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Optimization of the Seed Spacing Uniformity of a Vacuum Type Precision Seeder using Spherical Materials

Vakumlu Tip Tek Dane Ekim Makinası Sıra Üzeri Tohum Dağılım Düzgünlüğünün Küresel Materyaller Kullanılarak Optimizasyonu

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Key Words:

CCD, coated seed, planter, prediction functions, vacuum

ABSTRACT

The objective of this study was to optimize the seed spacing uniformity performance of a precision seeder using spherical materials and Response Surface Methodology (RSM) and to verify the optimum levels of the variables. The variables considered in the study included vacuum on seed plate, the diameter of seed holes and peripheral speed of the seed plate. Spherical materials made of plastic were used and experiments based on Central Composite Design (CCD), one of the designs in RSM, were carried out in the laboratory. The data obtained were divided into three different groups in order to obtain the values of Multiple Index, Quality of Feed Index, Miss Index. Other performance indicators called root mean square deviation and coefficient of precision (CP3) were also calculated and evaluated in the study. Prediction functions mostly for quality of feed index in polynomial form allowed the calculation of the optimum level of each independent variable. Optimum levels of the variables obtained for spherical materials resembling coated seeds were tested and verified.

Anahtar Sözcükler:

CCD, kaplanmış tohum, ekim makinası, tahminleme modelleri, vakum

ÖZET

Bu çalışmanın amacı vakumlu tip tek dane ekim makinası sıra üzeri tohum dağılım düzgünlüğü performansının küresel materyaller ve tepki yüzeyleri metodolojisi (RSM) kullanılarak optimizasyonu ve değişkenlerin optimum değerlerinin belirlenmesidir. Çalışmada, plakadaki vakum basıncı, plaka delik çapı ve plaka çevre hızı bağımsız değişkenler olarak ele alınmıştır. Denemelerde plastikten imal edilen küresel materyaller kullanılmış ve denemeler RSM dizaynlarından biri olan Merkez Esaslı Kompozit Dizayn (CCD)'a göre yürütülmüştür. Elde edilen veriler İkizleme Oranı, Kabul Edilebilir Tohum Aralığı Oranı ve Boşluk Oranı değerlerini belirlemek üzere üç gruba ayrılmıştır. Çalışmada ayrıca diğer performans göstergelerinden, ortalama sapma ve sıra üzeri tohum konumundaki doğruluk derecesi (CP3) değerleri de hesaplanmış ve değerlendirilmiştir. Bağımsız değişkenlerin optimum değerleri, çoğunlukla kabul edilebilir tohum aralığı oranına ilişkin polinomiyal formdaki tahminleme modelleri sayesinde hesaplanmıştır. Kaplanmış tohumları temsil eden küreseller materyallere ilişkin elde edilen optimum değerler denenerek doğruluğu sınanmıştır.

INTRODUCTION

Seeds are coated for ease of handling, singulation, precision placement and the incorporation of beneficial chemicals or microbials and coated seeds are accepted widely as a standard product for many crops (Kaufman, 1991). The coated seeds are larger, rounder, smoother, heavier and more uniform than the original seed and they can then be sown precisely with a belt, plate, cup or vacuum. Precision seeders equipped with vacuum plates are widely used in today's agriculture for planting seeds of various plants. Farmers using precision seeders usually have sets of plates to match each size of seed to be planted. There are many factors that contribute the accuracy of seed spacing in precision spacing. In the design process, it is assumed that the spacing between the seeds will be presumably uniform but the uniformity may change depending upon the soil conditions, machine related properties and the most important among them is the seed properties (Srivastava et al., 1993). Mean particle diameter, the geometry and the mass of the seeds differentiate the level of vacuum, the diameter of the holes and the peripheral speed of the vacuum plate.

Many studies in the past were conducted in order to determine the performance of precision seeders. These studies revealed information about how a metering system of a precision seeder performed in the laboratory or in the field. The studies on the performance of a precision seeder mostly focused on vacuum pressure applied to the vacuum plate, the most common metering system in precision seeders.

Singh et al. (2005) examined the effect of operational speed of the vacuum plate, vacuum pressure and shape of the entry of seed hole and evaluated the precision in spacing, miss index, multiple index and quality of feed index. However, they assumed that the appropriate hole diameter for cotton seeds was 2.5 mm. They found that the metering system with a speed of 0.42 m s^{-1} and a vacuum pressure of 2 kPa produced superior results with a quality of feed index of 94.7% and a coefficient of variation of 8.6% in spacing.

Panning et al. (2000) evaluated five seeder configurations for seed spacing uniformity at three field speeds using a seed location method in the field and a laboratory method involving an opto-electronic sensor system. They defined the planter seed spacing uniformity by using the coefficient of precision measure. They used sugar beet seed for their experimental study.

Moody et al. (2003) evaluated a row crop seeder performance in a field study and tested a vacuum-type seeder at three peripheral speeds of 0.16, 0.23 and 0.31 m s^{-1} with corresponding forward speeds of 1.33, 2.0 and 2.7 m s^{-1} using cotton and maize seeds. From the study, they concluded that the variability in seed spacing increased with increased peripheral speed.

Examples of the application of RSM to agricultural machinery related problems in the literature are very limited. One of these studies was conducted by Wang (1993) for performance testing of an onion-peeling machine using response surface methodology.

Another example of using RSM in the field of agricultural machinery is the one conducted by Yazgi and Degirmencioglu (2007). They optimized the performance of the metering systems of a precision seeder that delivers cotton seeds. They considered peripheral speed of the vacuum plate, hole diameter and the vacuum as independent variables that affect the seed spacing accuracy of the metering system. The study revealed that the optimum seed hole diameter of 3 mm while the vacuum pressure was found to be 5.5 kPa for cotton seeds used in the study.

In the other study, Yazgi and Degirmencioglu (2014) tried to put forward the effects of different vacuum plates with different hole numbers (20, 26, 36, 52 and 72 holes) on seeding performance using corn and cotton. They found that the highest performance was determined when 26 and 36 holes were used for cotton and corn, respectively.

RSM has been widely used in food science, chemistry and mechanical engineering problems. Underwood (1962) applied RSM in designing extrusion screws. In his experiment, the length of metering section, the channel depth in the feed section and the screw speed were considered as independent variables. Rate of extrusion, melt temperature, net power required smoothness of operation and thoroughness of mixing were dependent variables.

Wu (1964) successfully applied RSM to optimize the metal processing in a machine tool system, and a series of results were obtained in different subjects. Wu indicated that with RSM, the number of tests to develop tool-life predicting equations can be substantially reduced. The reliability of such an equation can also be estimated. Three independent variables, speed, feed and depth of cut, were investigated in the study.

Food engineering research has several characteristics that distinguish it from other research categories. Harper and Wanninger (1970) applied RSM to optimize a cereal toasting manufacturing process. The objective of the study was to determine the effect of the toaster's operation on the finished product flavor, color and specific volume. Raw product moisture, toaster conveying belt speed, toaster temperature and fan speed governing the hot air velocity were tested as independent variables.

The objective of this study was to optimize the performance of a precision seeder for planting spherical materials simulating coated seeds using response surface methodology and to verify the optimum level of the variables considered in the study.

MATERIALS and METHODS

A vacuum type precision seeder was used and the metering unit of the seeder consists of a vertically operating plate that the pressure differential is supplied by creating vacuum on the side of the disk opposite the seeds. Seed from the hopper enters the seed reservoir, where vacuum created by a fan holds the seeds in the seed cells on the rotating seed plate. The vacuum is blocked as the cells reach a point above the seed tube and the seeds fall into the tube by gravity. Adjustable singulation devices cause the doubles to fall back into the seed hopper. The mass of thousand spherical materials was found to be as 31.5, 105, 252 and 490.7 grams for 4, 6, 8 and 10 mm diameter, respectively.

RSM designs are not primarily used for understanding the mechanism of the underlying system and assessing treatment main effects and interactions, but to determine, within some limits, the optimum operating conditions of a system (Myers, 1971).

RSM consists of a group of statistical and mathematical techniques. It seeks to relate a *response*, or *output* variable to the levels of a number of *predictors*, or *input* variables, that affect the phenomena. To describe the effects of the single or combine independent variables and create a model that explained all of the process is possible with this technique (Box and Draper, 1987).

The design used in this study is a rotatable CCD and this design requires five levels for each independent variable. These levels were coded as -1.682, -1, 0, +1 and +1.682.

The seeder used in this study had a ground driven wheel that transfers the motion to the seed plate with a combination of gears available. The linear relation for the traveling speed and for the plate was that 1 m s^{-1} traveling speed means 0.138 m s^{-1} peripheral speed of the seed plate. The coded and uncoded peripheral speeds of the vacuum plate are given in Table 1. The selection of the peripheral speed of the plate was actually achieved considering the traveling speed of the seeder in the field.

Five different seed plates, each with a pitch diameter of 185 mm and 36 holes, were used. The plates were manufactured by a private company and the holes on seed plates were drilled on a laser cutting machine with a tolerance of ±0.1 mm. The determination of the range for hole diameter was based upon the determination of the maximum hole diameter since a certain value should be chosen as a maximum hole diameter so that the spherical materials can't go through it. The selected hole diameters in coded and uncoded form based on RSM design are tabulated in Table 2.

Table 1. Coded and uncoded levels of peripheral speed of the vacuum plate

Spherical material diameter	*Step value*	*Coded levels of the peripheral speed; X_1*				
		-1.682	-1	0	1	1.682
		(ms^{-1})				
4, 6, 8 and 10 mm Material	0.055	0.072	0.11	0.166	0.221	0.258

Table 2. Coded and uncoded levels of hole diameter

Spherical material diameter	*Step value*	*Coded levels of hole diameter; X_2*				
		-1.682 *(-α)*	-1	0	+1	1.682 *(+α)*
		(mm)				
4 mm	0.5	1.6590	2.0	2.5	3.0	3.3410
6 mm	1.4	1.1452	2.1	3.5	4.9	5.8548
8 mm	2.0	1.1360	2.5	4.5	6.5	7.8640
10 mm	2.6	1.1268	2.9	5.5	8.1	9.8732

α is defined as *[2k]1/4* and *k* is the number of factors (independent variables)

Vacuum applied on seed plate was varied between 2.32 and 5.68 kPa for spherical materials in the diameter of 4 and 6 mm while the vacuum range was between 2.64 and 9.36 kPa for those in the diameter of 8 and 10 mm. Coded and uncoded levels of vacuum are shown in Table 3.

Table 3. Coded and uncoded levels of vacuum applied on vacuum plate

Spherical material diameter	*Step value*	*Coded levels of hole diameter; X3*				
		-1.682 *(-α)*	-1	0	+ 1	1.682 *(+α)*
		(kPa)				
4 and 6 mm	1	2.32	3	4	5	5.68
8 and 10 mm	2	2.64	4	6	8	9.36

A number of measures based on the theoretical spacing of the seeder were defined by the International Organization for Standardization, as ISO Standard 7256/1-1984E (ISO, 1984). These measures include the quality of feed index, multiples index and miss index. In addition of these values, the coefficient of precision (CP3) and root mean square deviation from the theoretical seed spacing E_{rms} as proposed by Yazgi and Degirmencioglu (2007) were used.

Seed spacing accuracy tests were achieved on sticky belt and for this purpose, sticky belt test stand was used to measure the seed spacing in the laboratory. In order to facilitate this study, seed spacing measurements and its evaluations were made by means of a computerized measurement system, CMS, (Onal and Onal, 2009).

The test unit was equipped with a multi-speed drive arrangement to provide a range of belt surface speeds. In order to provide the theoretical seed spacing correctly, the seed metering mechanism was driven by another multi speed drive arrangement. Grease oil was smeared on the top surface of the belt to capture the seed as it was released from the seeder without rolling or bouncing of the seed on the belt surface. The seeder with a vacuum plate metering spherical materials was set to the theoretical seed spacing of 118 mm.

Each operating condition was set carefully and the vacuum level was measured with a manometer and each test was replicated three times.

The measured seed distances were entered in an excel spreadsheet for dividing the each data set into different groups of multiple, miss and quality of feed index. The performance data were then transferred into Minitab statistical package program for further analysis and for the development of response surface functions. All of the replications were used for the development of response surface functions. The response surface functions were tried to be developed for each performance namely quality of feed, multiple and miss index, E_{rms} and CP3. The functions developed were defined as full cubic polynomials. The mathematical software called Maple was used to find out the optimum levels of the variables from the developed polynomial functions for each spherical material. The seeder was then operated at optimum levels to verify the results for each spherical material.

RESULTS

The experimental results carried out in the laboratory based on CCD are given in Table 4 thru 7.

Stepwise regression analysis for each spherical material was achived at a probability level of 95%. This study indicated that the cubic polynomials provided better predictions even though quadratic functions are recommended in RSM designs. Hence, the models developed were in reduced cubic form since some of the terms were not included in the models. The quality of feed index functions were developed for 4, 6 and 10 mm spherical materials while only CP3 model was developed for 8 mm spherical one. The results from the regression analysis revealed no significant functions for the other performance indicators such as miss, multiple index and E_{rms} for all spherical materials while only significant CP3 model was obtained for 8 mm spherical material. In order to limit the performance between 0 and 100%, arcsin transformation was applied to the dependent performance indicator either I_{qf} or CP3.

For 4 mm spherical material, the developed performance function was for the transformed I_{qf} as in the following:

$$Y_{\phi 4} = \arcsin\left(\sqrt{\frac{I_{qf}}{100}}\right) \quad \textbf{(1)}$$

The function developed for 4 mm spherical material is written as in the following.

$$Y_{Ø4} = 1.316 - 0.091 X_1 + 0.034 X_2 - 0.023 X_1X_2 - 0.022 X_2X_3 - 0.0046 X_1^2 - 0.0493 X_2^2 + 0.0149 X_3^2 - 0.051 X_2^3 - 0.0314 X_1X_2X_3 \quad \textbf{(2)}$$

Table 4. Central composite design (CCD) with coded and uncoded independent variables and performance values for 4 mm spherical material

Run no	Independent variables			Dependent variables (Performance values[a])				
	X_1 [v, m s^{-1}]	X_2 [d,mm]	X_3 [P, kPa]	I_{qf} %	I_{miss} %	I_{mult} %	E_{rms}	CP3
1	-1	-1	-1	97.85	0.00	2.15	2.40	60.51
	[0.11]	[2]	[30]	(0.88)	(0.00)	(0.88)	(0.11)	(2.58)
2	-1	1	-1	97.67	1.78	0.55	1.80	75.71
	[0.11]	[3]	[30]	(0.84)	(0.22)	(0.95)	(0.06)	(4.00)
3	1	-1	-1	88. 60	6.74	4.66	4.18	41.47
	[0.221]	[2]	[30]	(0.92)	(1.39)	(2.24)	(0.06)	(10.09)
4	1	1	-1	90.23	6.54	3.23	3.75	49.04
	[0.221]	[3]	[30]	(1.85)	(1.26)	(2.97)	(0.34)	(8.67)
5	-1	-1	1	96.79	0.00	3.21	2.25	69.45
	[0.11]	[2]	[50]	(1.56)	(0.00)	(1.56)	(0.42)	(9.19)
6	-1	1	1	97.85	0.56	1.59	1.99	65.38
	[0.11]	[3]	[50]	(0.88)	(0.96)	(1.59)	(0.04)	(2.22)
7	1	-1	1	93.41	3.96	2.63	3.06	33.73
	[0.221]	[2]	[50]	(2.18)	(1.98)	(1.06)	(0.24)	(2.46)
8	1	1	1	81.54	13.18	5.28	3.89	36.85
	[0.221]	[3]	[50]	(2.67)	(2.45)	(2.36)	(0.25)	(1.03)
9	-1.682	0	0	96.61	1.69	1.69	1.80	77.36
	[0.072]	[2.5]	[40]	(0.11)	(0.06)	(0.06)	(0.15)	(3.85)
10	1.682	0	0	78.46	12.03	9.51	4.35	33.43
	[0.258]	[2.5]	[40]	(3.01)	(1.07)	(1.97)	(0.52)	(7.95)
11	0	-1.682	0	92.54	6.20	1.26	3.29	57.07
	[0.166]	[1.659]	[40]	(1.61)	(1.96)	(1.09)	(0.18)	(7.82)
12	0	1.682	0	63.86	18.08	18.06	6.17	23.48
	[0.166]	[3.341]	[40]	(2.80)	(0.38)	(2.93)	(0.64)	(2.89)
13	0	0	-1.682	90.85	5.45	3.70	2.94	53.20
	[0.166]	[2.5]	[23.18]	(0.26)	(1.69)	(1.94)	(0.22)	(5.69)
14	0	0	1.682	93.85	4.29	1.86	2.96	42.97
	[0.166]	[2.5]	[56.82]	(1.21)	(1.01)	(1.89)	(0.32)	(1.99)
15	0	0	0	93.71	4.41	1.89	2.96	56.69
	[0.166]	[2.5]	[40]	(1.09)	(1.09)	(0.04)	(0.38)	(7.54)
16	0	0	0	93.81	3.06	3.12	2.31	61.11
	[0.166]	[2.5]	[40]	(1.18)	(2.07)	(2.88)	(0.11)	(4.81)
17	0	0	0	94.48	3.09	2.43	2.66	50.16
	[0.166]	[2.5]	[40]	(1.12)	(2.22)	(2.10)	(0.26)	(10.91)
18	0	0	0	93.48	4.63	1.89	2.43	54.43
	[0.166]	[2.5]	[40]	(0.90)	(2.38)	(3.27)	(0.30)	(7.92)
19	0	0	0	93.98	3.62	2.40	2.64	50.00
	[0.166]	[2.5]	[40]	(0.96)	(1.79)	(1.01)	(0.18)	(1.79)
20	0	0	0	93.30	2.42	4.28	2.81	48.66
	[0.166]	[2.5]	[40]	(0.99)	(0.99)	(1.11)	(0.10)	(10.03)

Values in brackets are the uncoded values for independent variables: v, peripheral speed of the seed plate; d, hole diameter; P, vacuum pressure.
The dependent variables (performance values) are I_{qf}, quality of feed index; I_{miss}; miss index; I_{mult}, multiple index and E_{rms}, root-mean-square error.
[a] Average of three replication and values in parenthesis are the standard deviations

Table 5. Central composite design (CCD) with coded and uncoded independent variables and performance values for 6 mm spherical material

Run no	Independent variables			Dependent variables (Performance values[a])				
	X_1 [v, m s^{-1}]	X_2 [d,mm]	X_3 [P, kPa]	I_{qf} %	I_{miss} %	I_{mult} %	E_{rms}	CP3
1	-1	-1	-1	91.90	3.24	4.87	3.49	91.90
	[0.11]	[2.1]	[30]	(3.22)	(1.61)	(1.61)	(0.37)	(3.22)
2	-1	1	-1	93.53	1.08	5.40	2.95	93.53
	[0.11]	[4.9]	[30]	(1.69)	(0.93)	(2.49)	(0.15)	(1.69)
3	1	-1	-1	56.59	35.50	7.92	9.31	56.59
	[0.221]	[2.1]	[30]	(3.20)	(1.88)	(1.63)	(1.23)	(3.19)
4	1	1	-1	86.49	9.83	3.68	4.16	86.49
	[0.221]	[4.9]	[30]	(6.89)	(5.60)	(1.78)	(0.65)	(6.89)
5	-1	-1	1	97.92	0.00	2.08	2.54	97.92
	[0.11]	[2.1]	[50]	(0.87)	(0.00)	(0.87)	(0.26)	(0.87)
6	-1	1	1	88.76	4.85	6.39	3.87	88.76
	[0.11]	[4.9]	[50]	(4.20)	(3.21)	(1.45)	(0.69)	(4.20)
7	1	-1	1	67.69	19.61	12.70	6.04	67.69
	[0.221]	[2.1]	[50]	(2.34)	(1.59)	(2.11)	(0.79)	(2.34)
8	1	1	1	62.65	22.80	14.55	7.01	62.65
	[0.221]	[4.9]	[50]	(1.35)	(2.13)	(0.94)	(0.37)	(1.35)
9	-1.682	0	0	100.00	0.00	0.00	1.56	100.00
	[0.072]	[3.5]	[40]	(0.0)	(0.00)	(0.00)	(0.42)	(0.0)
10	1.682	0	0	81.51	14.01	4.48	4.49	81.51
	[0.258]	[3.5]	[40]	(3.10)	(1.19)	(2.24)	(0.37)	(3.10)
11	0	-1.682	0	0.00	0.00	0.00	0.00	0.00
	[0.166]	[1.145]	[40]	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
12	0	1.682	0	98.70	1.30	0.00	2.01	98.70
	[0.166]	[5.855]	[40]	(1.12)	(1.12)	(0.00)	(0.07)	(1.12)
13	0	0	-1.682	89.94	9.43	0.63	4.44	89.94
	[0.166]	[3.5]	[23.18]	(3.40)	(3.73)	(1.09)	(0.44)	(3.40)
14	0	0	1.682	100.00	0.00	0.00	1.98	100.00
	[0.166]	[3.5]	[56.82]	(0.0)	(0.00)	(0.00)	(0.04)	(0.0)
15	0	0	0	98.22	1.19	0.58	2.49	98.22
	[0.166]	[3.5]	[40]	(0.02)	(1.03)	(1.01)	(0.17)	(0.02)
16	0	0	0	99.39	0.00	0.61	2.18	99.39
	[0.166]	[3.5]	[40]	(1.05)	(0.00)	(1.05)	(0.10)	(0.00)
17	0	0	0	98.11	1.89	0.00	2.85	98.11
	[0.166]	[3.5]	[40]	(1.93)	(1.93)	(0.00)	(0.51)	(1.93)
18	0	0	0	99.39	0.61	0.00	2.49	99.39
	[0.166]	[3.5]	[40]	(1.05)	(1.05)	(0.00)	(0.35)	(1.05)
19	0	0	0	99.40	0.60	0.00	2.25	99.40
	[0.166]	[3.5]	[40]	(1.03)	(1.03)	(0.00)	(0.23)	(1.03)
20	0	0	0	97.58	1.82	0.60	2.53	97.58
	[0.166]	[3.5]	[40]	(1.01)	(0.03)	(1.03)	(0.29)	(1.01)

Values in brackets are the uncoded values for independent variables: v, peripheral speed of the seed plate; d, hole diameter; P, vacuum pressure.
The dependent variables (performance values) are I_{qf}, quality of feed index; I_{miss}; miss index; I_{mult}, multiple index and E_{rms}, root-mean-square error.
[a] Average of three replication and values in parenthesis are the standard deviations

Table 6. Central composite design (CCD) with coded and uncoded independent variables and performance values for 8 mm spherical material

Run no	Independent variables			Dependent variables (Performance values[a])				
	X_1 [v, m s^{-1}]	X_2 [d,mm]	X_3 [P,kPa]	I_{qf} %	I_{miss} %	I_{mult} %	E_{rms}	CP3
1	-1	-1	-1	66.96	33.04	0.00	9.51	33.17
	[0.11]	[2.5]	[40]	(1.62)	(1.62)	(0.0)	(1.98)	(1.74)
2	-1	1	-1	95.12	0.00	4.88	3.16	33.63
	[0.11]	[6.5]	[40]	(0.87)	(0.00)	(0.87)	(0.06)	(4.98)
3	1	-1	-1	15.38	83.51	1.11	40.23	1.11
	[0.221]	[2.5]	[40]	(1.79)	(3.35)	(1.92)	(1.98)	(1.92)
4	1	1	-1	85.45	11.38	3.17	4.61	30.19
	[0.221]	[6.5]	[40]	(0.94)	(1.79)	(1.11)	(0.55)	(3.27)
5	-1	-1	1	80.39	15.06	4.55	4.50	45.51
	[0.11]	[2.5]	[80]	(1.97)	(3.37)	(1.74)	(0.25)	(7.82)
6	-1	1	1	94.07	1.48	4.45	3.09	42.92
	[0.11]	[6.5]	[80]	(2.47)	(1.49)	(1.36)	(0.22)	(2.81)
7	1	-1	1	55.63	36.33	8.04	9.88	23.04
	[0.221]	[2.5]	[80]	(0.57)	(1.32)	(1.10)	(1.61)	(5.86)
8	1	1	1	72.37	14.75	12.89	6.27	17.58
	[0.221]	[6.5]	[80]	(3.92)	(3.81)	(3.71)	(0.75)	(3.78)
9	-1.682	0	0	96.94	0.00	3.06	2.97	43.70
	[0.072]	[4.5]	[60]	(1.46)	(0.00)	(1.46)	(0.52)	(3.69)
10	1.682	0	0	65.67	24.39	9.94	7.63	19.03
	[0.258]	[4.5]	[60]	(1.51)	(3.46)	(1.99)	(0.86)	(6.22)
11	0	-1.682	0	0.00	0.00	0.00	0.00	0.00
	[0.166]	[1.136]	[60]	(0.00)	(0.00)	(0.0)	(0.0)	(0.0)
12	0	1.682	0	88.92	7.02	4.06	4.46	36.93
	[0.166]	[7.864]	[60]	(1.72)	(1.74)	(2.59)	(0.83)	(4.57)
13	0	0	-1.682	71.21	17.99	10.80	6.37	35.54
	[0.166]	[4.5]	[26.4]	(2.59)	(2.19)	(1.88)	(0.79)	(5.03)
14	0	0	1.682	87.96	5.43	6.60	3.54	38.15
	[0.166]	[4.5]	[93.6]	(2.50)	(3.68)	(1.90)	(0.29)	(3.43)
15	0	0	0	86.25	8.16	5.59	3.98	35.41
	[0.166]	[4.5]	[60]	(3.48)	(0.82)	(3.15)	(0.09)	(1.89)
16	0	0	0	92.27	4.54	3.19	3.58	35.81
	[0.166]	[4.5]	[60]	(2.57)	(1.61)	(1.18)	(0.41)	(3.31)
17	0	0	0	85.59	6.96	7.45	3.90	31.47
	[0.166]	[4.5]	[60]	(1.94)	(1.58)	(2.88)	(0.31)	(3.69)
18	0	0	0	85.33	3.97	10.70	3.80	34.28
	[0.166]	[4.5]	[60]	(3.48)	(1.62)	(5.01)	(0.42)	(7.08)
19	0	0	0	86.58	6.12	7.29	3.93	35.41
	[0.166]	[4.5]	[60]	(1.97)	(1.49)	(0.49)	(0.21)	(8.04)
20	0	0	0	88.74	4.51	6.75	3.51	34.08
	[0.166]	[4.5]	[60]	(2.04)	(1.97)	(0.29)	(0.16)	(0.65)

Values in brackets are the uncoded values for independent variables: v, peripheral speed of the seed plate; d, hole diameter; P, vacuum pressure.
The dependent variables (performance values) are I_{qf}, quality of feed index; I_{miss}; miss index; I_{mult}, multiple index and E_{rms}, root-mean-square error.
[a] Average of three replication and values in parenthesis are the standard deviations

Table 7. Central composite design (CCD) with coded and uncoded independent variables and performance values for 10 mm spherical material

Run no	Independent variables			Dependent variables (Performance values[a])				
	X_1 [v, m s^{-1}]	X_2 [d,mm]	X_3 [P,kPa]	I_{qf} %	I_{miss} %	I_{mult} %	E_{rms}	CP3
1	-1	-1	-1	59.38	40.62	0.00	16.23	29.88
	[0.11]	[2.9]	[40]	(1.77)	(1.77)	(0.0)	(5.54)	(13.36)
2	-1	1 [8.1]	-1	96.42	3.58	0.00	2.12	93.40
	[0.11]		[40]	(1.87)	(1.87)	(0.0)	(0.51)	(5.61)
3	1	-1	-1	0.00	0.00	0.00	0.00	0.00
	[0.221]	[2.9]	[40]	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
4	1	1	-1	89.69	10.31	0.00	8.16	48.54
	[0.221]	[8.1]	[40]	(1.39)	(1.39)	(0.0)	(2.61)	(6.69)
5	-1	-1	1	76.60	22.12	1.28	6.63	37.81
	[0.11]	[2.9]	[80]	(2.19)	(4.29)	(2.22)	(0.36)	(5.34)
6	-1	1	1	99.49	0.00	0.51	2.56	44.37
	[0.11]	[8.1]	[80]	(0.88)	(0.0)	(0.88)	(0.26)	(12.09)
7	1	-1	1	47.91	51.11	0.98	19.19	11.98
	[0.221]	[2.9]	[80]	(1.82)	(1.92)	(1.69)	(5.47)	(7.92)
8	1	1	1	88.98	7.99	3.03	4.35	27.62
	[0.221]	[8.1]	[80]	(1.58)	(2.79)	(2.01)	(0.16)	(4.79)
9	-1.682	0	0	98.09	0.48	1.42	2.53	42.11
	[0.072]	[5.5]	[60]	(0.86)	(0.84)	(0.05)	(0.29)	(18.80)
10	1.682	0	0	64.10	22.87	13.03	7.12	19.72
	[0.258]	[5.5]	[60]	(2.37)	(2.87)	(1.45)	(0.50)	(5.32)
11	0	-1.682	0	0.00	0.00	0.00	0.00	0.00
	[0.166]	[1.127]	[60]	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
12	0	1.682	0	95.05	4.95	0.00	2.77	45.59
	[0.166]	[9.873]	[60]	(1.14)	(1.14)	(0.0)	(0.45)	(10.61)
13	0	0	-1.682	84.93	13.77	1.31	6.54	69.85
	[0.166]	[5.5]	[26.4]	(4.20)	(2.23)	(2.26)	(0.24)	(3.29)
14	0	0	1.682	94.83	2.87	2.30	3.58	36.21
	[0.166]	[5.5]	[93.6]	(0.00)	(0.99)	(0.99)	(0.73)	(0.00)
15	0	0	0	90.81	6.90	2.29	3.89	29.80
	[0.166]	[5.5]	[60]	(1.01)	(0.12)	(0.99)	(0.23)	(14.28)
16	0	0	0	90.31	6.64	3.05	3.57	37.57
	[0.166]	[5.5]	[60]	(0.80)	(0.76)	(1.10)	(0.29)	(3.12)
17	0	0	0	93.03	4.66	2.31	3.92	36.01
	[0.166]	[5.5]	[60]	(1.71)	(2.05)	(0.94)	(0.77)	(3.41)
18	0	0	0	88.86	7.65	3.49	4.42	38.59
	[0.166]	[5.5]	[60]	(1.39)	(2.23)	(1.66)	(0.55)	(0.40)
19	0	0	0	88.69	8.36	2.96	5.04	33.35
	[0.166]	[5.5]	[60]	(2.08)	(2.21)	(1.99)	(1.13)	(1.57)
20	0	0	0	91.83	5.85	2.32	3.84	41.28
	[0.166]	[5.5]	[60]	(2.20)	(2.13)	(2.01)	(0.46)	(4.01)

Values in brackets are the uncoded values for independent variables: v, peripheral speed of the seed plate; d, hole diameter; P, vacuum pressure.
The dependent variables (performance values) are I_{qf}, quality of feed index; I_{miss}; miss index; I_{mult}, multiple index and E_{rms}, root-mean-square error.
[a] Average of three replication and values in parenthesis are the standard deviations

The results from the regression analysis for 4 mm spherical material are tabulated in Table 8.

The performance function for 6 mm spherical materials was developed using the arcsin transformation of the square root of the I_{qf} value in decimals and the results from the regression analysis are given below (Table 9).

$$Y_{\varnothing 6} = 1.482 - 0.1517\,X_1 - 0.214\,X_2 - 0.075\,X_3 + 0.058\,X_1X_2 - 0.029\,X_1X_3 - 0.079\,X_2X_3 - 0.0464\,X_1^2 - 0.2621\,X_2^2 - 0.0246\,X_3^2 + 0.231\,X_2^3 + 0.06\,X_3^3 \quad \textbf{(3)}$$

The polynomial model for 8 mm spherical material was developed for the CP3 performance criteria and the following transformation was applied.

$$y_{\phi 8} = \arcsin\left(\sqrt{\frac{CP\,3}{100}}\right) \quad (4)$$

CP3 model as a performance model for 8 mm spherical materials has the following form. The results from the regression analysis are given in table 10.

Table 8. Results from the regression analysis for 4 mm spherical materials

Variable	***Coefficient***	***Standard error***	**R^2 (%)**
Constant	1.316	-	-
X_1	-0.091	0.0982	38.19
X_2^3	-0.051	0.0788	60.85
X_2^2	-0.0493	0.0654	73.54
$X_1X_2X_3$	-0.0314	0.0626	76.20
X_1X_2	-0.023	0.0612	77.63
X_2X_3	-0.022	0.0600	78.93
X_2	0.034	0.0590	80.04
X_3^2	0.0149	0.0579	81.12
X_1^{2*}	-0.0046	0.124	81.13

* Forced variable

Table 9. Results from the regression analysis for 6 mm spherical materials

Variable	***Coefficient***	***Standard error***	***R^2 (%)***
Constant	1.482	-	-
X_2^3	0.231	0.291	36.96
X_2^2	-0.2621	0.190	73.81
X_1	-0.1517	0.140	85.88
X_2	-0.214	0.114	90.90
X_2X_3	-0.079	0.102	92.80
X_3^3	-0.06	0.0923	94.23
X_1^2	-0.0464	0.0840	95.31
X_1X_2	0.058	0.0748	96.35
X_3	-0.075	0.069	96.96
X_3^2	-0.0246	0.0657	97.29
X_1X_3	-0.029	0.0631	97.55

Table 10. Results from the regression analysis for 8 mm spherical materials

Variable	***Coefficient***	***Standard error***	**R^2 (%)**
Constant	1.482	-	-
X_2^3	0.0664	0.168	30.19
X_1	-0.171	0.138	53.54
X_2^2	-0.1024	0.105	73.34
X_2X_3	-0.077	0.0933	79.47
$X_1X_2X_3$	-0.07	0.082	84.46
$X_1^2X_3$	0.064	0.0707	88.64
X_1X_2	0.059	0.059	92.25
X_1^3	0.0315	0.0538	93.67

$$Y_{Ø8} = 0.6271 - 0.171\ X_1 + 0.059\ X_1X_2 - 0.077\ X_2X_3 - 0.1024\ X_2^2 - 0.07\ X_1X_2X_3 + 0.064\ X_1^2X_3 + 0.0315\ X_1^3 + 0.0664\ X_2^3 \quad \textbf{(5)}$$

Only quality of feed index function was developed for 10 mm spherical materials while other performance models such as I_{miss}, I_{mult}, E_{rms} and CP3 were statistically insignificant. As in the case of 4 and 6 mm spherical materials, arcsin transformed I_{qf} model obtained is given below.

$$Y_{Ø10} = 1.236 + 0.362\ X_2 - 0.207\ X_2^2 - 0.181\ X_1 + 0.135\ X_1^2X_3 - 0.102\ X_2X_3 + 0.093\ X_1X_2 - 0.092\ X_1X_2X_3 \quad \textbf{(6)}$$

The results from regression analysis for 10 mm spherical materials are given below in table 11. The variables included in the model are given in the order they entered into the model.

Table 11. Results from the regression analysis for 10 mm spherical materials

Variable	*Coefficient*	*Standard error*	R^2 (%)
Constant	1.236	-	-
X_2	0.362	0.282	53.90
X_2^2	-0.207	0.218	72.79
X_1	-0.181	0.157	86.22
$X_1^2X_3$	0.135	0.130	90.63
X_2X_3	-0.102	0.113	93.15
X_1X_2	0.093	0.0948	95.23
$X_1X_2X_3$	-0.092	0.0726	97.25

DISCUSSION

Once the results from the stepwise regression analysis are reviewed, it is clear that the seed spacing accuracy performance for spherical materials is governed by the hole diameter except for 4 mm spherical materials. Yazgi and Degirmencioglu (2007) concluded the same result from their study when cotton seeds were used in order to optimize the performance of a precision seeder.

Quality of feed index or CP3 functions are the ones that should be maximized and this was done in Maple and the uncoded values of the peripheral speed, hole diameter and vacuum are calculated and employing the step value and center point as given in table 1 thru 3. The optimum levels of the variables for spherical materials are given in Table 12.

One of the interesting point in Table 12 is that there is an increasing tendency in both, peripheral speed of vacuum plate and hole diameter. On the other hand, the optimum vacuum level fluctuates as the diameter of spherical material increases. This means that the optimum vacuum level goes down from 5.236 kPa to 3.26 kPa as the diameter of spherical materials increases from 4 to 6 mm. This vacuum reduction could be the result of significantly increased hole diameter since it went from 1.89 to 4.9 mm once the diameter of the spherical material was increased from 4 to 6 mm. As a matter of fact, the interaction of variable X_2 and X_3 affects the performance and this interaction were brought into each spherical material model as given in equation 2,3, 5 and 6.

The optimum values indicated in Table 12 were verified in the laboratory and three replications were carried out for each spherical material and the findings from the verification tests are tabulated in Table 13.

Table 12. Coded and uncoded optimum levels of the variables for spherical materials

	Independent variables					
	Peripheral speed (X_1)		*Hole diameter* (X_2)		*Vacuum* (X_3)	
Material	*Coded*	*Uncoded* (ms^{-1})	*Coded*	*Uncoded* (mm)	*Coded*	*Uncoded* (kPa)
Ø4 mm	-1.656	0.075	-1.2262	1.89	1.2362	5.23
Ø6 mm	-0.757	0.124	1.0346	4.90	-0.7394	3.26
Ø8 mm	-0.7082	0.127	1.1701	6.84	-0.3163	5.36
Ø10 mm	-0.5532	0.135	0.8085	7.60	-0.4729	5.05

Table 13. Results from the verification tests at optimum levels of the variables

	I_{qf} (%)			E_{rms}			*CP3* (%)		
	Replication			*Replication*			*Replication*		
Material	1	2	3	1	2	3	1	2	3
Ø4 mm	100	100	100	1.91	1.45	1.71	38.30	38.66	38.89
Ø6 mm	100	100	100	1.31	1.39	1.28	72.73	72.22	80.33
Ø8 mm	100	100	100	1.12	1.13	1.21	80.33	79.63	76.79
Ø10 mm	100	100	100	1.21	1.23	1.22	83.93	76.27	79.66

As seen from Table 13, the quality of feed index obtained from the verification tests is 100% for all spherical materials and E_{rms} and CP3 values are at acceptable levels. For 4 mm spherical materials, the quality of feed index results from the CCD based design tests given in table 4 ranged between 78.46 (run number 10) and 97.85 % (run number 6). The corresponding E_{rms} and CP3 values for run number 10 were 4.35 and 33.43, respectively while the test for run number 6 resulted in E_{rms} and CP3 values of 1.99 and 65.38. But the tests carried out at optimum levels of the variables provided I_{qf} of 100 % while E_{rms} ranged between 1.45 and 1.91. But the CP3 values obtained at optimum levels of the variables are lower as compared to the case of run number 6. But E_{rms} is a more price performance criteria than CP3.

On the other hand, it is interesting to note that verification tests carried out for 6 mm spherical materials resulted in 100 % quality of feed index and E_{rms} and CP3 indicators were in the range of 1.28 -1.39 and 72.22 – 80.33 range, respectively as seen from table 5. Even though 100 % of I_{qf} was obtained in run number 9 and 14 but the verification tests at optimum levels gave reasonably lower E_{rms} values.

For 8 and 10 mm spherical materials, none of the runs tabulated in table 6 and 7 generated a quality of feed index of 100 % while the verification tests for both materials at optimum levels reached 100 % I_{qf} and the lowest value of E_{rms} as compared to CCD based tests. Some typical view from the response surface functions are depicted in figure1 thru 3.

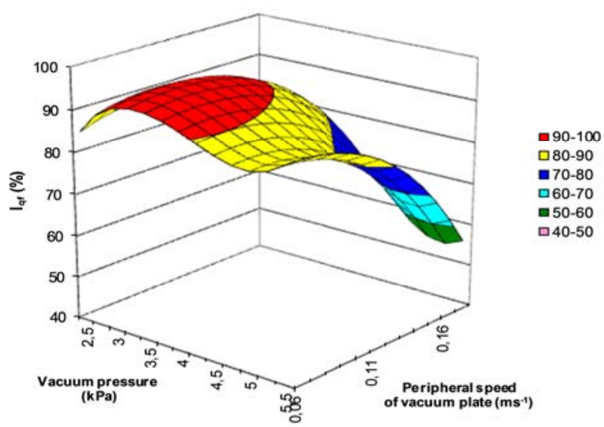

Figure 1. Quality of feed index as a function of vacuum and peripheral speed of vacuum plate (hole diameter: 4.9 mm) for 6 mm spherical materials

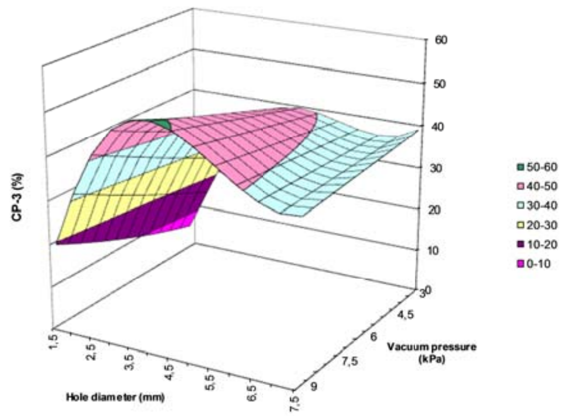

Figure 2. CP3 as a function of vacuum and hole diameter(peripheral speed of vacuum plate:0.127 m s^{-1}) for 8 mm spherical materials

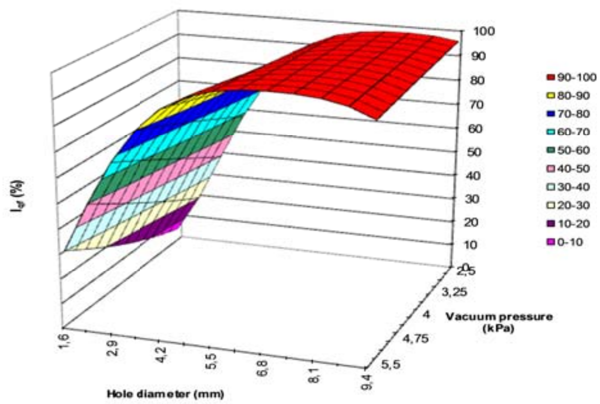

Figure 3. Quality of feed index as a function of vacuum and hole diameter (peripheral speed of vacuum plate: 0.135 m s^{-1}) for 10 mm spherical materials

The followings were drawn from the study conducted:

- The quality of feed index (I_{qf}) is mostly affected by the hole diameter on seed plate while peripheral speed of the vacuum plate is of importance. The level of vacuum fluctuates as the diameter of spherical material increases. This fluctuation could be explained by the significantly increased diameter, especially if the diameter increases from 4 to 6 mm.
- The peripheral speed of the seed plate and hole diameter on seed plate are correlated with the physical properties of the spherical materials.
- The level of vacuum for each spherical material seems to be the one that enough suction is applied to hold a seed on hole and the interaction of hole diameter and vacuum significantly affects the seeder performance.

- The peripheral speed of the vacuum plate and corresponding forward speed of the seeder increases as the diameter of the spherical material increases from 4 to 10 mm and this means that the field capacity of the seeder increases if the spherical material diameter increases under practical conditions and seeding at desired accuracy can be achieved.

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