant independent variables for *cv. Clark* (a) and *Sahar* (b) cultivars. The most significant parameter that affects seed cracking was drying air temperature in both, but for *cv. Sahar* the cracks were more at higher temperature and moisture contents. Figure 3 shows the contour plot of the germination ratio SOP model. The germination ratio of the soybean seeds after drying tended to increase when using drying air temperatures lower than 55ºC, with the highest of 90% for *Clark* (a), but for *cv. Sahar* to achieve this value we have to keep the drying air temperature below 47ºC (b). In both cultivars, the higher the initial moisture content, the more the drying air temperatures have to decrease. For *cv. Clark* the germination ratio decreased at high loading depths but the increase in air velocity balanced it (data are not shown).

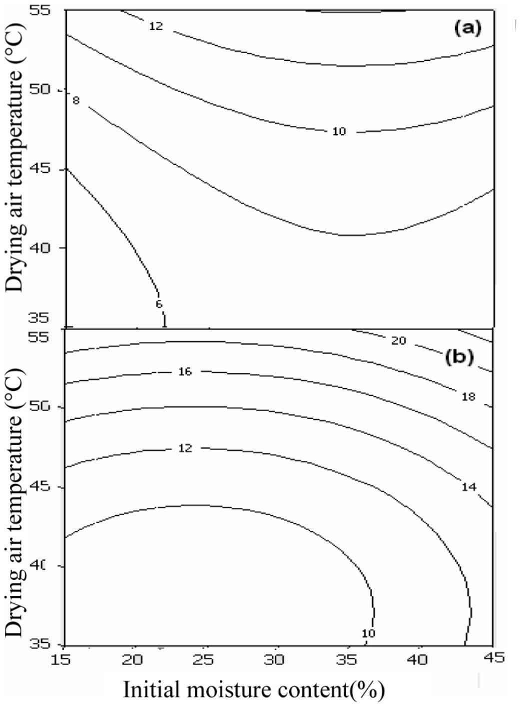

Figure 2. Contour plot for the cracked grains ratio as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

As shown in Figure 4, the rate of germination for *cv. Clark* is affected by the initial moisture content and the drying air temperature. The rate of germination was higher at lower drying air temperatures and moisture content (a) while, for *cv. Sahar*, the effect of drying air temperatures was more significant. The germination rate of this cultivar was more susceptible to drying air temperature (b). The contour plots for the number of normal seedlings as a function of the significant independent variables are shown in Figure 5. The most significant parameters that affect number of normal seedlings were drying air temperature, air velocity and loading depth for *cv. Clark*. The number of normal seedlings after drying tended to increase when drying air temperatures below than 50ºC were used, with the highest of 90% using seeds with a moisture content of about 40% (a). Lower depths and air velocity give the best result (data are not shown). For *cv. Sahar*, to gain these results, the drying air temperature not to be over 41ºC (b). Vigor index I decreased with an increasing drying air temperature

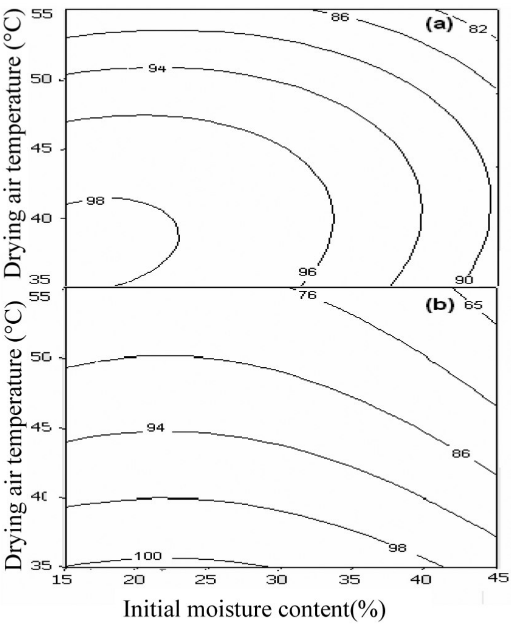

Figure 3. Contour plot for the germination ratio as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars..

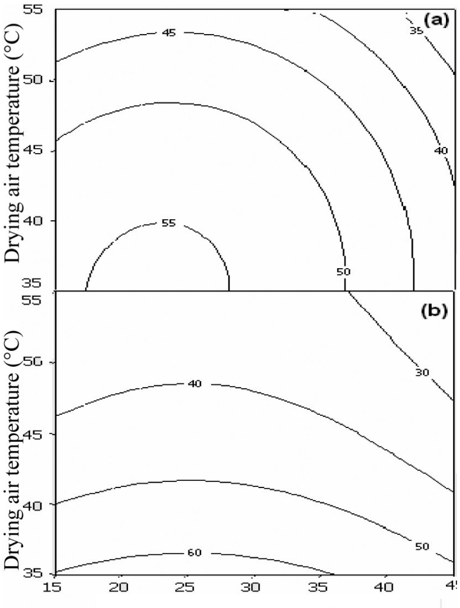

Figure 4. Contour plot for the rate of germination as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

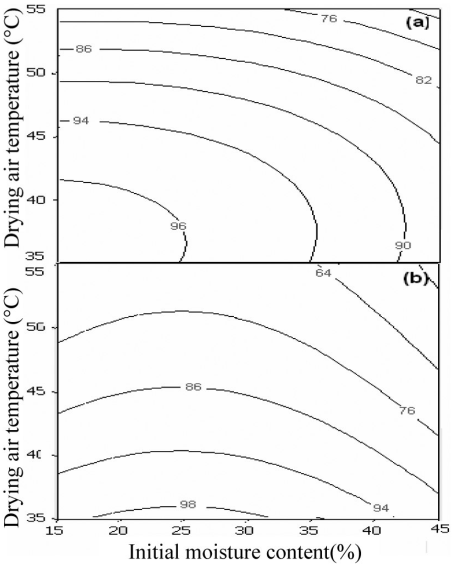

Figure 5. Contour plot for the normal seedling ratio as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

and initial moisture content, while *Clark* seeds (a) were more susceptible to initial moisture, but they tolerated a higher temperature than *Sahar* seeds (b) (Figure 6). Vigor index II (Figure 7) decreased with increasing initial moisture content for *cv. Clark* but its seeds showed less response to drying air temperature (a) while, for *cv. Sahar*, the vigor index II is affected mainly by increasing the drying air temperature instead of the initial moisture content (b). Figure 8 shows the contour plot of the electrical conductivity SOP model. For *cv. Clark* the seeds that were dried at low drying air temperatures had a lower EC value, but their initial moisture content did not affect the EC value (a); for *Sahar* seeds, the drying air temperature didn't show a sharp effect on the EC value, however the seeds which were harvested at a higher initial moisture content showed lower EC (b). The contour plots for the germination ratio after accelerated aging are shown in Figure 9. Drying air temperatures below 47ºC for seeds with moisture content about 30% d.w.b give an acceptable amount of this trait, with about 90% for *cv. Clark* (a); for *Sahar*, this will be achieved with drying air temperatures below 45ºC. Therefore there was no problem with seeds with a higher initial moisture content (b). According to Figure 10, the acceptable value for field emergence (80%) achieved

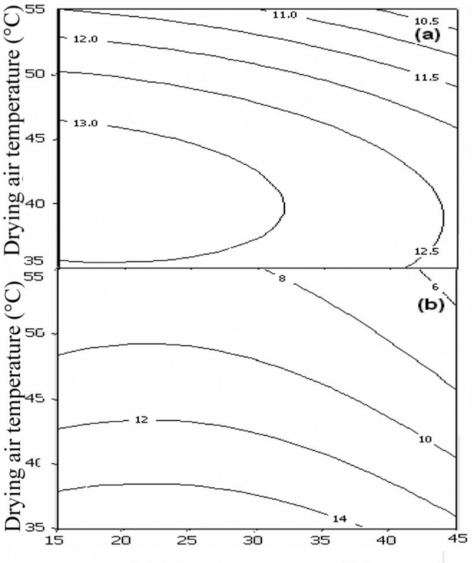

Figure 6. Contour plot for vigor index I as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

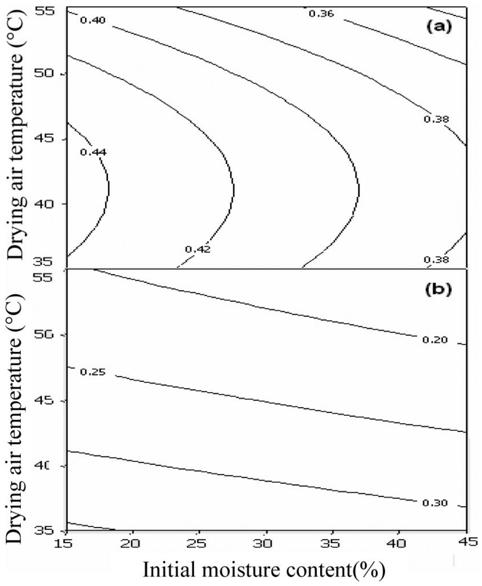

Figure 7. Contour plot for vigor index II as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

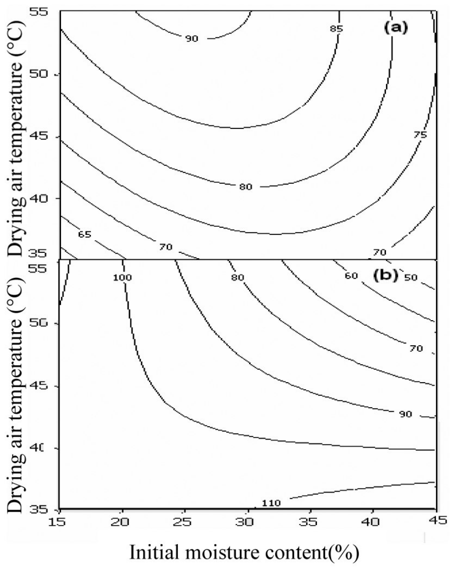

Figure 8. Contour plot electrical conductivity as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

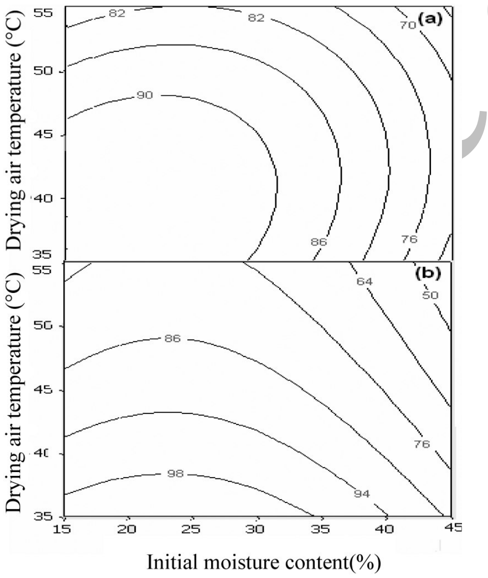

Figure 9. Contour plot for the germination ratio after accelerated ageing as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

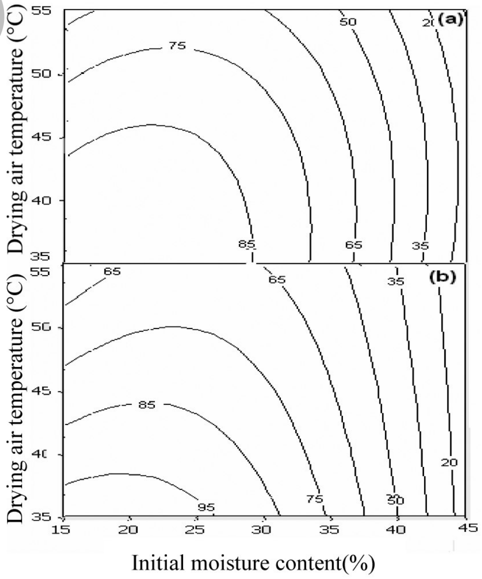

Figure 10. Contour plot for field emergence as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

by seeds under 35% moisture content that were dried with air drying temperatures of 50 and 48ºC for *cv. Clark* (a) and *Sahar* (b), respectively. Finally, the best rate of germination under field conditions were obtained for seeds which were dried at temperatures under 52ºC for *Clark* (a) and *Sahar* (b) as are shown in Figure 11. However, seeds with a lower initial moisture content germinated faster.

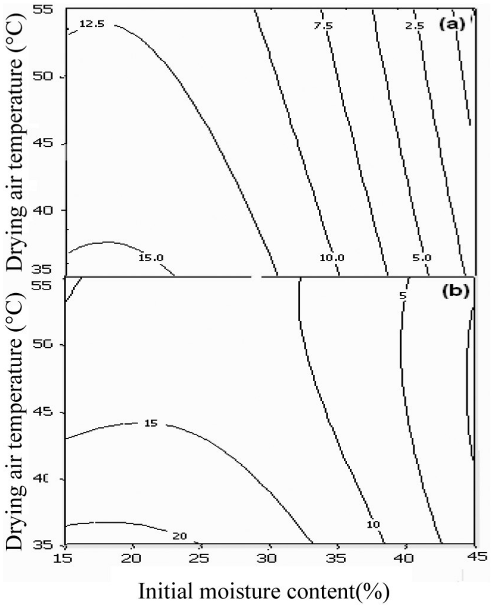

Figure 11. Contour plot for the rate of germination at field as a function of drying air temperature and initial moisture content in: (a) *Clark* and (b) *Sahar* cultivars.

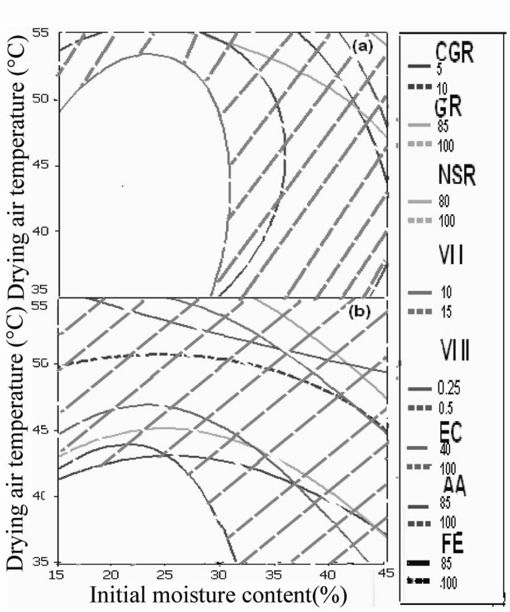

Figure 12. The optimum drying conditions for soybean seeds after overlaying the contour plots in: (a) *Clark* and (b) *Sahar* cultivars.

DISCUSSION

Results indicated that soybean seeds are susceptible to drying parameters depending on the cultivars. The seed quality traits of soybean such as germination ratio, rate of germination, normal seedling ratio, vigor indices, electrical conductivity, accelerated ageing, field emergence ratio and rate of field emergence were determined and effects of drying variables on them were modeled. Then effect of the more important parameters, i.e. drying air temperature and initial moisture content, were shown as contour plot diagrams (Figures 2-11). The cracked grains ratio shows the structural injury to the seeds correlated negatively (r= -0.50**) with germination characters and were shown in Figure 2. This means that the less the cracking ratio, the higher the quality that will be achieved. Except for the EC value, the other germination traits have to be high. Normally, total germination, normal seedlings and a field emergence higher than 80%, beside a higher rate of germination and vigor indices are expected for high quality seeds and optimum drying conditions should provide these. The optimum drying conditions can then be determined by overlaying the contour plots of relevant and statistically significant responses. An optimum area is generated and calculating this area forms the basis of the optimum drying conditions. From Figure 12, a feasible estimation of the optimum drying conditions for soybean seed drying can be determined. For *cv. Clark* (a) optimum air drying temperatures below 52ºC were acceptable if the initial moisture content is below 30% d.w.b, giving a reliable value for seed quality. Seed harvesting can start at about 30% d.w.b. initial moisture content (the area with no lines). For *cv. Sahar* (b), drying air temperatures must not exceed 41ºC and, if there is high initial moisture content, it has to decrease. Harvesting can start at about 32% d.w.b. initial moisture content. The recommended loading depths are low and moderate, due to better air circulation and avoidance of overdrying. For air to penetrate into the seed mass uniformly and avoidance of damping, the air velocity has to be adequate. In general, the results of this study were in agreement with the literature, namely that increasing initial moisture content and drying temperature augment seed cracking and lessen seed quality characteristics (Overhults *et al.,* 1973; Hirunlabh *et al.,* 1992; Zeng *et al.,* 1996); however, harvesting time and genotype affect the seed structure and characteristics (Rahman *et al.,* 2004; Ma *et al.,* 2004). Also Barrozo *et al.,* (2006) showed that soybean seed cracking is associated with a high drying rate and over drying.

Generally, the results showed that the best conditions for harvesting and drying soybean seeds were the time which seeds are at 15% d.w.b. moisture content and are dried at 35ºC. But the main purpose of this study was to estimate the possibility of initiating harvest at a higher moisture content, which we come across in some regions of soybean seed production in Iran, without seed quality hazard. Therefore, this study's intention was modeling and optimization of this process to overcome the problem. Therefore, controlling seed drying conditions is an important process for maintaining the high quality of produced seeds. This study has definitely shown that farmers can set up early harvesting and, consequently, the careful drying of soybean seeds without any anxiety over germination and the vigor characteristics of produced seeds. The main response of this study was final field emergence that correlated positively with germination after accelerated ageing (r= 0.86**), number of normal seedlings (r= 0.65**), germination ratio and rate of germination (r= 0.71**) and, negatively, with the number of cracked grain ratio (r= -0.50*). So, accelerated ageing is a more valuable trial for soybean seed vigor tests that can be used in next experiments.

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REFERENCES

1. Amer, B. M. A., Morcos, M. A. and Sabbah, M. A. 2003. New Method for the Determination of Drying Rates of Fig Fruits Depending on Empirical Data under Conditions Suiting Solar Drying. *The International Conference Institute of Agricultural Engineering*, 18–19 September, 2003, LUA Raudondvaris, Lithuania.
2. Barrozo, M. A. S., Felipe, C. A. S., Lacerda, A. F. and Lisboa, M. H. 2005. Analysis of Soybean Seed Quality Related to Drying in Parallel Flow Sliding Bed. *Seed Sci. Technol.*, **33:** 675-685.
3. Barrozo, M. A. S., Felipe, C. A. S., Sartori, D. J. M. and Freire, J. T. 2006. Quality of Soybean Seeds Undergoing Moving Bed Drying: Countercurrent and Crosscurrent Flows. *Dry. Technol.*, **24:** 415-422.
4. Box, G. E. P., and Behnken, D. W. 1960. Some new three level designs for the study of quantitative variables. *Technometrics*, 2, 455–475.
5. Boyd, A. H., Welch, G. B. and Baskin, C. C. 1975. *Some Thoughts on Seed Drying.* Seed Technology Laboratory Mississippi State, Mississippi State University, 2 PP.
6. Crapiste, G. H. and Rotstein, E. 1997. Design and Performance Evaluation of Dryers, In: *"H. Food Eng. Prac."*. CRC Press, Boca Raton, PP. 125-166.
7. Delouche, J. C., Mattes, R. K., Dougherty, G. M. and Boyd, A. H. 1973. Storage of Seed in Sub-tropical and Tropical Regions. *Seed Sci. Technol.,* **1:** 671-700.
8. Egli, D. B. and Tekrony, D. M. 1995. Soybean Seed Germination, Vigor and Field Emergence. *Seed Sci. Technol.*, **23:** 595-607.
9. Gazor, H. R. and Hoseinkhah, R. 2006. *Assessment of Canola Drying Process and Product Oil Characteristics Using a Fluidized Bed Dryer.* Report No: 85/792, Agricultural Engineering Research Institute, Karaj, Iran. 50 PP.
10. Haber, A. and Runyon, R. (1977). *General Statistics.* 3rd Edition, Addison-Wesley Publishing Company.

11. Hampton, J. G. and Tekrony, D. M. 1995. *H. Vigor Test Meth.* 3rd Edition, ISTA, Zurich, 117 PP.
12. Henderson, S. M. and Perry, R. L. 1976. *Agricultural Process Engineering*. Westport, Connecticut: AVI Publishing Corporation Inc.
13. Hirunlabh, J., Tirawanithakul, S. and Soponronnarit, S. 1992. Strategies for Drying Soybean: Batch Process. *Songklanakarin. J. Sci. Technol.*, **14**: 33-46.
14. *International Seed Testing Association*, 1985. International Rules for Seed Testing. *Seed Sci. Technol.,* **13:** 307–520.
15. *International Seed Testing Association,* 1999. International Rules for Seed Testing. *Seed Sci. Technol.*, **27(Suppl):** 333.
16. Ma, F., Ewa, C., Tasneem, M., Peterson, C. A. and Gijzen, M. 2004. Cracks in the Palisade Cuticle of Soybean Seed Coats Correlate with Their Permeability to Water. *Ann. Bot.*, **94:** 213-228.
17. Madamba, P. S. and Liboon, F. A. 2001. Optimization of the Vacuum Dehydration of Celery (*Apium graveolens*) Using the Response Surface Methodology. *Drying Technol.*, **19:** 611–626.
18. Madamba, P. S. 2002. The Response Surface Methodology: An Application to Optimize Dehydration Operations of Selected Agricultural Crops. *LWT. Food Sci. Technol.*, **35:** 584–592.
19. Madamba, P. S. and Lopez, R. I. 2002. Optimization of the Osmotic Dehydration of Mango (*Mangifera indica* L.) Slices. *Dry. Technol.*, **20:** 1227–1242.
20. Madamba, P. S. and Yabes, R. P. 2005. Determination of the Optimum Intermittent Drying Conditions for Rough Rice (*Oryza sativa* L.). *LWT. Food Sci. Technol.*, **38:** 157–165.
21. Marcos-Filho, J., Chamma, H. M. C. P., Casagrande J. R. R. and Marcos, E. A. 1994. Effect of Harvesting Time on Seed Physiological Quality, Chemical Composition and Storability of Soybeans. *Sci. Agric.*, **51:** 298-304
22. Matthes, R. K., Boyd, A. H. and Welch, G. B. 1974. *Heated Air Drying of Soybean Seed.* Mississippi State, Mississippi State University, 4 PP.
23. Mclaren, C. G., Bartolome, V. I., Carrasco, M. C., Quintana, L. C., Ferino, M. I. B., Mojica, J. Z., Olea, A. B., Paunlagui, L. C., Ramos, C. G. and Ynalvez, M. A. 1977. *Experimental Design and Data Analysis for Agricultural Research.* Vol. 1, International Rice Research Institute,Los Ban˜ os, Laguna.
24. Mullen, K. and Ennis, D. M. 1979. Rotatable Designs in Product Development. *Food Technol.*, **33**: 74–80.
25. Myers, R. H. and Montgomery, D. C. 2002. Process and Product Optimization Using Designed Experiments, In: *"Response Surface Methodology".* 2nd Edition, John Wiley and Sons, Inc., New York, PP. 328–335.
26. Overhults, D. G., White, G. M., Hamilton, H. E. and Ross, I. J. 1973. Drying Soybean with Heated Air. *Trans. Am. Soc. Agric. Eng.*, **16:** 112-113.
27. Peske, S. T., Hofs, A. and Hamer, E. 2004. Seed Moisture Range in a Soybean Plant. *Rev. Bras. Sem.*, **26:** 120-124.
28. Rahman, M. M., Hampton, J. G. and Hill, M. J. 2004. Effect of Seed Moisture Content Following Hand Harvest and Machine Threshing on Seed Quality of Cool Tolerant Soybean (*Glycine max* (L.) Merrill.). *Seed Sci. Technol.*, **32:** 149-158.
29. Sumner, P. E. and Clark E. J. 2006. Grain and Soybean Drying on Georgia Farms. College of Agricultural and Environmental Sciences and Family and Consumer Science, University of Georgia, *Bull.,* **873:**12 PP.
30. White, G. M., Loewer, O. J., Ross, I. J. and Egli, D. B. 1976. Storage Characteristics of Soybean Dried with Heated Air. *Trans. Am. Soc. Agric. Eng.,* **19:** 306-310.
31. Zeng, S. X., Ruan, R. R., Fulcher, G. R. and Paul, C. 1996. Evaluation of Soybean Seed Coat Cracking during Drying: Part I. Using Drying Tests. *Dry. Technol.*, **14**: 1575-1593.
32. Zhang, M., Li, C., Ding, X. and Cao, C. W. 2003. Optimization for Preservation of Selenium in Sweet Pepper under Low-vacuum Dehydration. *Dry. Technol.*, **21:** 569–580.

بهینه سازی پارامترهای فرآیند خشک کردن بذر سویا در خشک کن بستر ثابت آزمایشگاهی با استفاده از تکنیک سطح پاسخ

ع. عباسی سورکی، ف. شریف زاده، ر. توکل افشاری، ن. مجنون حسینی و ح. ر. گازر

چکیده

در برخی موارد، به منظور جلوگیری از زوال و خسارت مزرعه ای بذر سویا (*Glycine max* Merr.) در شرایط نامساعد آب و هوایی آخر فصل رشد، کشاورزان شروع به برداشت بذر در رطوبت های بالا می کنند. در این حالت به منظور حفظ کیفیت بذر بایستی خشک کردن بذر سویا با نهایت دقت انجام گیرد. به منظور بهینه سازی فرایند خشک کردن بذر سویا از تکنیک سطح پاسخ (RSM) استفاده شد. این مطالعه با استفاده از آزمایش فاکتوریل جزئی چهار فاکتوره در سه سطح به منظور تعیین شرایط مناسب رطوبت بذر در زمان برداشت و نیز اثر دما، سرعت جابجایی هوا و عمق بستر در طی خشک شدن بذرکه باعث بیشترین میزان جوانه زنی، بنیه و ظهور مزرعه ای می شود، انجام شد. بذور دو رقم سویای کلارک و سحر با رطوبت های بذری ۱۵ تا ۴۵ درصد (در واحد وزن خشک) با استفاده از خشک کن بستر ثابت در ترکیب های مختلف تیمار حرارتی ۳۵ تا۵۵ درجه سانتی گراد، سرعت باد ۰/۵ تا ۱/۵ متر بر ثانیه و عمق بستر تک لایه تا ۱۰ سانتی متر خشک شدند. نتایج آزمایشات جوانه زنی و بنیه بذر نشان داد، در رقم کلارک شرایط بهینه خشک شدن در دمای ۵۲ ^{o}C درجه به دست می آید که با افزایش رطوبت برداشت بایستی کاهش یابد. در صورت اعمال شرایط مناسب خشک شدن می توان برداشت را در رطوبت زیر ۳۰ درصد شروع کرد، اما رقم سحر حساسیت بیشتری به دما نشان داد به نحوی که دمای خشک شدن نبایستی بیش از ۴۱^{o}C باشد و برداشت را باید تا زمان رسیدن رطوبت بذرها به رطوبت ۳۲ درصد یا کمتر به تعویق انداخت. بعلاوه عمق های متوسط به سبب تهویه و سهولت جریان هوا و جلوگیری از خشک شدن بیش از حد توصیه می شوند. شاخصهای کیفیت بذر در این آزمایش به دمای خشک شدن و رطوبت اولیه بذر بیش از سرعت جریان هوا و عمق بستر بذر حساس بودند. نتایج به دست آمده در این بررسی می توانند در صنایع خشک کردن بذر سویا به منظور حفظ کیفیت بذر مورد توجه قرار گیرد.