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Development of Prediction Functions for a Maximized Precision Seeding Performance Based on Optimized Variables *

Tek Dane Ekim Performansı Maksimizasyonunda Optimum Değişkenlere Bağlı Genel Model Denklemlerinin Geliştirilmesi

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*E.Ü. Fen Bilimleri Enstitüsü'nde yapılmış doktora tezinin (Yazgı, 2010) bir bölümüdür.

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Key Words:

Central composite design, physical properties, seed, performance, mathematical modeling.

ABSTRACT

The objective of this study was to develop prediction functions for the variables that affect precision seeding performance. The variables considered were the amount of vacuum, peripheral speed and the diameter of the holes on vacuum plate. On the other hand, these variables are significantly affected by physical properties of the seeds and govern the seeding phenomenon that is the capture, release and incorporation of seeds into the soil. Experiments using Central Composite Design which is one of the designs in Response Surface Methodology (RSM) were conducted in the lab and different seeds were used to meet the objective. Hence, using different seeds with different physical and aerodynamic properties such as sphericity, thousand seed mass, projected area, terminal velocity, mean particle diameter and coefficient of friction of material on metal are expected to contribute the development of prediction models for a maximized seeding performance. According to results of the statistical analyses, hole diameter and vacuum pressure models were developed while no significant model was developed for the peripheral the speed of the vacuum plate. The appropriate hole diameter was found to be the function of mean particle diameter and sphericity with a coefficient of determination of 92.69%, while vacuum pressure was correlated to sphericity and terminal velocity (R^2=76.74 %). The developed models were verified by the use of different seeds and seed distribution was evaluated.

Anahtar Sözcükler:

Merkez esaslı dizayn, fiziksel özellikler, tohum, performans, matematik modelleme

ÖZET

Bu çalışmanın amacı tek dane ekim performansı üzerinde etkisi olan değişkenlerin tahminleme eşitliklerinin geliştirilmesidir. Çalışmada, tohumun fiziksel özelliklerine bağlı olarak değişen, tohumun yakalanması, bırakılması ve toprakla temasında sistemi yöneten parametrelerden olan vakum basıncı, plaka çevre hızı ve plaka delik çapı değişkenleri bağımlı değişkenler olarak ele alınmıştır. Denemeler, Tepki Yüzeyleri Metodolojisi (RSM) deneme desenlerinden biri olan Merkez Esaslı Dizayna göre farklı tohumlar kullanılarak laboratuvarda yürütülmüştür. Küresellik, bin dane ağırlığı, yüzey izdüşüm alanı, kritik hız, ortalama anma çap ve metal üzerinde sürtünme katsayısı vb. fiziksel ve aerodinamik özellikleri birbirinden farklı tohumlar kullanılarak ekim performansını maksimize eden tahminleme modellerinin geliştirilmesi hedeflenmiştir. İstatistik analiz sonuçlarına göre, plaka delik çapı ve vakum basıncına ilişkin tahminleme modelleri geliştirilirken, plaka çevre hızına ilişkin istatistiksel olarak anlamlı bir model elde edilememiştir. Uygun plaka delik çapının, tohumun ortalama anma çapı ve küresellik değerlerinin bir fonksiyonu olduğu ve model denkleminin tahminleme katsayısının %92.69 olduğu saptanmıştır. Vakum basıncı ise küresellik ve kritik hız değerlerinin bir fonksiyonu olup tahminleme katsayısı %76.74'dir. Geliştirilen model denklemlerinin geçerliliği farklı tohumlarla da test edilerek tohum dağılımları değerlendirilmiştir.

INTRODUCTION

Uniform seed spacing reduces the plant competition by providing a better soil medium for each seed and results in a higher yield when seeding that considers certain number of plant per unit area is achieved. For uniform seed spacing, seeders with vacuum type metering systems are used in all over the world.

The precision seeding with a vacuum type metering system is such phenomena that two processes have to be achieved to precisely incorporate seeds at requested seed spacing. Holding seeds on holes of a vacuum plate is the first process and this requires a specific vacuum, hole diameter and a certain peripheral speed. Once this process is achieved properly, the second process that is the release of seeds from vacuum plate determines the performance of precision seeding.

Seed related properties such as 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 (Srivastava et al., 1993). Hence, these variables should be carefully chosen for an acceptable performance.

The studies on the performance of precision seeding in the past mostly targeted the amount of vacuum on vacuum plate while the other important variables such as hole diameter and the peripheral speed of the vacuum plate were assumed. Singh et al. (2005) conducted a study using cotton seeds and they concluded that a vacuum pressure of 2 kPa produced superior results that provided a quality of feed index of 94.7% and a coefficient of variation in spacing of 8.6%. In another study, Moody et al. (2003) worked on the performance of a precision seeder that was used at different ground speeds of 4.8, 7.2 and 9.7 kmh^{-1} and they used cotton and maize seeds. From the study they conducted they found that the variability in seed spacing increased with increasing seed metering unit rotational speed. In another study, Karayel et al (2004) focused on vacuum need of different crops in precision seeding with a vacuum type metering unit. As it differs from this study they assumed a certain hole diameter for crops used in their study while the traveling speed was kept constant at 1 ms^{-1}. Using the raw data obtained, they developed a vacuum prediction model based on the highest quality of feed index values obtained from ten different crops. But, it is believed that precision seeding with vacuum plates is such a phenomena that variables such as hole diameter and peripheral speed of the vacuum plate along with vacuum pressure and their interactions play a significant role on seeding performance.

The study that considered the three variables, namely vacuum pressure, seed hole diameter and the peripheral speed of the vacuum plate was conducted by Yazgi and Degirmencioglu (2007) and they tried to optimize the performance of the vacuum type precision seeder and they used different performance indicators. 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. The interesting finding from their study was that the effect of the peripheral speed of the vacuum plate linearly correlated to the seed spacing accuracy. Increase in peripheral speed as linearly associated with the ground speed of the seeder cause a reduction in seed spacing accuracy.

A recent study conducted by St Jack et al. (2013) targeted the development of a seed metering unit for precision seeding of santalum spicatum seeds. Nine vacuum discs were tested and three different vacuum levels were used to obtain a theoretical seed spacing of 200 mm at a ground speed of 4 km h^{-1}. The most accurate configurations from their study were found with the discs with seven holes at a diameter of 10 or 12 mm at a vacuum pressure of 17 kPa for precision seeding of sandalwood seeds. As understood from the past studies on precision seeding, the physical properties of the seeds significantly change the constructional and operational variables. It is believed that the generalized models for the three variables, vacuum pressure, hole diameter and the peripheral speed of the vacuum plate may help operating the seeders at a maximized performance. Hence a study conducted and the objective of this study was to develop prediction functions for the variables that affect precision seeding performance. The variables considered were the amount of vacuum, peripheral speed and the diameter of the holes on vacuum plate.

MATERIAL and METHODS

A precision seeder with a vertically operating vacuum plate was used in this study and operated in the laboratory in order to obtain the performance while different seeds were employed. The metering unit of the precision seeder is depicted in figure 1 while the physical properties of the seeds used in the seed spacing accuracy performance tests are tabulated in table 1. In order to simulate the precision seeding in the laboratory, a greased belt stand was used. The seeder for the performance testing for all of the seeds was set to a theoretical seed spacing of 118 mm.

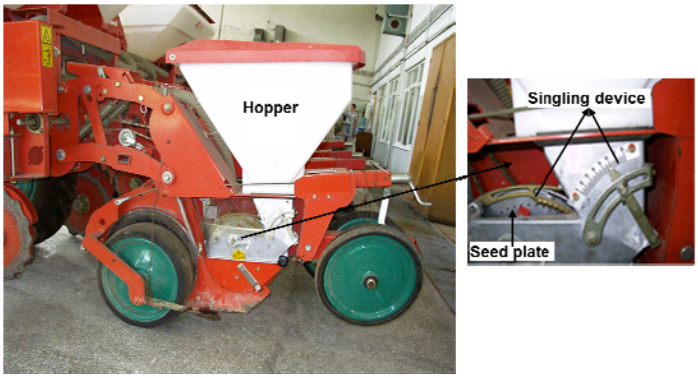

Figure 1. The 4-row vacuum type precision seeder and metering unit

Table 1. Physical properties of the seeds used in the study

Seeds	Sphericity (Φ,%)*	Thousand seed mass (m_{1000}, g)	Projected area (A_p, mm^2)	Terminal velocity (V_t, ms^{-1})	Mean particle diameter** (D_p ,mm)	Coefficient of friction of material on metal (μ)
Maize	75.0	343.75	17.29	13.5	8.03	0.294
Chickpea	80.3	596.30	36.18	13.7	9.77	0.276
Cotton	65.9	90.55	7.38	10.7	5.41	0.336
Sunflower	54.8	59.68	11.43	6.5	5.69	0.335
Soybean	89.3	180.79	9.77	13.9	6.57	0.297
Sugar beet	87.5	16.55	3.25	7.5	3.41	0.302
Canola	92.4	3.32	3.13	7.1	1.96	0.297

*calculated as $\Phi = \frac{\sqrt[3]{l\,wt}}{l}x100$ and ** $D_p = \sqrt[3]{l\,wt}$ where l; length, w; width, t; thickness of kernel

To optimize the performance of the precision seeder, an optimization technique called RSM was employed. The experiments based on Central Composite Design (CCD), one of the RSM designs that require five levels for each independent variable was conducted (Box and Draper, 1987). The independent variables considered in the study in coded form for CCD are given in table 2.

Table 2. Coded levels of of independent variables for CCD

Run number	X_1	X_2	X_3
1	-1	-1	-1
1	+1	-1	-1
1	-1	+1	-1
1	+1	+1	-1
1	-1	-1	+1
1	+1	-1	+1
1	-1	+1	+1
1	+1	+1	+1
1	-1.682	0	0
1	+1.682	0	0
1	0	-1.682	0
1	0	+1.682	0
1	0	0	-1.682
1	0	0	+1.682
6	0	0	0

Total number of experiments : 20

Five different peripheral speeds of the vacuum plate were provided by driving the ground wheel on the seeder at five different travelling speeds since the motion from the ground wheel to the metering unit is transferred with different gears that allow different seed spacings. The peripheral speeds of the vacuum plate in coded and uncoded form are given in table 3. As a requirement of the CCD, the vacuum plates with five different hole diameters were used along with five different vacuum pressures for each seed.

Five different vacuum plates with a pitch diameter of 185 mm and 36 holes were manufactured by a private company and the holes with a tolerance of ± 0.1 mm were drilled on a laser cutting machine. The selected hole diameters and vacuum levels ranging between 2.318 and 9.36 kPa according to seed size are tabulated in table 4 and 5, respectively.

Even though many different performance indicators were developed and presented in the literature, the most common used one is the one defined by the International Organization for Standardization, as ISO Standard 7256/1-1984E (ISO, 1984). This standard includes three measures named as the quality of feed index, multiples index and miss index.

Table 3. Coded and uncoded levels of peripheral speed of the vacuum plate

		Coded levels of peripheral speed; X_1				
		-1.682	-1	0	1	1.682
Material	Step value			(ms^{-1})		
For all seeds	0.04	0.052	0.08	0.12	0.16	0.187

Table 4. Coded and uncoded levels of hole diameter for seeds

		Coded levels of hole diameter ; X_2				
		-1.682	-1	0	1	1.682
Seed	Step value			(mm)		
Maize	1.0	2.3	3.0	4.0	5.0	5.7
Chickpea	1.0	4.1	4.8	5.8	6.8	7.5
Cotton	0.5	1.7	2.0	2.5	3.0	3.3
Sunflower	0.5	1.2	1.5	2.0	2.5	2.8
Soybean	1.0	1.8	2.5	3.5	4.5	5.2
Sugar beet	0.4	1.1	1.4	1.8	2.2	2.5
Canola	0.25	0.6	0.75	1.0	1.25	1.4

Table 5. Coded and uncoded levels of vacuum applied on vacuum plate for different seeds

		Coded levels of vacuum; X_3				
		-1.682	-1	0	1	1.682
Seed	Step value			(kPa)		
Maize	2	2.64	4.0	6.0	8.0	9.36
Chickpea	2	2.64	4.0	6.0	8.0	9.36
Cotton	2	2.64	4.0	6.0	8.0	9.36
Sunflower	2	2.64	4.0	6.0	8.0	9.36
Soybean	1	2.32	3.0	4.0	5.0	5.68
Sugar beet	1	2.32	3.0	4.0	5.0	5.68
Canola	1	2.32	3.0	4.0	5.0	5.68

The quality of feed index is such a measure that is calculated as the percentage of seeds within a range of $> 0.5\ Z_t$ to $\leq 1.5\ Z_t$ whereas the Z_t is the theoretical seed spacing. On the other hand the multiple index represents the multiple seeds delivered from the metering unit within a range of 0 to $\leq 0.5\ Z_t$ while the miss index is considered to be the percentage of seeds dropped at a distance of $> 1.5\ Z_t$.

In ideal conditions in the field, the seeder is expected to incorporate seeds with a quality of feed index of %100. This means that no multiples and misses occur.

In order to conduct performance tests in the laboratory, the grease smeared belt test stand of 0.14 m wide and 15 m long was used and seed spacing measurements were achieved by means of a computerized measurement system. For detailed information, the reader is referred to read the article written by Onal & Onal, 2009.

The precision metering unit and sticky belt stand were driven by separate speed drive arrangement and the theoretical seed spacing of 118 mm was kept constant in each test and three replications were made.

The vacuum level was measured with a digital manometer and each test was replicated three times.

The data obtained from each test were divided into three different groups and the indexes defined above were found for each seed. These groups were then compiled in an Excel sheet and all of the replications were used to develop performance functions. The functions in either quadratic or cubic polynomials were analyzed in Minitab Statistical package program while the optimum level of the variables was calculated in a software called Maple. The optimum level of the variables for each seed was tested.

RESULTS and DISCUSSION

The functions only for the quality of feed index were developed for all of seeds used in this study since the results from the Stepwise Regression Analysis revealed no significant functions for the other performance indicators such as miss and multiple index. In order to limit the performance between 0 and 100%, some transformations were applied to the dependent performance indicator, I_{qf}. These transformation used were; "*arcsin*" transformation for maize, soybean and canola, "*ln*" transformation for sunflower and "*square root*" transformation for cotton and chickpea.

The following performance functions for maize (Y_{maize}), chickpea ($Y_{chickpea}$), cotton (Y_{cotton}), sunflower ($Y_{sunflower}$), soybean ($Y_{soybean}$), sugarbeet ($Y_{sugarbeet}$) and canola (Y_{canola}) were developed (Yazgi, 2010; Yazgi & Degirmencioglu, 2007):

$$Y_{maize} = \arcsin\left(\sqrt{\frac{I_{qf}}{100}}\right) = 1.351 - 0.089 X_1 + 0.0721 X_2 + 0.0459 X_3 + 0.0546 X_1X_2 - 0.048\ X_2X_3 - 0.0391 X_1^2 - 0.0837 X_2^2 - 0.0341 X_3^2 \ldots \quad (R^2=92.35\%) \tag{1}$$

$$Y_{chickpea} = \sqrt{I_{qf}} = 9.48 - 0.219 X_1 + 0.393 X_2 + 0.225 X_1X_2 + 0.137 X_1X_3 - 0.589 X_2X_3 - 0.111 X_2^2 - 0.564 X_3^2 - 0.118 X_1X_2X_3 + 0.408 X_3^3 \ldots \quad (R^2=94.28\%) \tag{2}$$

$$Y_{cotton} = \sqrt{I_{qf}} = 9.33 - 0.412 X_1 + 0.943 X_2 + 0.702 X_3 + 0.351 X_1X_2 - 0.693 X_2X_3 - 0.361 X_2^2 - 0.385 X_3^2 \ldots \quad (R^2=94.75\%) \tag{3}$$

$$Y_{sunflower} = \ln(I_{qf}) = 4.327 - 0.088 X_1 + 0.141 X_2 + 0.062 X_3 + 0.084 X_1X_2 + 0.095 X_1X_3 - 0.14 X_2X_3 + 0.025 X_1^2 - 0.115 X_2^2 - 0.035 X_1X_2X_3 \ldots \quad (R^2=90.46\%) \tag{4}$$

$$Y_{soybean} = \arcsin\left(\sqrt{\frac{I_{qf}}{100}}\right) = 1.298 + 0.041 X_2 + 0.089 X_3 + 0.022 X_1X_3 - 0.052 X_2X_3 - 0.0214 X_1^2 - 0.1351 X_2^2 - 0.0415 X_3^2 - 0.15 X_1X_2^2 - 0.0208 X_1^3 + 0.0535 X_2^3 - 0.0193 X_3^3 \quad (R^2=95.71\%) \tag{5}$$

$$Y_{sugarbeet} = 90.6 - 2.88 X_2 - 1.15 X_3 + 1.96 X_1X_2 - 1.39 X_1X_3 - 3.2 X_2 - 1.82 X_3 - 2.6 X_1X_2^2 \quad (R^2=81.28\%) \tag{6}$$

$$Y_{canola} = \arcsin\left(\sqrt{\frac{I_{qf}}{100}}\right) = 1.203 - 0.1417 X_1 - 0.067 X_2 - 0.1888 X_2^2 - 0.0319 X_3^2 + 0.034 X_1X_2X_3 + 0.0289 X_1^3 + 0.0531 X_2^3 \ldots \quad (R^2=92.77\%) \tag{7}$$

The above functions as in the form of either quadratic or cubic polynomials were transferred to the mathematical software called Maple to find out the optimum levels of the variables. The seeder was then operated at optimum levels calculated to verify the results for each seed. The findings from the verification tests are as follows.

Verification tests for the quality of feed index performance at optimum level of the variables

The optimum level of the variables found from Maple, using a special code written in the package program is tabulated in table 6. The I_{qf} values predicted from the use of optimum levels of each variable by using the functions as in coded form given above are also given in the table. The sticky belt tests for each seed at optimum level of the variables were also conducted and three replications were achieved in order to compare the sensitivity of the models and to test the optimum levels.

As seen from table 6, the quality of feed index found from the verification tests is greater than the predicted ones for all of the seeds except for cotton and canola. It should be noted that the results obtained for the verification tests of the two models with the lowest coefficient of determination (R^2), namely sugar beet and sunflower models showed the highest variation with the predicted values but it could be stated that the precision seeding performance obtained from all of the verification tests point out very high seeding performance and the objective in precision seeding such as high precision seed spacing accuracy was met.

Table 6. Coded and uncoded optimum levels of independent variables for each seed and experimental seeder performance tested at the optimum conditions (Yazgı, 2010)

	Independent Variables						Predicted quality of feed index (I_{qf})	Quality of feed index (I_{qf}) values obtained from verification tests
	Peripheral speed of the vacuum plate (X_1)		Hole diameter (X_2)		Vacuum Pressure (X_3)			
Seed	Coded	Uncoded (ms^{-1})	Coded	Uncoded (mm)	Coded	Uncoded (kPa)	(%)	Mean (%)
Maize	-1.301	0.068	-0.233	3.77	0.837	7.68	96.34	99.48 [0.90]
Chickpea	-1.469	0.061	1.005	6.81	-0.387	5.23	97.69	100 [0]
Cotton	-0.586	0.96	1.173	3.08	-0.11	5.78	100.00	99.67 [1.73]
Sunflower	-0.497	0.1	0.119	2.06	0.584	7.17	82.77	95.24 [1.03]
Soybean	-0.586	0.096	0.318	3.82	0.525	4.53	93.93	100 [0]
Sugar beet	0.395	0.136	-0.248	1.7	-0.466	3.53	91.26	100 [0]
Canola	-1.281	0.069	-0.178	0.96	0.121	4.12	94.31	93.89 [0.96]

The numbers in brackets next to experimental mean I_{qf} values are the standard deviation calculated from three replications.

In order to meet the objective in this study, the seed related variables such as sphericity, thousand seed mass, projected area, terminal velocity, mean particle diameter and coefficient of friction of material on metal of seeds were correlated with the optimum level of the variables separately to develop general prediction functions for hole diameter, peripheral speed and vacuum pressure. The findings from the statistical analysis are given below.

Results for the development of a prediction model for hole diameter on vacuum plate

As a result of the stepwise regression analysis, the prediction model for the hole diameter *(Y_D; mm)* on vacuum plate given below (Eq. 8) was obtained by using the optimum levels of the hole diameter for seven different seeds.

$$Y_D = -5.177 + 0.819 * D_p + 0.047 * \Phi \quad (8)$$

As seen from the equation given above, only mean particle diameter (D_p;mm) and the sphericity (Φ; %) was found to be significant at 95% probability level used in stepwise regression analysis and the two seed related properties contribute to the prediction of appropriate hole diameter. The model has a coefficient of determination of 92.69% and the mean particle diameter of seed alone was able to explain the 83.08% of the variation in hole diameter while sphericity made a contribution of 9.61%.

Results for the development of a prediction model for vacuum pressure

The prediction model (Eq. 9) for the vacuum pressure *(Y_V; kPa)* was developed as a result of the stepwise regression analysis of seed-specific optimum levels of vacuum pressure as they were correlated to the physical and aerodynamic properties of the seeds.

$$Y_V = 10^{2.833} * \Phi^{(-1.31)} * V_c^{(0.37)} \quad (9)$$

As seen from above written equation, the vacuum need on vacuum plate only included the sphericity (in percent); Φ and terminal velocity (in ms^{-1}); V_c. The sphericity and terminal velocity of the seeds were able to explain the variation of 58.87% and 17.87%, respectively. This means that the coefficient of variation of the resultant model was 76.7 %. But it should be pointed that there is an inverse relationship between the vacuum pressure and sphericity of the seed while increase in terminal velocity increases the vacuum need for precision seeding phenomena.

Even though the coefficient of determination of the above written model is less than the hole diameter model but it could be considered as an meaningful model since terminal velocity of a seed is directly related to the mass a material such as seed and the sphericity is of importance to suck and hold a seed on a hole.

The analysis carried out to create a prediction model for the peripheral speed of the vacuum plate revealed no significant model. The detailed investigation using the results tabulated in table 6 in terms of optimum level of the peripheral speed shows that the peripheral speed varies in a narrow range between 0.061(for chickpea) and 0.13 (for sugar beet). These values correspond to 0.61 and 1.3 ms^{-1} traveling speed of the precision seeder. This narrow range limited the development of a prediction function for the peripheral speed of the vacuum plate. Considering to achieve a high field work rate (hah^{-1}) the peripheral speed as linearly corresponds to traveling speed was set to an average value of 0.1 ms^{-1} in the verification tests for the seeds selected. The prediction models developed are valid under the following conditions (Table 7).

Table 7. The boundary conditions of the prediction models

Characteristics of Seed	Model limits
Sphericity (Φ,%)	$54.8 \leq \Phi \leq 92.4$
Thousand seed mass (m_{1000}, g)	$3.32 \leq m_{1000} \leq 596.3$
Projected area (A_p, mm^2)	$3.13 \leq A_p \leq 36.18$
Terminal velocity (V_c, ms^{-1})	$6.5 \leq V_c \leq 13.9$
Mean particle diameter (D_p, mm)	$1.96 \leq D_p \leq 9.77$
Coefficient of friction of material on metal (μ)	$0.276 \leq \mu \leq 0.336$

Sensitivity analysis of the developed hole diameter and vacuum pressure models

Using the equations (Eq. 8 and 9), seed-specific hole diameter and vacuum pressure were calculated and these predictions were compared with the optimum seed-specific hole diameter and vacuum pressure. The data obtained from general model equations are given in table 8 and table 9 and the graphical views are depicted in figure 2 and 3. A perfect fit with a coefficient of determination of 100% in figures is represented by a diagonal line. As seen from the figures, there is a good agreement between the measured and the predicted data and the predictions are acceptable level for both hole diameter and vacuum pressure.

Table 8. Comparison of the optimum and predicted hole diameter calculated from prediction model (Eq. 8)

Seed	Optimum hole diameter (mm)	Predicted hole diameter obtained from general hole diameter model (mm)
Maize	3.77	4.92
Chickpea	6.81	6.60
Cotton	3.08	2.35
Sunflower	2.06	2.06
Soybean	3.82	4.40
Sugar beet	1.70	1.73
Canola	0.96	0.77

Table 9. Comparison of the optimum and predicted vacuum pressure calculated from the prediction model (Eq. 9)

Seed	Optimum vacuum pressure (kPa)	Predicted vacuum pressure obtained from general vacuum pressure model (kPa)
Maize	7.68	6.24
Chickpea	5.23	5.73
Cotton	5.78	6.78
Sunflower	7.17	7.18
Soybean	4.53	5.02
Sugarbeet	3.53	4.09
Canola	4.12	3.37

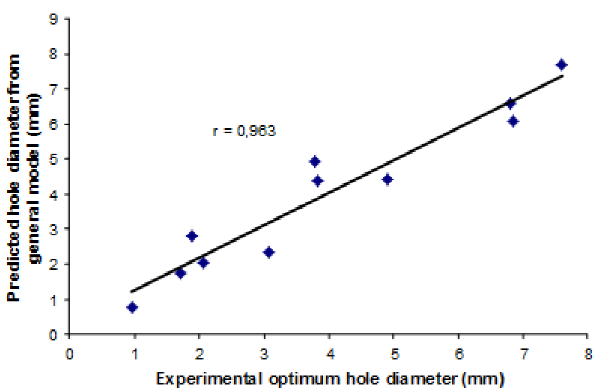

Figure 2. Sensitivity analysis of optimum and predicted hole diameters

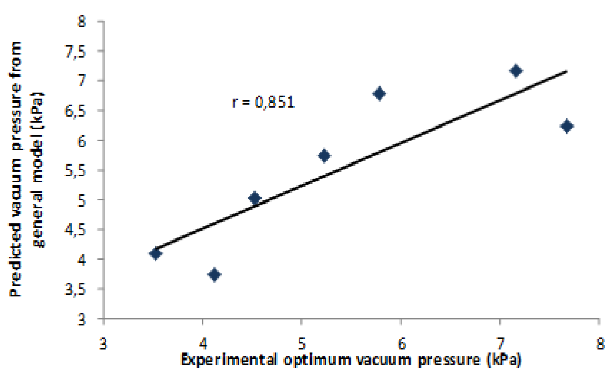

Figure 3. Sensitivity analysis of optimum and predicted vacuum pressures

Results from the verification tests using hole diameter and vacuum pressure prediction models for different seeds

The two models developed in order to meet the objective of this study were tested using different seeds that were not used in this study but the physical properties are within the boundaries. For this reason, special verification tests with two different seeds (black eyed pea and popcorn) were carried out in the lab. The sphericity, mean particle diameter and terminal velocity of these seeds were determined and the hole diameter and vacuum pressure values were calculated from the general prediction models (Y_D and Y_V). The machine was operated again on the sticky belt based on the hole diameter and vacuum pressure as calculated from the prediction models. The peripheral speed was set to 0.1 ms^{-1} (traveling speed of 1 ms^{-1}) to test the performance at the highest peripheral speed obtained from the experiments in order to achieve the highest field work rate. The physical properties of black eyed peas and popcorn seeds as shown in figure 4 and the calculated values of hole diameter and vacuum pressure for these seeds are tabulated in table 10. The chosen seeds are appropriate for the verification tests because the values of their sphericity, terminal velocity and mean particle diameter are in the range of the limits.

The seed spacing results obtained from sticky belt tests are given in Figure 5 and 6 as graphs and the views are shown in Figure 7. Three replications were achieved for the verification tests and the quality of the feed index was found to be 100% for all replications for each seed. These results could be considered to be the success of the models developed in this study.

Figure 4. Black eye pea and popcorn seeds

Table 10. Physical properties of the seeds used in the verification of the prediction model and the calculated values of hole diameter and vacuum pressure for these seeds

Seed	Sphericity (Φ,%)	Terminal velocity (V_c, ms^{-1})	Mean particle diameter (D_p ,mm)	Peripheral speed of the vacuum plate (ms^{-1})	Predicted hole diameter obtained from general hole diameter model (mm)	Predicted vacuum pressure obtained from general vacuum pressure model (kPa)
Black eye pea	75.8	12.2	7.0	0.1	4.12	5.9
Popcorn	72.2	12.5	6.1	0.1	3.21	6.4

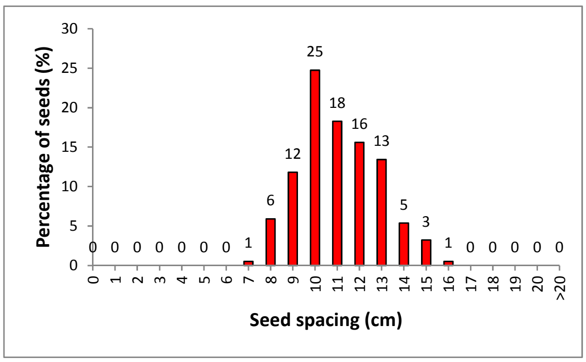

Figure 5. Seed spacing obtained from verification tests for black eye seeds

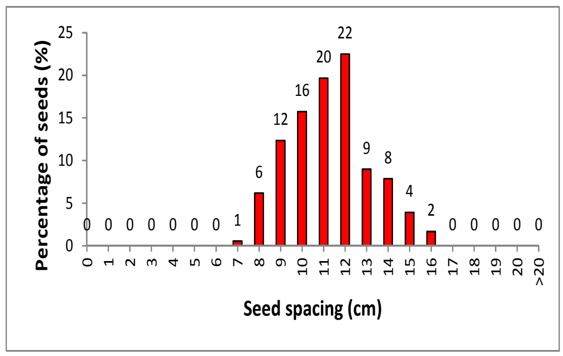

Figure 6. Seed spacing obtained from verification tests for popcorn seeds

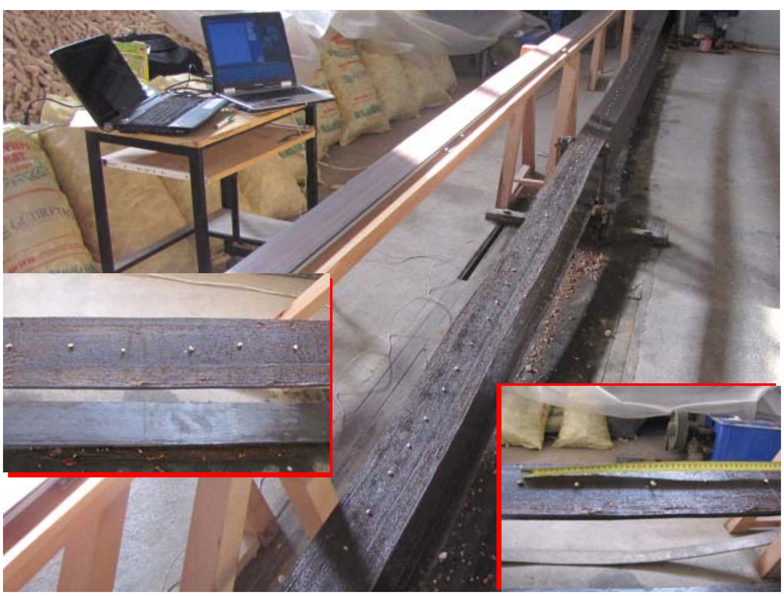

Figure 7. A view from the sticky belt verification test using black eyed pea seeds

CONCLUSION

The main objective of this study was to develop prediction functions that allow the calculation of the appropriate hole diameter, peripheral speed and vacuum pressure so that an acceptable level of precision seeding performance can be obtained by using the functions.

The followings may be concluded from the study conducted and analysis made by using the raw data and polynomial functions developed in this study.

- The hole diameter, vacuum pressure on vacuum plate and the peripheral speed are the most important three variables that govern the success in precision seeding phenomena.
- The interaction of these three variables is of importance as well as the main effect of each variable on precision seeding performance.
- The peripheral speed of the vacuum plate is the variable that limits the precision seeding performance and it should not go beyond 0.13 ms^{-1} or an average value of 1 ms^{-1} (or corresponding travelling speed of 1 ms^{-1}).
- The physical properties play an important role on selecting the appropriate hole diameter and vacuum pressure on vacuum plate. An increase in mean seed diameter and sphericity increases the seed hole diameter while there is always an optimum diameter for seeds with different physical properties. On the other hand, an increase in sphericity reduces the vacuum need and once the seeds become spherical, the seeding performance becomes less sensitive to vacuum pressure. This was a result of the raw data obtained from the experiments. This means that a higher seeding performance can be achieved at a wide range of vacuum pressure but at an optimum level of hole diameter within a limited range of peripheral speed.

It is believed that the use of functions developed in this study will help farm machinery manufacturers and farmers to obtain a higher performance during precision seeding.

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