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Optimization of the performance of a metering unit for precision seeding of Coriander seeds (*Coriandrum sativum* L.) using Box-Behnken Design

Kişniş tohumlarının (*Coriandrum sativum* L.) tek dane ekiminde ekici ünite performansının Box-Behnken dizaynı kullanılarak optimizasyonu

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ABSTRACT

Objective: The objective of this study was to find out the seed spacing performance of a vacuum type precision metering unit for seeding coriander seeds (*Coriandrum sativum* L.).
Materials and Method: In order to meet this objective, experiments were conducted in the laboratory conditions and a vacuum type precision seeder was used. Box-Behnken design based experiments with three independent variables, with three levels for each was conducted in the laboratory. These variables were considered to be the hole diameter on vacuum plate, forward speed of the seeder and the vacuum. The data obtained were evaluated for five different performance indicators for defining the seed spacing quality. The performance indices were selected to be quality of feed (I_{qf}), multiple (I_{multi}) and miss index (I_{miss}), precision (I_p) and coefficient of precision (CP3).
Results: Polynomial functions were tried to develop for each indicator. As a result of regression analysis for all indices, only one polynomial function for I_{qf} was obtained without lack of fit. From the polynomial function, the optimum diameter of the hole on vacuum plate, forward speed of the seeder and vacuum was found to be 1.75 mm, 1.5 ms^{-1} and 47.7 mbar, respectively.
Conclusions: The I_{qf} value at these optimum points was calculated to be 94.7 % while the verification tests of these optimums experimentally resulted in an average value of 97.3%.

Keywords: Mathematical modelling, medicinal and aromatic plants, Response Surface Methodology, seed spacing accuracy

ÖZ

Amaç: Bu çalışmanın amacı Kişniş (*Coriandrum sativum* L.) tohumlarının tek dane kiminde vakumlu tip bir ekici düzenin sıra üzeri tohum mesafesine ilişkin performansının belirlenmesidir.
Materyal ve Yöntem: Söz konusu amaca ulaşabilme yolunda, laboratuvar koşullarında denemeler yürütülmüş ve denemelerde vakumlu tip tek dane ekim makinası kullanılmıştır. Box-Behnken deneme desenine uygun olarak her birimin üç seviyesi olan üç bağımsız değişkenle laboratuvar koşullarında denemeler yürütülmüştür. Bu değişkenler, vakum plakası üzerindeki deliklerin çapı, ekim makinası ilerleme hızı ve vakum olarak düşünülmüştür. Elde edilen veriler, tohum mesafesindeki kalitenin düzgünlüğünü ifade etmede kullanılan beş farklı performans kriteri açısından değerlendirilmiştir. Bu performans kriterleri de kabul edilebilir tohum aralığı (I_{qf}), ikizlenme (I_{multi}) ve boşluk oranı (I_{miss}), hassasiyet (I_p) ve 3 cm mod esasına dayalı hassasiyet katsayısı olan (CP3) olarak seçilmiştir.
Araştırma Bulguları: Her bir performans kriteri için polinomiyal fonksiyonların geliştirilmesi denenmiş olup sadece kabul edilebilir tohum aralığı (Iqf) için uyum noksanlığı olmayan tek bir polynomiyal denklem geliştirilebilmiştir. Elde edilen ve kübik formdaki modelden optimum delik çapı, makina ilerleme hızı ve vakumun optimum değerleri sırasıyla 1.75 mm, 1.5 ms-1 ve 47.7 mbar olarak bulunmuştur.
Sonuç: qf değeri yukarıda belirtilen optimum değerlerde 94.7% olarak hesaplanmış olup söz konusu optimumlarda yapılan sınama denemelerinde ortalama olarak 97.3% değeri elde edilmiştir.

Anahtar sözcükler: Matematiksel modelleme, tıbbi ve aromatik bitkiler, Tepki Yüzeyleri Metodolojisi, tohum aralığında hassasiyet

INTRODUCTION

Medicinal and Aromatic Plants (MAPs) are of special importance since they are used in traditional and modern medicine as a medicine for maintaining health, cure and prevent diseases for diseases. Additionally, they are consumed as herbal tea and flavor. MAPs have also special importance for cosmetic and perfumery industry. The demand for MAPs has increased significantly due to local and global interest. Hence, the market of MAPS has been growing in the world. The export value for MAPs and their products was 48.7 billion dollars in 2001 in the world but increased to 207.5. This increasing trend was also valid for the import value. The increase in export and import in the world was also observed in the foreign trade of Turkey. The export potential of MAPs for Turkey was 143.6 million dollars in 2001 and with a big increase it reached 1.02 billion dollars in 2019. In terms of the import value of MAPS, it was 282.7 million dollars in 2001 and it increased to 1.36 billion dollars in 2019 (Boztaş et al., 2021).

The reason for growing market in all over the world could be attributed to the fact that MAPs have versatile effects while they do not have side effects as compared to synthetically obtained substances (Anonymous, 2020).

The climate and ecological conditions of our country creates a big economical potential in terms of growing MAPs. Hence, Turkey has an important country for the production and trade of MAPs (Yaldız & Çamlıca, 2018) There are 347 MAPs species in our country and 30% of these is traded in the world market (Faydaoğlu & Sürücüoğlu, 2011).

One of these MAPS grown in our country is coriander and the production area significantly increased from 155 ha in 2019 to 2455 ha in 2020 while the yield fluctuated from one year to another and it was around 770 kg ha^{-1} (Anonymous, 2022).

Coriander seeds can be spread by hand or incorporated into the soil by mechanical means. Mechanical means include the use of drills or precision seeders. Seeding with drills is achieved a certain seeding rate (kg ha$^{-1)}$ and seeds incorporated into the soil at specific segment lengths calculated based on row spacing and thousand seed mass. On the other hand, seeding with precision seeders, seeds are incorporated into the soil at equal distances. The main objective for using precision seeders is to have the highest yield with uniform seed spacing and reducing plant competition for moisture and nutrition to be obtained from the soil.

For coriander seeds, the row spacing and seeding rate can vary between 20-40 cm and 15-25 kg ha^{1}, respectively. If seeding process will be achieved with precision seeders, the seed spacing varies between 10 and 15 cm (Anonymous, 2021).

There are many studies conducted about the performance of the metering unit of drills and precision seeders. The most common metering unit in drills is usually equipped with fluted or studded rolls. On the other hand, the most common precision seeder used in the world is the vacuum type seeders and many variables contribute to the performance of such seeders. The forward speed of the precision seeder (as linearly associated with the peripheral speed of the vacuum plate), seed plate position, the amount of vacuum, the diameter and number of holes on vacuum plate, seed tube geometry and the physical properties of seeds and the geometry of seed tube in disc opener seeders etc. Hence, to study such a complex performance phenomenon of the precision seeders by considering many factors requires an effective methodology. Response Surface Methodology is such a methodology that it significantly reduces the number of experiments. As a result, less labor and time is spent. There are different types of RSM designs and each design has its own features.

Ferreira et al. (2007) reviewed and compared different RSM designs and revealed the advantages and limitations of Box-Behnken design. They concluded that the Box-Behnken design and Doehlert matrix are slightly more efficient than the central composite design but much more efficient than the three-level full factorial designs. Hence, Box-Behnken design was used in this study.

The first study that used Response Surface (RSM) in a precision seeding problem was carried out by Yazgi & Degirmencioglu (2007). They used cotton seeds in order to study the performance of the vacuum type precision seeder. Similar to this study, Yazgı (2010) optimized the seed spacing accuracy of different crop seeds (corn, chickpeas, sunflower, soybean, sugar beet and canola) along with spherical materials in diameter of 4,6,8 and 10 mm.

In a latest study, Ahmad et al. (2021) focused on sowing uniformity of bed-type pneumatic planter at various seedbed preparation levels and planter forward speeds. They have found that the uniformity indices (missing, multiple, quality feed and precision index) were significantly affected by tillage levels and forward speed of the planter statistically.

Singh et al. (2005) studied the effects of factors such as rotational speed of seed meter, shape of seed entry and vacuum pressure on seed spacing as well as in miss and multiple indices. They have found that the hole diameter, peripheral speed of seed meter and vacuum were about 2.5 mm, 0.42 m s^{-1} and 2 kPa, respectively.

There are significant number of studies about the performance of precision seeders as conducted with different crop seeds as mentioned above but there is no study in the literature about seeding of MAPs. Hence a study was conducted and the objective of this study was to to find out the seed spacing uniformity performance of a vacuum type precision metering unit for seeding coriander seeds (*Coriandrum sativum* L.).

Simerjeet et al. (2017) studied the seed meter performance at varying ground speeds and seeding rates. As a result of their study, they concluded that seed meter speed as a function of ground speed of the seeder and seeding rate Seed meter performance at a certain row spacing. The plant spacing and crop emergence were directly influenced by meter speed. An increase in meter speed caused a decline in crop emergence and seed/plant spacing uniformity.

MATERIALS and METHOD

Experiments for the optimization of the performance of the vacuum type precision seeder were conducted in the laboratory and coriander seeds used for this study. The physical properties of the coriander seeds are tabulated in Table 1.

Table 1. Physical properties of coriander seeds

Çizelge 1. *Kişniş tohumlarının fiziksel özellikleri*

Physical property	Mean	Standard error
Length (l; mm)	3.90*	0.346
Width (w; mm)	3.43*	0.311
Thickness (t; mm)	3.24*	0.313
Sphericity (ϕ; %)	90.1*	2.976
Thousand seed mass (g)	9.68**	0.899

ϕ: calculated as $\frac{(lwt)^{1/3}}{l}$; * Average of 100 and ** average of 10 measurements.

The precision seeder used for the experiments was a four-row seeder as illustrated in Figure 1. The main principle of such seeders is to use vacuum generated by a fan on the machine on one side of the metering unit that consists of a vertically operating circular plate. Seeds to be planted come from the hopper by gravity and held on holes on the other sides of the rotating plate. Then, seeds are dropped once they are released due to a vacuum block. A singulation device prevents more than one seed to be sucked on a hole.

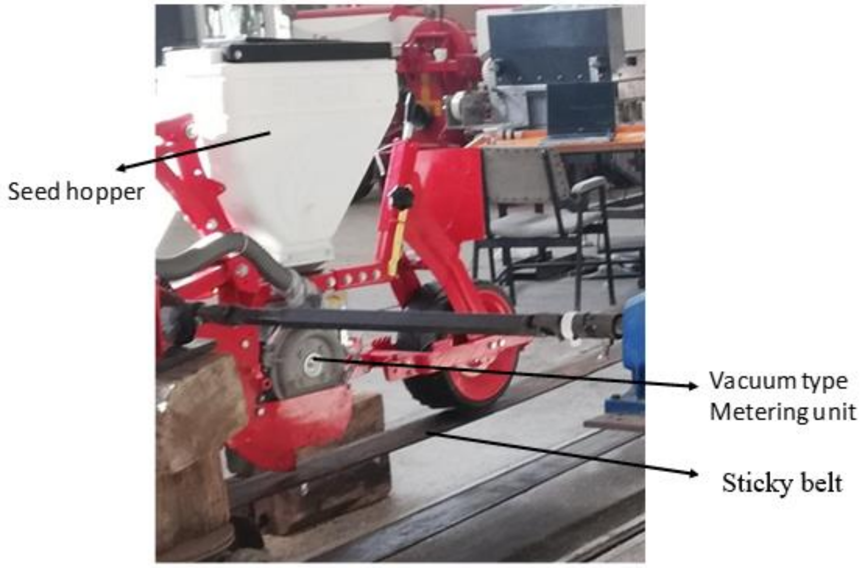

Figure 1. A view of the vacuum type precision seeder used on sticky belt for seed spacing measurements.

Şekil 1. *Yapışkan bant üzerinde tohumlar arası mesafe ölçümleri için kullanılan tek dane ekim makinasının bir görünümü.*

Experiments to determine the seed spacings were achieved on sticky belt for this purpose in the laboratory. One of the metering unit of the four –row precision seeder was used during the experiments. Seed spacing measurements were made and a computerized measurement system designed and developed by Onal & Onal (2009) was used for this purpose. This system includes an optical mouse coupled with laser pointer and a laptop computer.

The data obtained from the sticky belt tests are sent to Microsoft Excel for further statistical analysis to calculate the performance indices. Sticky belt was 15 m long and the measurement of seed distances was carried out at a distance of 10 m approximately for each test. The sticky belt speeds are provided by a multi-speed drive arrangement. The belt and metering unit speed were synchronized and they were activated by a multi-speed drive system. The vacuum was provided by a fan electronically controlled mechanism driven by a shaft. The belt surface was made sticky by smearing grease oil so that the seeds released from the metering unit are captured. For each experiment, the vacuum level was measured with a manometer at the entrance point of the metering unit. The vacuum plate with a pitch diameter of 190 mm and 72 holes were used for seeding coriander seeds. The plates were manufactured by a private company and the holes were drilled on a laser cutting machine with a tolerance of ± 0.1 mm. The theoretical seed spacing (Z_t) was set to 10 cm.

In order to optimize the seed spacing performance, experiments were carried out based on Box-Behnken design, one of the designs in Response Surface Methodology (RSM).

Response Surface Methodology is a mixture of statistical and mathematical techniques and it relates a response, or dependent variable(s) with a number of predictors, or input variables. This technique helps to explain the effects of the single or combine independent variables and create a model to explain the process (Box & Draper, 1987).

The response surface problem usually centers on an interest in some response *y*, which is a function of *k* independent variables.

Response surface can take the different forms according to the function types of response as in the following.

$$Y_k = \beta_0 + \sum_{i=1}^{n} \beta_i X_i + \sum_{i=1}^{n} \beta_{ii} X_i^2 + \sum_{i=1}^{n} \sum_{j=1}^{n} \beta_{ij} X_i X_j + \varepsilon_0 \quad (1)$$

where:

Y_k : Response

β_0 : Intercept

β_i, β_{ii}, β_{ij} : Regression coefficients

X_i X_j : Coded variables

ε_0 : Error

Quadratic or cubic polynomial functions are developed from the data obtained based on design. Then, the optimum levels of the independent variables are calculated either by taking the partial derivatives with respect to each variable if the function is in quadratic form. If it has a cubic form, then finding the optimum level of each variable requires to use a mathematical software. For the development of polynomial function, each independent variable is transformed to coded values. The coding of independent variables into X_i is expressed by the following equation:

$$X_i = \frac{\varepsilon_i - \varepsilon_{io}}{s} \quad (2)$$

where;

X_i : coded variable (such as -1,0 ve +1)

ε_i : actual value in original units

ε_{i0} : mean value (center point of the variable in original unit)

s : step value

For three independent variables and three levels for each as it was the case in this study, the required number of experiments for full factorial design with three replications is 81. On the other hand, Box-Behnken design requires 15 experiments (3 experiments at the center point). Considering three replications, the total number of experiments becomes 45. The schematic view of full factorial vs Box-Behnken design is depicted in Figure 2.

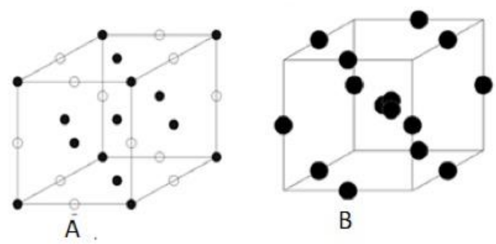

Figure 2. Schematic view of Full factorial (A) and Box-Behnken (B) design.

Şekil 2. *Tam faktöriyel ve Box-Behnken dizaynının şematik gösterimi.*

Three variables, hole diameter (*D*), forward speed of the seeder (*V*) and vacuum pressure (*P*) were transformed into coded values as in the following;

$$X_1 = \frac{D-1.6}{0.6} \quad (3)$$

$$X_2 = \frac{V-1.5}{0.5} \quad (4)$$

$$X_3 = \frac{P-50}{20} \quad (5)$$

Based on these transformations the coded and uncoded values of the variables are given in Table 2.

Table 2. Independent variables and their coded levels

Çizelge 2. *Bağımsız değişkenler ve kodlanmış seviyeleri.*

Variable	Code	Step value (s)	Coded level		
			-1	0	+1
Hole diameter (mm)	X_1	0.6	1	1.6	2.2
Forward speed (ms^{-1})	X_2	0.5	1	1.5	2
Vacuum Pressure (mbar)	X_3	20	30	50	70

Using the data from the experiments conducted based on Box-Behnken design, generally quadratic polynomial functions (equation 6; for three variables) are built. In some cases, cubic polynomial functions (equation 7; for three variables) can be developed.

$$Y_k = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_1 X_2 + \beta_5 X_1X_3 + \beta_6 X_2X_3 + \beta_7 X_1^2 + \beta_8 X_2^2 + \beta_9 X_3^2 \quad (6)$$

$$Y_k = \text{quadratic function} + \beta_{10}X_1^2X_2 + \beta_{11} X_1^2X_3 + \beta_{12} X_1X_2^2 + \beta_{13} X_1X_3^2 + \beta_{14} X_2^2 X_3 + + \beta_{15} X_2 X_3^2 \beta_{16} X_1^3 + \beta_{17} X_2^3 + \beta_{87} X_3^3 \quad (7)$$

The seed spacing evaluations were achieved based on the ranges as a function of theoretical seed spacing (Z_t) as tabulated in Table 3 while the classification of performance indices of I_{qf}, I_{multi} and I_{miss} are given in Table 4.

Table 3. Seed spacing ranges and definitions (Kachman & Smith, 1995)

Çizelge 3. *Tek dane ekimde tohumlar arası mesafe aralıkları ve tanımlaması (Kachman & Smith, 1995)*

Seed spacing	Definition
$<0.5 Z_t$	Multiple index (I_{multi})
$(0.5 -1.5) Z_t$	Quality of feed index (I_{qf})
$>1.5 Z_t$	Miss index (I_{miss})

Z_t; theoretical seed spacing

Table 4. Classification of performance indices

Çizelge 4. *Performans göstergelerinin klasifikasyonu*

Quality of feed index (I_{qf}; %)	Multiple index (I_{multi}; %)	Multiple index (I_{multi}; %)	Classification
>98.6	<0.7	<0.7	Very good
>90.4- ≤98.6	≥0.7- <4.8	≥0.7- <4.8	Good
≥82.3- ≤90.4	≥4.8- ≤ 7.7	≥4.8- ≤ 10	Moderate
<82.3	>7.7	>10	Insufficient

Another performance criterion as indicated in ISO 7256/1- 1984(E), namely “precision”, was also evaluated along with the above mentioned indices in this study (ISO, 1984). The precision is the coefficient of variation (CV_m)of the seed spacings measured as singles.

$$CV_m = \frac{s}{Z_m}.100 \quad (8)$$

where:

s: standard deviation of the seed distribution

Z_m: Mean seed distance of the seed distribution

It is recommended that CV_m value should be less than 29%. The last performance criterion is the CP3 and it is known as the 3-cm mode range, was used to determine the ability of the precision seeder to space seeds and includes only spacings within ±1.5 cm of the theoretical spacing. For a good performance, it should be minimum 40% (Brinkmann et al., 1980).

RESULTS and DISCUSSION

The performance indices obtained from the experiments based on Box-Behnken design are tabulated in table 5 and 6. As seen from the tables, the highest I_{qf} for Box-Behnken was 95.2 at the center point (1.6 mm hole diameter, 1.5 ms^{-1} forward speed and 50 mbar vacuum). It is noteworthy that two out of fifteen I_{qf} values ranged in a narrow range (81.8 and 95.2%). All precision values were lower than 29% and ranged between 13 and 20.8%. On the other hand, the CP3 values were mostly above 40% and varied between 30.2 and 83%.

The analysis for all performance indices were made separately and polynomial functions were tried to be developed in either quadratic or cubic form. But, only one model without lack of fit with an acceptable coefficient of determination (R^2) was built only for I_{qf} data. The low coefficient of determination values and/or lack of fit occurred as a result of stepwise regression analysis for other performance indices. The reason for not obtaining polynomial functions for CV_m and CP3 could be attributed to the fact that they are independent of theoretical seed spacing.

The data obtained for all cases with replications (45 data points) were used and the following equation was obtained from the stepwise regression at a probability level of 95%:

$$Log\left(\frac{100}{100-I_{qf}}\right)=1.25+0.224X_1-0.0792X_2+0.0574X_1X_2-0.127X_1X_3+0.0712X_2X_3-0.439X_1^2-0.0721X_2^2-0.106X_3^2+0.14X_1^2X_3-0.125X_1X_2^2-0.076X_2X_3^2 \quad (9)$$

As seen from the model, log transformation (Rawlings, 1988) was applied to original I_{qf} (%) values. This transformation was necessary since it prevents the I_{qf} prediction values from greater than 100%. The sensitivity analysis which means the comparison of measured and predicted I_{qf} values are shown in Figure 3. As seen from the figure, the measured and predicted I_{qf} (%) values are in good agreement (correlation coefficient r= 0.987).

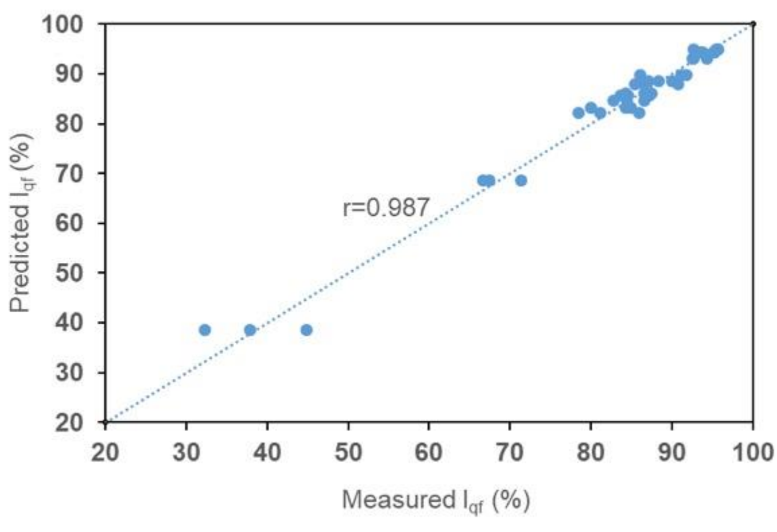

Figure 3. Comparison of measured and predicted I_{qf} (%) values.

***Şekil 3.** Ölçülen ve tahmin edilen I_{qf} (%) değerlerinin kıyaslanması.*

Table 5. Performance values of I_{qf}, I_{miss} and I_{multi} obtained from the experiments based on Box-Behnken design

Çizelge 5. *Box-Behnken dizaynına göre yapılan denemlerden elde edilen I_{qf}, I_{miss} and I_{multi} performans değerleri*

Run No	D – mm (X_1)	V- m/s (X_2)	P-mbar (X_3)	I_{qf} (%)	I_{miss} (%)	I_{multi} (%)
1	1 (-1)	1 (-1)	50 (0)	83.1 [2.72]	15.3 [2.70]	1.6 [0.06]
2	2.2 (+1)	1 (-1)	50 (0)	86.1 [1.65]	8.9 [1.78]	4.9 [3.41]
3	1 (-1)	2 (+1)	50 (0)	68.5 [2.55]	30.0 [3.14]	1.4 [1.23]
4	2.2 (+1)	2 (+1)	50 (0)	84.6 [1.95]	11.9 [1.89]	3.4 [0.06]
5	1 (-1)	1.5 (0)	30 (-1)	38.3 [6.29]	61.7 [6.29]	0 [0]
6	2.2 (+1)	1.5 (0)	30 (-1)	87.6 [2.75]	10.1 [2.35]	2.2 [0.85]
7	1 (-1)	1.5 (0)	70 (+1)	81.8 [3.81]	17.0 [4.64]	1.2 [1.05]
8	2.2 (+1)	1.5 (0)	70 (+1)	88.5 [1.43]	5.7 [3.76]	5.7 [5.16]
9	1.6 (0)	1 (-1)	30 (-1)	94.6 [1.65]	2.9 [1.46]	2.4 [0.8]
10	1.6 (0)	2 (+1)	30 (-1)	85.1 [1.88]	14.8 [1.88]	0 [0]
11	1.6 (0)	1 (-1)	70 (+1)	93.1 [0.95]	3.4 [1.72]	3.3 [0.77]
12	1.6 (0)	2 (+1)	70 (+1)	89.7 [3.1]	6.0 [1.27]	4.2 [4.35]
CP	1.6 (0)	1.5 (0)	50 (0)	95.2 [0.04]	3.7 [0.9]	1.0 [0.92]
CP	1.6 (0)	1.5 (0)	50 (0)	94.1 [0.93]	5.2 [0.74]	0.6 [0.94]
CP	1.6 (0)	1.5 (0)	50 (0)	93.5 [0.06]	5.3 [1.83]	1.1 [1.86]

CP is the experiment at center points; the numbers in parenthesis are the coded values of the variables; the numbers in brackets are the standard deviations

Table 6. Performance values of CV_m and CP3 obtained from the experiments based on Box-Behnken design

Table 6. *Box-Behnken dizaynına göre yapılan denemlerden elde edilen CV_m and CP3 performans değerleri*

Run No	D – mm (X_1)	V- m/s (X_2)	P-mbar (X_3)	CV_m	CP3
1	1 (-1)	1 (-1)	50 (0)	13.9 [2.19]	72.2 [3.76]
2	2.2 (+1)	1 (-1)	50 (0)	22.7 [1.01]	48.0 [10.3]
3	1 (-1)	2 (+1)	50 (0)	15.5 [3.15]	37.0 [8.0]
4	2.2 (+1)	2 (+1)	50 (0)	18.9 [1.02]	47.1 [3.58]
5	1 (-1)	1.5 (0)	30 (-1)	15.5 [6.46]	30.2 [5.44]
6	2.2 (+1)	1.5 (0)	30 (-1)	16.6 [2.77]	66.3 [2.94]
7	1 (-1)	1.5 (0)	70 (+1)	16.6 [1.17]	59.5 [4.02]
8	2.2 (+1)	1.5 (0)	70 (+1)	20.8 [2.17]	55.9 [6.49]
9	1.6 (0)	1 (-1)	30 (-1)	13.0 [0.75]	83.0 [3.56]
10	1.6 (0)	2 (+1)	30 (-1)	15.3 [1.90]	55.4[4.12]
11	1.6 (0)	1 (-1)	70 (+1)	15.6 [2.67]	74.2 [8.53]
12	1.6 (0)	2 (+1)	70 (+1)	18.0 [1.22]	55.1 [4.07]
CP	1.6 (0)	1.5 (0)	50 (0)	15.6 [1.30]	70.7 [4.73]
CP	1.6 (0)	1.5 (0)	50 (0)	15.7 [1.6]	59.9 [6.32]
CP	1.6 (0)	1.5 (0)	50 (0)	17.8 [4.88]	56.7 [11.2]

CP is the experiment at center points; the numbers in parenthesis are the coded values of the variables; the numbers in brackets are the standard deviations

The details of the analysis of variance for I_{qf} model (Equation 9) are tabulated in Table 7. As seen from the Table, I_{qf} equation given above is governed by hole diameter on vacuum plate (D) since the two terms, D^2 and D made the highest contribution into the model and they explained the 50.75 and 15.62% of the variation in the model, respectively. Yazgı & Değirmencioğlu (2007) and Yazgı et al. (2010) also came to the same conclusion that the hole diameter is the most effective term for the seeding performance of a precision seeder. The forward speed of the seeder (V) followed these two variables. The vacuum itself (P) did not entered into the model but its quadratic effect, interaction with forward speed (V) and hole diameter (D) was brought into the model by the stepwise regression analysis at a probability level of 95%. The most important issue here is that the lack of fit was insignificant. This means that the model is adequate can be used for optimization and prediction purposes.

Using Maple (2005) package program, the optimum level of the variables in coded form was found as in the following:

$$X_1= 0.261;\ X_2=-0.01 \text{ and } X_3=-0.115 \qquad (10)$$

Transforming them into original values using equations 4 thru 6, the optimum values for hole diameter (D), seeder forward speed (V) and vacuum (P) were found to be 1.75 mm, 1.5 ms^{-1} and 47.7 mbar. At these optimum points in coded form given above, the I_{qf} value was calculated to be 94.76%.

These optimums were also experimentally tested with three replications and the results from these tests are tabulated in Table 8. For the tests, the hole diameter of 1.75 mm and the vacuum level of 47.7 mbar was rounded up to 1.8 mm and 48 mbar, respectively.

Table 7. Results from the stepwise analysis for I_{qf}

Çizelge 7. *I_{qf} verilerinin stepwise analiz sonuçları*

Variable	Contribution to the model	P-Value
Regression (R^2)	95.33%	<0.001
D	15.62%	<0.001
V	8.24%	<0.001
DV	0.98%	0.013
DP	4.84%	<0.001
VP	1.51%	0.003
D^2	50.75%	<0.001
V^2	1.13%	0.003
P^2	3.13%	<0.001
D^2P	5.90%	<0.001
DV^2	2.35%	<0.000
VP^2	0.87%	0.018
Error	4.67%	
Lack-of-Fit	0.05%	0.547
Pure Error	4.62%	
Total	100.00%	

Table 8. Results from the verification tests of the optimums obtained from the I_{qf} model

Çizelge 8. *I_{qf} modelinden elde edilen optimumlarını sınama testlerine ilişkin sonuçlar*

D – mm (X_1)	V- m/s (X_2)	P-mbar (X_3)	Replication no	I_{qf} (%)	I_{miss} (%)	I_{multi} (%)	CV_m	CP3
			1	98.48	0	1.52	16.78	66.15
≅1.8* (0.261)	≅1.5 (-0.01)	≅48* (-0.115)	2	96.78	1.61	1.61	15.91	73.77
			3	96.83	3.17	0	18.90	59.67

*rounded up values.

The I_{qf} values obtained in these verification tests as seen from Table 8 are classified to be moderate quality seeding based on the classification given in Table 3. A view from the seed distributions obtained in one of the verification tests carried out at optimum values is depicted in Figure 4.

Figure 4. A view of seed distribution of coriander seeds on sticky belt at optimum level of the variables.

Şekil 4. *Değişkenlerin optimumlarında yapışkan bant üzerinde gerçekleşen tohum dağılımının bir görünüm.*

The response surfaces of I_{qf} as a function of hole diameter, seeder forward speed and vacuum level are depicted in Figure 5 thru 7. It should be stated that the values in figure axis are given in original units as transformed by equations 3 thru 5.

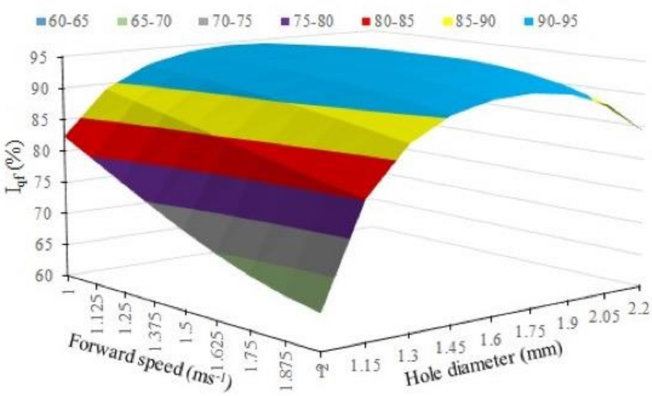

Figure 5. Quality of feed index (I_{qf}) as a function of forward speed and hole diameter (Vacuum was kept constant at the optimum value of -0.115).

Şekil 5. *Tek dane ekim makinası ilerleme hızı ve delik çapının bir fonksiyonu olarak kabul edilebilir tohum aralığı (Iqf) değerleri (vakum, optimum değeri olan -0.115 kodlu değerinde sabit tutulmuştur).*

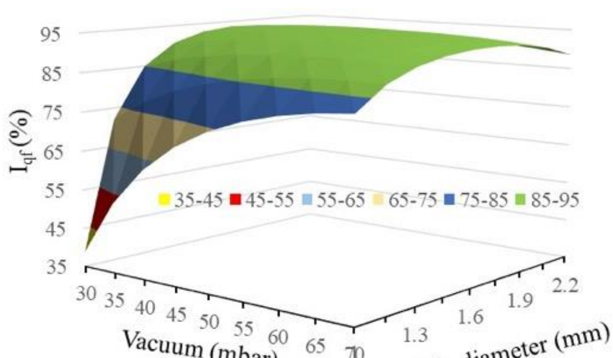

Figure 6. Quality of feed index (I_{qf}) as a function of vacuum and hole diameter (Forward speed of the seeder was kept constant at at the optimum value of -0.01).

Şekil 6. *Tek dane ekim makinasında vakum ve delik çapının bir fonksiyonu olarak kabul edilebilir tohum aralığı (Iqf) değerleri (Ekim makinası ilerleme hızı, optimum değeri olan -0.01 kodlu değerinde sabit tutulmuştur).*

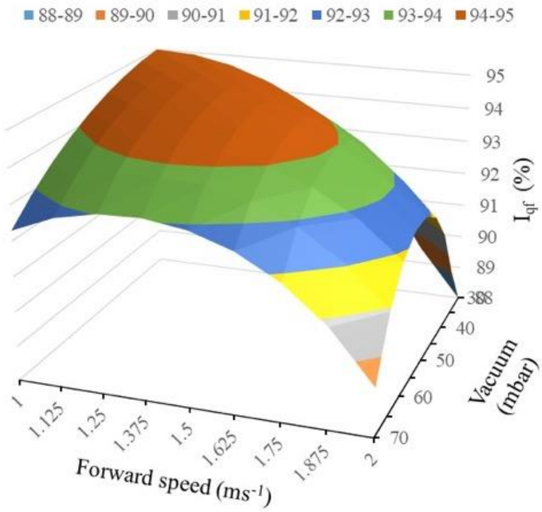

Figure 7. Quality of feed index (I_{qf}) as a function of forward speed of the seeder and vacuum (Hole diameter was kept constant at at the optimum value of 0.261).

Şekil 7. *Tek dane ekim makinasında ilerleme hızı ve vakumun bir fonksiyonu olarak kabul edilebilir tohum aralığı (Iqf) değerleri (Delik çapı, optimum değeri olan 0.261 kodlu değerinde sabit tutulmuştur).*

The I_{qf} model obtained from the Box-Behnken design was also verified at different level of the variables that are not used for developing the model. The comparison results are tabulated in Table 9.

Table 9. I_{qf} model verification tests performed at different levels of the variables that are not included in the Box-Behnken design

Çizelge 9. *Box-Behnken deneme deseninde yeralmayan ve değişkenlerin farklı seviyelerinde gerçekleştirilen I_{qf} model sınamaları*

Verification Exp. No	D – mm (X_1)	V- m/s (X_2)	P- mbar (X_3)	Measured I_{qf} (%)	Predicted I_{qf} (%)
1	2.2 (+1)	1.5 (0)	50 (0)	90.0 [1.35]	90.8
2	1.6 (0)	2 (+1)	50 (0)	86.8 [4.1]	92.0
3	1.6 (0)	1.5 (0)	70 (+1)	86.8 [4.1]	92.8
4	1.6 (0)	1.25 (-0.5)	40 (-0.5)	88.7 [1.5]	94.4
5	1.6 (0)	1.75 (+0.5)	60 (+0.5)	86.7 [2.8]	93.0
6	1.9 (+0.5)	1.25 (-0.5)	40 (-0.5)	91.1 [0.9]	94.4
7	1.9 (+0.5)	1.25 (-0.5)	60 (+0.5)	87.4 [1.7]	93.6
8	1.9 (+0.5)	1.75 (+0.5)	40 (-0.5)	90.9 [2.8]	92.9

The numbers in parenthesis are the coded values of the variables, measured, I_{qf} values are the average of three replications; the numbers in brackets are the standard deviations

As seen from the table, the further verification tests performed on sticky belt indicate that the measured and predicted I_{qf} values are in good agreement. This shows how robust the I_{qf} model is.

CONCLUSIONS

The followings were concluded from the study conducted:

- Only the model developed in this study for seed spacing performance was the I_{qf} (%) model and it allowed to calculate the optimum levels of the variables.
- Box-Behnken was found to be an effective design and allowed to optimize seeding performance of the precision metering unit.
- The most important variable that governs the seed spacing uniformity performance for seeding coriander seeds is the hole diameter. The diameter was found to be around 1.8 mm.

- The forward speed of the seeder was found to be 1.5 ms^{-1} and this could be considered as a good speed in order to have a maximized field capacity. The forward speed higher than 1.5 ms^{-1} caused a reduction in the performance of the seeder.
- The vacuum needed on vacuum plate for seeding corianders seeds is about 48 mbar.
- It is believed that the findings in this study will help conducting other studies for different Medicinal and Aromatic Plants if they can be seeded with a precision seeding concept.

REFERENCES

Ahmad, F., M. Adeel, B. Qiu, J. Ma, M. Shoaib, A. Shakoor & F. A. Chandio, 2021. Sowing uniformity of bed-type pneumatic maize planter at various seedbed preparation levels and machine travel speeds. International Journal of Agriculture & Biological Engineering, 14 (1): 165-171. Doi: 10.25165/j.ijabe.20211401.5054

Anonymous, 2020. Medicinal and aromatic plants. (Web page: https://gthmyo.bingol.edu.tr/en/programlar_/medicinal-and-aromatic-plants/#:~:text=Medicinal%20and%20aromatic %20plants%20are,herbal%20tea%2C%20flavor %20 and%20condiment) (Date accessed: December 2020).

Anonymous, 2021. Kişniş Yetiştiriciliği ve Kullanım Alanları. (Web page: https://yetistir.net/kisnis-yetistiriciligi -ve-kullanim-alanlari/)) (Date accessed: June 2021).

Anonymous, 2022. Türkiye İstatistik Kurumu (Web page: https://www.tuik.gov.tr) (Date accessed: February 2022).

Box, G.E.P. & N. Draper, 1987. Empirical Model-Building and Response Surfaces. New York, NY, USA: John Wiley & Sons, 688 pp.

Boztaş, G., A. B. Avcı, O. Arabacı & E. Bayram, 2021. Tıbbi ve aromatik bitkilerin dünyadaki ve Türkiye'deki ekonomik durumu , Teorik ve Uygulamalı Ormancılık, 1: 27-33. Doi: 10.53463/tafor.2021vol1iss1pp27-33

Brinkmann, W., E. Flake & W. Gehlen, 1980. Test: Einzelkornsaegeraete fuer Zuckerrueben. DLZ Die Landtechnische Zeitschrift, 3: 1-8.

Faydaoğlu, E. & M.S. Sürücüoğlu, 2011. Geçmişten günümüze tıbbi ve aromatik bitkilerin kullanılması ve ekonomik önemi. Kastamonu Üniversitesi Orman Fakültesi Dergisi, 11 (1): 52-67. (Web page: https://dergipark.org.tr/tr/pub/kastorman/issue/17236/180072.

Ferreira, S.L.C., R.E. Bruns, H.S. Ferreira, G.D. Matos, J.M. David, G.C. Brandao, E.G.P. da Silva, L.A. Portugal, P.S. dos Reis, A.S. Souza & W.N.L. dos Santos, 2007. Box-Behnken design: An alternative for the optimization of analytical methods. Analytica Chimica Acta, 597: 179-186. Doi:10.1016/j.aca.2007.07.011

ISO, 1984. ISO 7256/1-1984(E) Standard. Sowing Equipment-Test Methods - Part One, Single Seed Drills (Precision Drills), 7256/1. Geneva, Switzerland: International Organization for Standardization.

Kachman, S. D. & J.A. Smith, 1995. Alternative measures of accuracy in plant spacing planter using single seed metering. Transactions of the ASAE, 38: 379-387. Doi: 10.13031/2013.27843

Maple, 2005. Mapple Getting Started guide.Canada. 88 ppMinitab19, 2009. User Manual, Getting Started with Minitab 19 for Windows, www.minitab.com, (V19; Free Trial Version), Pennsylvania, USA. 294 pp.

Onal, O. & I. Onal, 2009. Development of a computerized measurement system for in-row seed spacing accuracy. Turkish Journal of Agriculture & Forestry, 33 (2): 99-109. Doi:10.3906/tar-0804-12

Rawlings, J. O., (1988). Applied Regression Analysis. Pacific Grove, CA, USA: Wadsworth & Brooks/Cole Advanced Books & Software, 553 pp.

Simerjeet, S. V., J. P. Fulton, W. M. Porter & G.L. Pate, 2017. "Field validation of seed meter performance at varying seeding rates and ground speeds, Paper Number: 1701309: 1-9. 2017 ASABE Annual International Meeting (July 16-19, 2017, Spokane, Washington, USA).

Singh, R. C., G. Singh & D. C. Saraswat, 2005. Optimisation of design and operational variables of a pneumatic seed metering device for planting cottonseed. Biosystems Engineering, 92 (4): 429-438. Doi.org/10.1016/j.biosystemseng.2005.07.002

Yaldız, G. & M. Çamlıca, 2018. Türkiye'de tibbi ve aromatik bitkilerin üretimi ve ticareti. Bahçe 47 (Özel Sayı 2: Uluslararası Tarım Kongresi, (UTAK 2018): 224-229.

Yazgı, A. & A. Değirmencioğlu, 2007. Optimisation of the seed spacing uniformity performance of a vacuum-type precision seeder using response surface methodology. Biosystems Engineering, 97: 347-356. Doi:10.1016/j.biosystemseng.2007.03.013

Yazgı, A., 2010. Vakumlu Tek Dane Ekimde Optimizasyon ve Makina Performansının Matematiksel Modellemesi. Ege Üniversitesi Fen Bilimleri Enstitüsü, (Basılmamış) Doktora Tezi, İzmir, 189 s.