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Full Length Research Paper

Optimization of seed flow evenness of fluted rolls used in seed drills by Taguchi method

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The purpose of this study is to optimize the seed flow evenness in seed drills of the fluted feed rolls; wheat was used in the experiments. Experiments were conducted according to Taguchi optimization method and L_9 orthogonal array is selected. Flute shape (asymmetric, trapezoid and semicircular), flute lengths (5, 10 and 15 mm), and axis rotational speed (25, 30, and 35 min^{-1}), and coefficient of variation used to measure the flow evenness were chosen as independent variables and dependent variable, respectively. According to the results of variance analysis, the order of the importance of factors affecting to the flow evenness are found to be flute length, axis rotation speed and flute shape, respectively. Minimum coefficient of variation was obtained at the flute shape of trapezoid, flute length of 15 mm and axis rotation speed of 35 min^{-1}. At the optimum conditions, coefficient of variation for wheat was obtained as 2.87. As a result of this study, it was shown that Taguchi method is a significant tool for such optimization problems and can be effectively used in any experimental studies on agricultural subjects.

Key words: Taguchi method, seed drill, fluted roll, flute shape, flow evenness, CV.

INTRODUCTION

The metering devices with fluted roller are widely used in tractor-drawn seed drills in Europe and North America (Bansal et al., 1989). These have some advantages such as simple constructions, light weights, easy adjustment of seed rate (Turgut et al., 1995; Ryu and Kim, 1998). In addition, one of the most important properties of these metering devices is that they can meter seeds being different shape and size. In previous studies conducted with semicircular fluted, it was reported that the fluted diameter, number, helical angle, active length of fluted roller and the revolution speed of fluted roller have an important effect on the seed flow evenness (Benacki et al., 1972; Ozsert et al., 1997; Turgut et al., 1995; Yildirim et al., 2004; Yildirim and Turgut, 2007). Ryu and Kim (1998) reported that the fluted number and shape of roller affected the flow of seed from hopper to seed tube. The desired seeding rate in these metering devices was obtained by adjusting the active roll length and/or the rotational speed of fluted roller (Heege and Billot, 1999). In this paper, the results of an investigation carried out by Yildirim et al. (2004) are presented to optimize the seed flow evenness in seed drills of the fluted feed rolls, the wheat was used as seed. The experimental work was designed to give, using the Taguchi method, the optimum working conditions of the factors that affects seed flow evenness. One of the advantages of the Taguchi method over the conventional experimental design methods, in addition to keeping the experimental cost at the minimum level is that it minimizes the variability around the investigated parameters when bringing the performance value to the target value. Its other advantage is that the optimum working conditions determined from the laboratory work can also be reproduced in the real production environment.

There is a wide range of applications of Taguchi

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methods, from pharmacy to engineering. Although they have a wide application range, Taguchi methods are applied mainly in engineering (Phadke et al., 1983; Kackar, 1985; Ross, 1987; Taguchi, 1987; American Supplier, 1988; Phadke, 1989; Celik and Burnak, 1998; Hinislioglu and Bayrak, 2004).

TAGUCHI METHODS

The objective of the ‘‘Taguchi method’’ is to obtain products (or processes) more robust under varying environmental conditions and to consider the variability in the products' components (sub-products). The Taguchi method after bringing the mean performance of products to some targeted values has shown that experimental designs could be used to make the variability around the targeted value minimum. According to Taguchi, the performance of a product (that is optimum working conditions) may be affected by 1) environmental conditions in which it is going to be used and 2) components used in its production. Thus, when determining the optimum working conditions, environmental conditions in which the product will be used and details of components used in its production should be taken into account. Parameters affecting the product may be divided into two groups as follows:

1) Controllable.
2) Uncontrollable.

Because of the very high cost, instead of determining uncontrollable parameters and removing them, values of controllable parameters which will remove or reduce the negative effects of uncontrollable parameters should be investigated. Controllable parameters can further be divided into three groups with respect to their effects on the performance of the product:

1) Control parameters.
2) Adjustment parameters.
3) Ineffective parameters.

When analyzing experimental results, after applying this classification, the variability in the performance of the product is reduced by using control parameters, to the target value by using the adjustment parameter(s), while considering ineffective parameters of their most suitable values from the point of view of economical considerations and practicality. Taguchi, during this process, suggested the use of a new experimental design method different from conventional ones such as orthogonal array (OA), performance statistics (signal to noise ratio), loss function, etc. Optimum working conditions determined by using the experimental data should always be able to provide the same or very close performance values (that is mechanical properties) at different times and different working environments. The optimization criteria used to meet this task should be able to control both whether the target value has been reached, and also whether the variability around the target is kept at the minimum. According to Taguchi, performance statistics can meet the aforementioned requirement. Kackar (1985) reported that Taguchi has developed more than 60 performance statistics which can be used depending on the problem being investigated. Without a systematic approach, there may occur some difficulties in solving problems or developing projects in any area. For that reason, a systematic approach covering the necessary steps of the method applied is very beneficial.

A successful application of Taguchi method to a product or a process depends on this systematic approach. A systematic and efficient approach for this purpose is given in Figure 1. The operations of the flowchart can be grouped into 13 operational steps for achieving design optimization. The steps are:

1) Determination of the problem and organizing the team.
2) Determination of the performance characteristic(s) and the measuring system.

The performance characteristics are chosen as the optimization criteria. There are three categories of performance characteristics; the larger-the better, the smaller-the better and the nominal-the better. These performance characteristics are evaluated by using Equations 1 to 3:

Larger the better $$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{Y_i^2}\right) \quad (1)$$

Smaller the better $$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}Y_i^2\right) \quad (2)$$

The nominal the better

$$S/N = -10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}(Y_i - Y_0)^2\right) \quad (3)$$

Where, S/N are performance statistics, defined as the signal to noise ratio (S/N unit: dB), n is the number of repetitions for an experimental combination, Y_i is a performance value of the ith experiment and Y_o nominal value desired.
3) Determination of the variables (parameters) affecting the performance characteristic(s).
4) Conducting the screening design.
5) Determination of the number of the levels and values of the controllable variables (parameters) and uncontrollable variables (parameters).

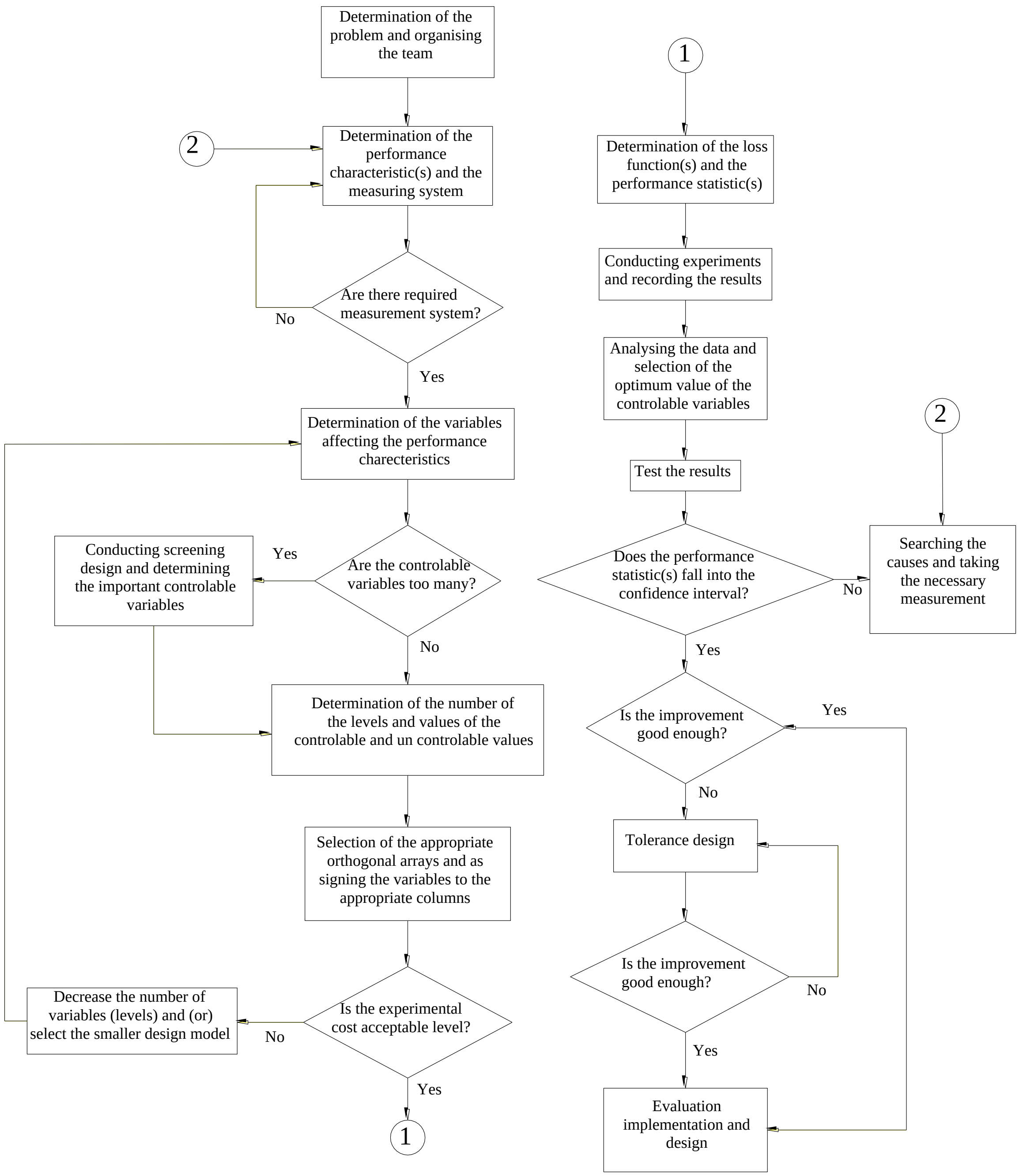

Figure 1. Flowchart of the systematic approach to the application of Taguchi methods.

6) Determination of the interactions to be examined.
7) Selection of appropriate OAs and assigning the variables to the suitable columns.
8) Determination of the loss function(s) and performance statistics.
9) Conducting experiments, recording results.
10) Analyzing data and selection of the optimum value of the controllable variables.
11) Test the results.
12) Tolerance design.
13) Evaluation, implementation and observation.

Readers who are interested in the explanations of the steps are referred to Celik and Burnak (1998). Those readers who are also interested in the Taguchi method are referred to Kackar (1985), Taguchi (1987) and

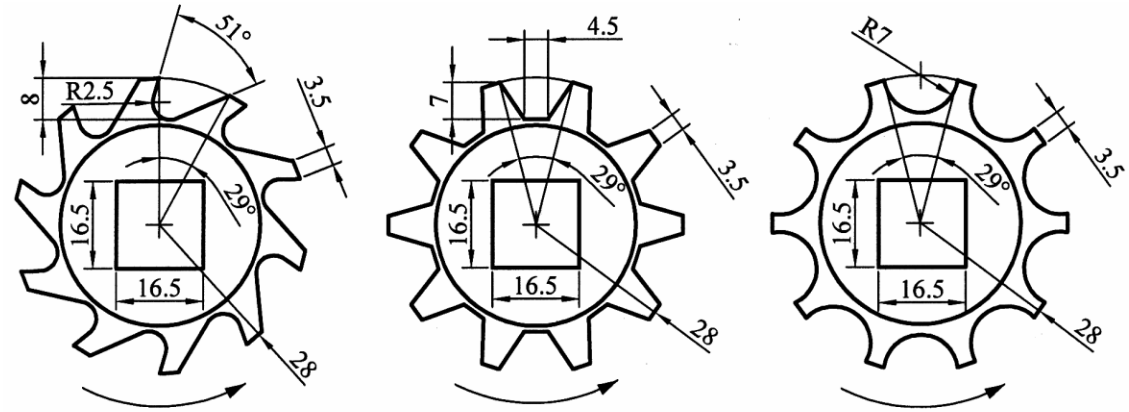

Figure 2. The technical dimensions of fluted roller used in tests.

Table 1. Factors and their levels studied in the experiments.

Factors	Levels		
	1	2	3
A: Flute shape	Asymmetric	Trapezoid	Semicircular
B: Flute lengths (mm)	5	10	15
C: Axis rotational speed (min^{-1})	25	30	35

Phadke (1989).

MATERIALS AND METHODS

The three fluted feed roller made of delrin with a 56 mm of diameter were used in the study. The technical properties of these rollers are shown in Figure 2. The fluted feed rollers had the same open angle (29°) of groove, therefore the same the groove number. The cross-sectional areas, the open angle, the number, and the diameters of groove of all rollers were the same, but the groove shapes were different. Therefore, the analyses were focused on the effect of the groove shape. Wheat was used as seed in the study. The bulk density, repose of angle, 1000 kernel weight, and sphericity of wheat were 834 kg/m^3, 25.64°, 40.48 g and 55.25%, respectively.

The study (Yildirim et al., 2004) was performed on a measurement and record set in Department of Agricultural Machinery, Ataturk University. In the experiment, each feed roller with asymmetric, trapezoid, and semicircular flute-shaped was run at three active lengths (5, 10 and 15 mm) and at seven speeds of revolution (5, 10, 15, 20, 25, 30 and 35 min^{-1}). Each run test had three replications. In each replication, the material discharged from fluted roller was weighed continuously and cumulatively by a precision balance placed under the fluted roller. The data were transmitted to PC with continuous stream by RS 232 C interface circuit of the balance (Özsert et al., 1988). The time scaling-recording was selected as 1/10 s for the forward speeds of 1.5 m/s to weigh the material discharging in the row. For each replication, the 200 values were taken from the balance and the flowing of the seed along the row of 30 m was determined. The CV values were calculated by using these 200 values for each replication. The height of seed in the hopper was the half of height of hopper during the experiment. Taguchi method was applied to the data obtained; in that way based on the orthogonal array technique in order to determine the optimum parameters for the flow evenness. Factors and their levels affecting seed flow evenness in seed drills were decided based on the brainstorming session and literature review on the subject. Three factors and three levels of each factor have been taken for experimentation (Table 1). In the orthogonal array technique, the minimum required experiments for three factors at three levels are 9. It is therefore designed in L_9 (3^4) (Table 2).

The order of the experiments was obtained by inserting parameters into columns of the orthogonal array, L_9 (3^4), but the order of experiments was randomly made to avoid noise sources which had not been considered initially and which could take place during an experiment and affect the results in a negative way.

PROCEDURE FOR TAGUCHI METHOD

In the optimization, the experiments were conducted with three replications. Since it is aimed to minimize the coefficient of variation, S/N values were calculated based on the quality characteristic of “the smaller the better” using Equation 2. The levels of each factor that minimize the S/N were optimum. The order of experiments was obtained by inserting parameters into the columns of OA, L_9 (3^4), chosen as experimental plan given in Table 2. But the order of experiments was made random in order to avoid noise sources which had not been considered initially and which could take place during an experiment and affect the results in a negative way. The interactive effects of parameters were not taken into account in the theoretical analysis because some preliminary tests showed that they could be neglected. The validity of this assumption was checked by confirmation experiments conducted at

Table 2. L_9 (3^4) experimental plan used in the study.

Experiment no	A	B	C	Empty column	S/N	$\Omega(db)$ Omega transformations
1	1	1	1	1	-20.424	-9.311
2	1	2	2	2	-12.180	-13.734
3	1	3	3	3	-10.164	-14.831
4	2	1	2	3	-16.306	-11.571
5	2	2	3	1	-10.729	-14.56
6	2	3	1	2	-10.803	-14.478
7	3	1	3	2	-16.019	-11.791
8	3	2	1	3	-14.831	-12.393
9	3	3	2	1	-11.626	-14.05
		Average			-13.676	-12.969

Table 3. Results of ANOVA.

Factor	DF	Sum of squares	Variance	F-ratio	Pure sum	Percent contribution
Factor A	2	5.1	2.55	2.112	2.686	2.828
Factor B	2	73.112	36.556	30.285	70.698	74.427
Factor C	2	14.362	7.181	5.949	11.948	12.578
Error	2	2.413	1.206			10.167
Total		94.989				100

the optimum conditions. In order to see the order of the significant for each factor, analysis of variance (ANOVA) was performed (Table 3).

In the Taguchi method, the experiment corresponding to optimum working conditions might not have been performed during experiments. In such cases the performance value corresponding to optimum working conditions can be predicted by utilizing the balanced characteristic of the orthogonal array using Equation 4:

$$Y_i = \mu + X_i + e_i \tag{4}$$

Where µ is the overall mean of performance value, X_i is the fixed effect of the parameter level combination used in ith experiment and e_i is the random error in ith experiment. Because Equation 4 is a point estimation which is calculated by using experimental data in order to determine whether results of the confirmation experiments are meaningful or not, the confidence interval must be evaluated. The confidence interval at a chosen error level may be calculated by Equation 5:

$$CI = \mu \pm \sqrt{F(1,n_2) x V_e / N_e} \tag{5}$$

Where,

µ = average expected performance statistic at the optimum conditions, F $(1,n_2)$ = F value from the F table from any statistical book at the required confidence level and at DF 1 and error DF n_2, V_e = variance of error term (from ANOVA) and N_e = effective number of replications:

$$N = \frac{Total\ number\ of\ results (or\ number\ of\ S/N\ ratios)}{DF\ of\ mean (=1\ always) + DF\ of\ all\ factors\ included\ in\ the\ estimate\ of\ the\ mean}$$

If the experimental results are in percentages, before Equations 4 and 5 are evaluated, omega transformation of the percentage values should be performed by means of the following equation:

$$\Omega(db) = -10\log\left[\frac{1}{P} - 1\right] \tag{6}$$

Where Ω (db) is the decibel value of the percentage value subjected to omega transformation and P is percentage of the product obtained experimentally. Values of interest can be determined later by reverse transformation with the same Equation 4.

RESULTS

The average S/N values for each factor are shown in Figure 3 to 5. The minimum one of the numerical values according to the absolute value in each graph marks the best value of that particular factor. In addition, if the experimental plan given in Table 1 is studied carefully, it can be seen that an experiment corresponding to the optimum conditions A2B3C3 was not performed during the experimental work. Thus, expected performance (EP) for the optimum condition A2B3C3 is calculated using the average omega values for each factor of A2, B3 and C3 (Table 4). It was seen that the expected performance (EP) at the optimum conditions giving the minimum coefficient of variation was calculated as -15.78. The omega transformation of this value is 2.87. The

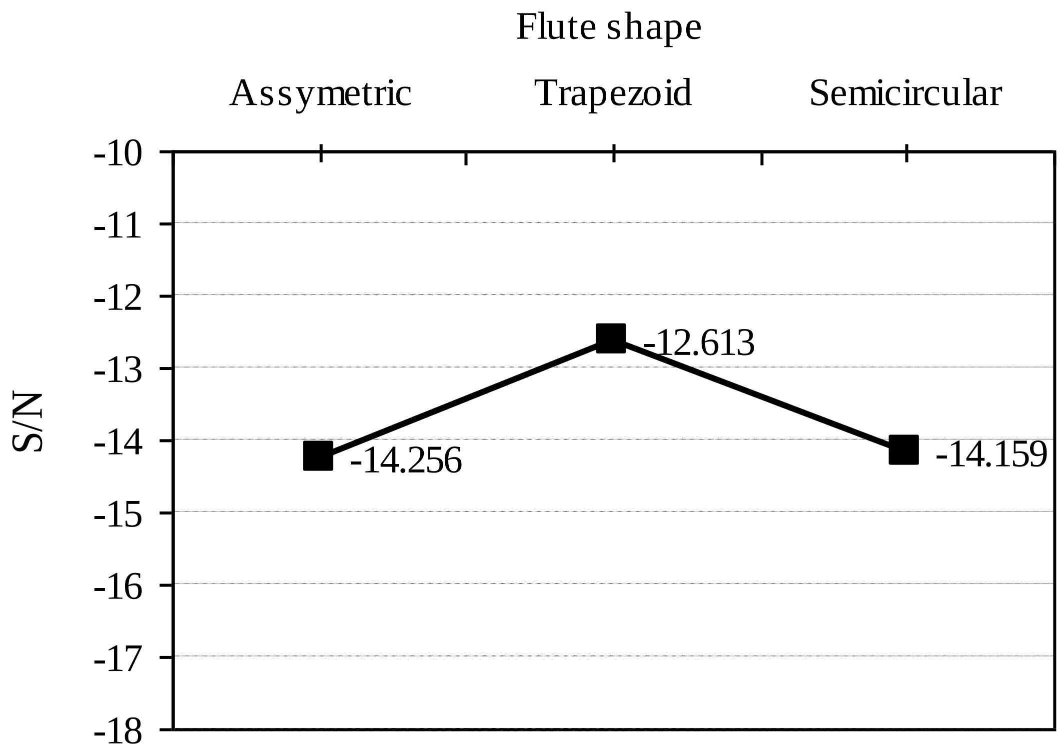

Figure 3. Average S/N effects of flute shape on the seed flow evenness.

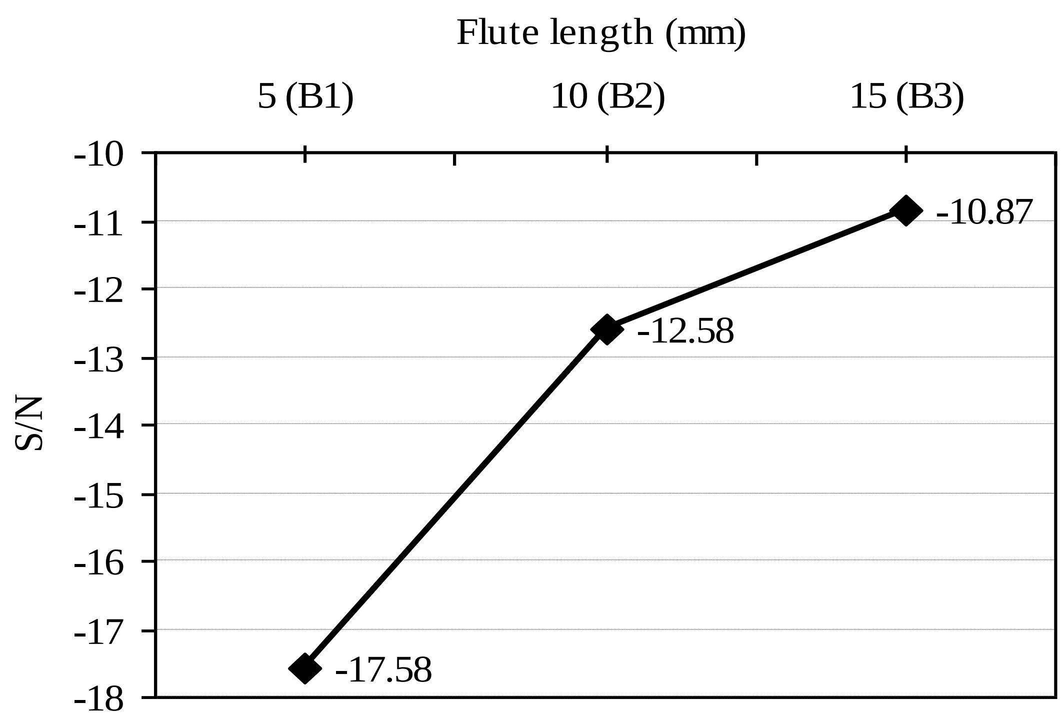

Figure 4. Average S/N effects of flute length on the seed flow evenness.

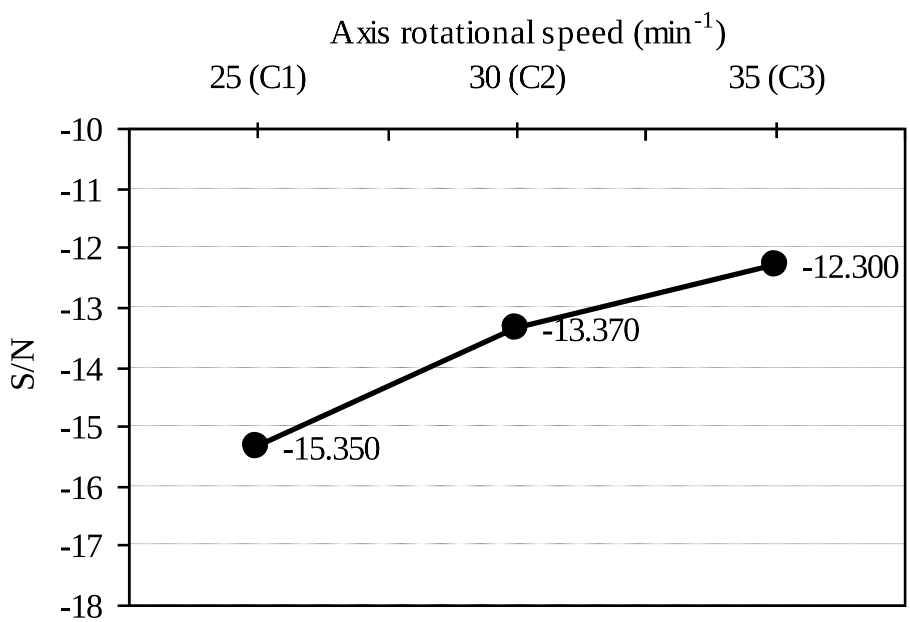

Figure 5. Average S/N effects of axis rotational speed on the seed flow evenness.

Table 4. Prediction of the optimum conditions based on the omega values $\Omega(db)$.

Factors	Contribution
A2 (Trapezoid)	-0.568
B3 (15 mm)	-1.485
C3 (35 min^{-1})	-0.759
Total contribution of the factors	-2.81
Average of Omega values	-12.969
Total	-15.78
95% confidence intervals (CI)	15.78 ± 1.17 (-16.95/-14.61)
Back transform of Omega $\Omega(db)$ results for the CI	2.262 to 2.927%
Confirmation test result (coefficient of variation)	2.87%

confidence interval was calculated as ± 1.17 using Equation 5:

$$EP = -12.969 + (-13.536 - (-12.969)) + (-14.453 - (-12.969)) + (-13.73 - (-12.969))$$

$$EP = -15.78$$

DISCUSSION

The confirmation test result, coefficient of variation, 2.87% is well within the calculated confidence interval 2.262 to 2.927% (Table 4). It can be said that the experimental results are within 95% confidence level. These results show that the interactive effects of the factors are negligible for evenness of the flow and also that the Taguchi method can successfully be applied to the experiments to the determination of the seed flow evenness with a limited number of experiment and in a shorter time. According to the ANOVA results (Table 3), the most important factor affecting the flow evenness is flute length with 74.43%. It is also seen from Figure 4 that flute length of 15 mm gives the minimum coefficient of variation. The axis rotational speed and the flute shape have the second and third order effect on the coefficient of variation, respectively. In addition, coefficient of variation decreases with increasing of the axis rotational speed.

Conclusions

According to the results of variance analysis, the order of the importance of factors affecting the flow evenness are found to be flute length, axis rotation speed and flute shape, respectively. Minimum coefficient of variation, optimum conditions was obtained at the flute length of 15 mm, axis rotation speed of 35 min^{-1} and flute shape of trapezoid. At the optimum conditions, coefficient of variation for wheat was obtained as 2.87. As a result of this study, it was shown that Taguchi method is a significant tool for such optimization problems and can be effectively used in any experimental studies on agricultural subjects.

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