Shahid Bahonar University of Kerman

Biomechanism and Bioenergy Research

Online ISSN: 2821-1855
Homepage: https://bbr.uk.ac.ir

Iranian Society of Agricultural Machinery Engineering and Mechanization

Optimizing the Effect of Spike Density and Combine Speed for Reducing Wheat Loss Using Response Surface Methodology

Isa Hazbawi[1]✉, Mojtaba Safaeinezhad[2]

[1] Department of Biosystem Engineering, Faculty of Agriculture, Lorestan University.
[2] Department of Mechanization, Lorestan Province Agricultural Jehad Organization.

✉ Corresponding author: hazbawi.i@lu.ac.ir

ARTICLE INFO

Article type:

Research Article

Article history:

Received 04 October 2023

Received in revised form 12 October 2022

Accepted 18 November 2023

Available Online 28 December 2023

Keywords:

Forward speed, Minimization, Quality loss, Combine, Wheat.

ABSTRACT

Wheat is the most important crop and food in the feed consumption pattern. By reducing wheat loss in the harvesting stage, it is possible to significantly increase the production of this crop. Due to the acceptance of farmers in the use of straw collecting combines, the number of this type of combines is increasing, especially for harvesting wheat. This research was conducted in order to investigate the effect of spike density per unit area (340, 350 and 440) and the combine forward speed (1, 2 and 3 km/h) on the percentage of quality loss of wheat in harvesting with a straw collecting combine in Khorramabad city. In this research, Response Surface Methodology (RSM) was used to model and minimize the wheat quality loss. The results showed that process variable was statistically significant as quadratic regression model for response ($p<0.01$). The wheat quality loss is strongly influenced by the combine forward speed and the spike density per unit area. The lowest percentage of wheat quality loss (1.9%) was related to the speed of 1 km/h and the spike density of 340 spikes/m^2.

Cite this article: Hazbawi, I., Safaeinezhad, M. (2023). Optimizing the Effect of Spike Density and Combine Speed for Reducing Wheat Loss Using Response Surface Methodology. *Biomechanism and Bioenergy Research*, *2*(2), 19-27. https://doi.org/10.22103/BBR.2023.22269.1055

Publisher: Shahid Bahonar University of Kerman
DOI: https://doi.org/10.22103/BBR.2023.22269.1055

INTRODUCTION

Wheat (Triticum aestivum L.) as a strategic crop, is the most important grain after corn and rice in terms of cultivated area and grain production to provide protein and carbohydrates at the global level (Mandal & Mukhopadhyay, 2015). Wheat, as one of the major agricultural products, provides the most food needs of humans in different countries of the world, especially third world countries; Many researches have been done on the methods of increasing its yield (Ghasemi Nejad Raeini et al., 2018). The economic importance of wheat both in terms of production and nutrition in the world is more than other agricultural products. Wheat is the most important agricultural product in the world with the largest cultivated area and in Iran, due to its essential role in providing food and livestock nutrition, it is also the most important and strategic agricultural product (Khosravani & Rahimi, 2005; Motiei et al., 2016).

In the threshing system of the straw collection combine, the file-type thresher has been converted into a hammer (finger). There are approximately 60 pieces fingers, each individually bolted to the thresher cylinder. The body of fingers is made of ordinary iron, but the tips of fingers is made of hardened iron to have a longer life. The concave is also mesh (Figure 1). Due to the increase in the need for straw, the cost and difficulty of collecting it, this type of combine, which is known as the straw collecting combine, has met with great acceptance by farmers, especially in the areas with the livestock farming system, so that even the big companies producing combine harvesters in the country have started producing straw collecting combine. These combines are greatly affected by performance, forward speed, moisture content of the wheat, weeds, land slope, service hours and many other conditions. So far, no complete research has been done in this field, so it is necessary to investigate and evaluate the factors affecting the increase in the loss of this type of combines by fully understanding this combine (Rostami et al., 2018).

Many studies have been carried out in the field of measuring the loss of normal combines and the factors affecting them. The measurement of wheat harvest losses with combine harvesters in the three cities of Marvdasht, Eghlid and Darab showed that the average total wheat waste at the harvest stage is 4.8% and the highest amount of these wastes is 6.8% related to the loss of the combine head (Khosravani & Rahimi, 2005). The results of the study of the effect of design parameters on grain separation in the threshing section to minimize the loss of the combine separator showed that the effect of the factors of stem cutting height, feeding rate and the ratio of the threshing looseness on the amount of separation and as a result, the loss of the separator unit was significant (Mirzazadeh et al., 2011).

Ahmadi Chenarbon et al. (2009) conducted a study on wheat harvesting losses by combine harvesters in Varamin region (in Iran). They reported an average total loss of 7% per hectare, and the losses were as follows: head loss of 4.2%, quality loss of 1.6%, crushing loss of 0.6%, sieves loss of 0.6%. They have considered the impact of land integration and mechanized cultivation, training of combine drivers, adjustments of different components of the combine to be positive on waste reduction. Shaker and Zare (2010) examined the impact of combine type and threshing cylinder rotation speed on wheat loss during harvesting. Four combine types (New Holland, Class, John Deere 955, and John Deere 1165) and three-cylinder speeds (650, 750, and 850 rpm) were studied, with the combine's forward speed within the recommended range (2.5 to 3 km/h). Class harvester combine had the highest farm capacity at 1.02 ha/h, followed by New Holland, John Deere 1165, and John Deere 955with 0.81, 0.62, and 0.26 ha/h, respectively. John Deere 1165 showed the highest quality losses at 5.57%, while Class combines had the lowest at 3.69%.

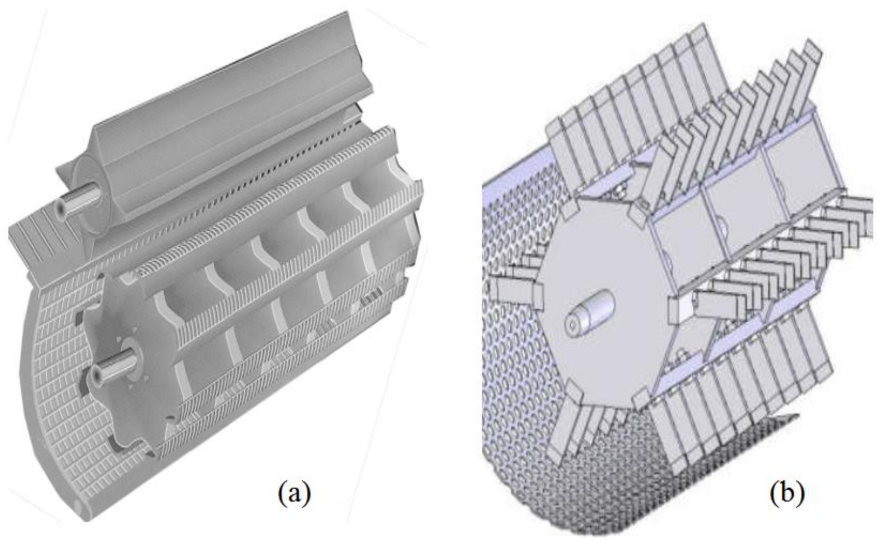

Figure 1. Comparison of thresher in normal combine (a) and straw collection combine (b)

The response surface method is a set of statistical and mathematical methods that is used to analyze and model the responses of a process, and its ultimate goal is to optimize the process parameters (Myers et al., 2016). The central composite design, Box-Benken, and Dehlert are the three main methods of designing the response surface. The purpose of the response surface method is to find the appropriate values of each of the variables to reach the most desirable answers. It is possible to use the simulation with the built model instead of conducting real experiments that require a lot of time and money to examine various factors. This subject becomes especially important with the increase in the number of input parameters. Also, due to the fact that three input values are determined for each parameter, the central compound design or Box-Benken design provides the possibility of examining and measuring the effect of binary combinations of parameters in addition to the separate and direct effect of each of them (Eriksson et al., 2008).

Considering that not much research has been done in the field of optimizing (minimizing) the percentage of wheat quality loss using mathematical patterns and models based on experimental data, Therefore, the current research was designed and implemented, emphasizing the minimization of the quality loss of wheat under the influence of spike density per unit area and forward speed of the combine harvester in autumn wheat cultivation in the climatic conditions of Khorramabad, investigating the change process and the effect of different ratios of forward speed and spike density on the percentage of wheat quality loss.

MATERIALS AND METHODS

According to the information obtained from the experts, agricultural service centers and agricultural jihad of several provinces, the acceptance of the straw collecting combine is much higher in areas with animal husbandry-agriculture system. Based on this, Lorestan province and Khorramabad city (Gerit region with geographical coordinates of 33 degrees and 16 minutes north latitude and 48 degrees and 43 minutes east longitude and 940 m above sea surface) was selected as a region with animal husbandry-agriculture system. In order to apply the same conditions, wheat variety Azar2, which is suitable for cultivation in cold and temperate regions of the country (Hosseinpour et al., 2014) and rainfed cultivation, one combine and one driver were used. Also, fields with the same climatic conditions were used.

The classification of the fields in this region was done according to the number of spikes per unit area based on the initial measurements. For this purpose, at first, the fields with the identical slope and the same cultivar were determined randomly and in four replications by sampling using one m^2 frames from different parts of the field. The time of harvest and measurement of harvest losses was done in July 2023 and the moisture content of the product was 14% (w.b). The length and width of the used plots were considered to be 30 and 20 m, respectively. The selection of the combine was done according to the highest percentage of the available combine in the country, and based on this, the John Deere 1165 combine, which has been widely converted into a straw collection combine, was selected. The characteristics of the used combine are shown in Table 1. This research was conducted using the response surface method (RSM) in the form of a central composite design.

Table 1. The general specifications of the studied combine harvester

Cutter bar width (m)	4
Grain tank capacity (Lit)	4
Straw tank capacity (m3)	8
Separation system	Vacuum fan
Engine model	JD 6068
Type of threshing system	Spike-tooth cylinder with 60 tooth in cylinder
Number of engin's cylinders	6
Engine power (hp)	160

Due to the installation of the straw tank (Figure 2) and the changes made in the threshing, separating and cleaning unit of this type of combine harvester, there is no loss in its end part. So, the loss measurement of these units is different from the normal combine.

In general, two types of quantity and quality losses in these stages can be considered for this type of combines. The quantity loss includes semi-pounded or unpounded seeds and bunches, which are transferred to the straw tank along with the straw. Quality loss includes broken seeds that are in the seed tank. To measure the quality loss of wheat, a bag was placed in the grain inlet channel to the grain tank, and then a certain length of path was taken with the combine, and after stopping the combine and working in stop mode for three minutes (exiting all the material from the combine units), the seed collected in the bag was emptied and weighed, and with this, the yield of the seed was also obtained. Using manual sieves, broken seeds in the seed tank were separated from healthy seeds, and their percentage (based on weight) in the seed tank was considered as quality loss (Amiri et al., 2022; Rostami et al., 2018).

This research was conducted with the response surface method in the form of central composite design (Table 2) with Design Expert 7 software (Felegary et al., 2023). The fitted regression model in this project was chosen in such a way that the linear and quadratic effects as well as the interaction effects between the factors can be evaluated (full quadratic). The test treatments included wheat spike density (340, 390 and 440 per m^2) and the forward speed of the straw collecting combine (1, 2 and 3 km/h) and the central point was repeated five times in order to better fit the model and estimate the error of the experiment (Table 2).

It should be noted that the central composite plan was executed in face centered mode. The values of spike density and forward speed of the straw collecting combine were chosen to cover the commonly used values in the region. Spike density treatments per unit area were selected among different wheat treatments with densities of 80 to 220 kg per hectare available in the region and cultivated under the same conditions. In order to analyze the results, the complete quadratic model with opposite effects was fitted to the experimental data (Equation 1) and then the best model was selected based on the statistical criteria of regression analysis (including lack of fit, P values, and R^2) (Tabaei et al., 2020).

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_1X_2 + a_4X_1^2 + a_5X_2^2 \quad (1)$$

In this equation, Y: dependent variable, which in this study is the percentage of wheat quality loss, X_1: independent variable of wheat spike density and X_2: independent variable of forward speed of the straw collecting combine, a_1 to a_5 are coefficients of the equation and a_0 is a point with a vertical distance from the origin.

Figure 2. Straw tank of the straw collection combine

Table 2. Values of treatments according to the central compound design

Run	Wheat spike density ($1/m^2$)	Forward speed (km/h)	wheat quality loss (%)
1	340	1	1.91
2	440	2	3.12
3	390	2	2.41
4	390	2	2.50
5	390	1	2.21
6	340	3	2.30
7	340	2	1.99
8	390	2	2.51
9	390	3	2.95
10	440	3	3.82
11	390	2	2.51
12	440	1	2.70
13	390	2	2.55

RESULTS AND DISCUSSION

The results of the variance analysis of the full square regression model along with the regression coefficients and the coefficient of determination (R^2) for the percentage of quality loss of wheat in harvesting with a straw collecting combine harvester are shown in Tables 3 and 4.

Figure 3 shows the percentage of actual quality loss compared to the estimated values of the model provided by the response surface method, for wheat harvested with a straw collecting combine. As can be seen in this Figure, the values of the percentage of wheat quality loss are close to the bisector line and it is proof of the high accuracy of the model.

The response of the percentage of quality loss of wheat in harvesting with straw collecting combine to spikes density per unit area and the forward speed of the combine followed a quadratic function, and this function explained 99.6% of the changes (explanation coefficient R^2 in Table 3). According to the results of Table 3, the linear, quadratic and interaction effects of the investigated factors were significant ($p<0.01$), except for the quadratic X_2, which was significant at 5%. On the other hand, the lack of fit test of model was non-significant ($p \leq 0.05$), which shows that the quadratic regression model obtained has the ability to predict the effects of the independent variable on the dependent variable and the ability of the model to fit. In Figure 4, the response surface diagram of the effect of spike density per unit area and the forward speed of the combine on the percentage of wheat quality loss is shown.

Table 3. Variance analysis of the effect of spike density and forward speed of the combine on the quality loss of whea

Source variation	Degrees of freedom	Mean square
Regression model	5	0.59^{**}
x_1	1	0.84^{**}
x_2	1	1.95^{**}
$x_1 \times x_2$	1	0.12^{**}
x_1^2	1	0.03^{**}
x_2^2	1	0.02^{*}
Lack of Fit	3	0.0005^{ns}
Pure Error	4	0.003
R^2=0.996	-	-

^{ns} not significant, * significant at 5% level, and ** significant at 1% level x_1 (forward speed of combine), x_2 (spike density)

Table 4. Quadratic polynomial regression coefficients for wheat quality loss (coded model)

$$Y = a_0 + a_1X_1 + a_2X_2 + a_3X_1X_2 + a_4X_1^2 + a_5X_2^2$$

a_0	a_1	a_2	a_3	a_4	a_5
2.48	0.57	0.37	0.18	0.08	0.1

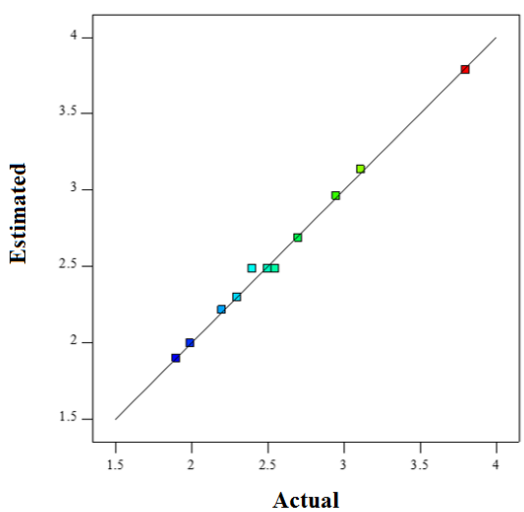

Figure 3. The relationship between the actual and estimated quality loss percentage

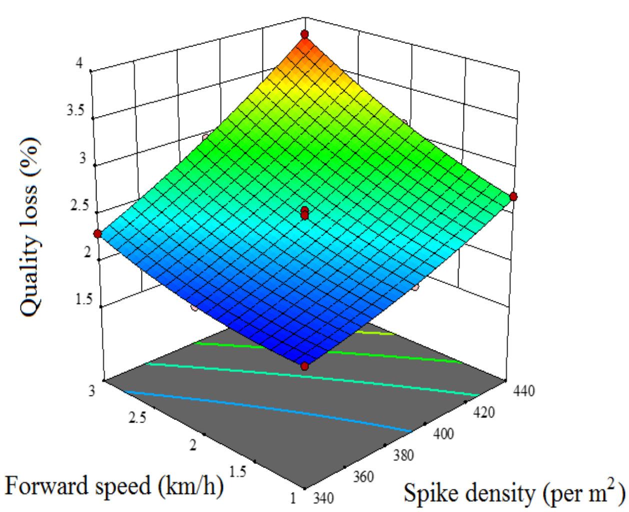

Figure 4. The response surface of the effect of spike density and forward speed of straw collecting combine on the percentage of wheat quality loss

As can be seen in Figure 4, spike density per area unit had a major effect on the percentage of wheat quality loss, which is confirmed by the coefficients in Table 4. These changes have been more in the high values of the forward speed of the combine (3 km/h) and the percentage of wheat quality loss has increased from 2.3 to 3.8 %, but in the low speed of the combine (1 km/h) the percentage of wheat quality loss has increased from 1.9 to 2.7%. The results of the variance analysis and the shape of the response show that increasing the forward speed of the combine from 1 to 3 km and the spike density from 340 to 440 per m^2 had a positive and increasing effect on the quality loss of wheat.

At high levels of spike density (440 per m^2), the changes in the percentage of wheat quality loss were more and the percentage of wheat quality loss increased from 2.7 to 3.8%, but at a low level of spike density (340 per m^2), the percentage of wheat quality loss has increased from 1.9 to 2.3%. This mode of positive influence of independent factors is confirmed according to the positive coefficients of the model (Table 4) and the response surface (Figure 4). Also, considering the significance of the quadratic expression of wheat spike density and the forward speed of the combine, the presence of curvature in the shape of the response surface is observed.

The highest percentage of quality loss of wheat was harvested with a straw collecting combine harvester at a forward speed of 3 km and the spike density was 440 per m^2. Also, the lowest percentage of wheat quality loss in harvesting with a straw collecting combine was in 340 spikes per m2 and 1 km/h of combine forward speed. Increasing the forward speed of the combine as well as increasing the feeding rate causes an increase in the quality loss of wheat. Due to the fact that the product remains in the threshing part for a longer period of time in the threshing combine than in the normal combine, grain breakage occurs more often. An increase in the density of spikes causes an increase in overloading and an increase in the quality loss of wheat. In the straw collecting combine, due to the limitation in the threshing part, field performance has a significant impact on the amount of harvest losses in this type of combine.

The forward speed of the straw collecting combine and spike density per m^2 led to an increase in the quality loss of wheat up to 3.8%, which is a high-quality loss compared to developed countries (Ghari et al., 2013). In a study in Fars province, with multi-stage sampling of 68 farms during harvest, the quality loss of the combine was between 1.65 to 4.03%, and the decrease and increase of this loss were dependent to combine type, combine forward speed and relative farm yield (Khosravani & Rahimi, 2005).

By using the response surface method, in addition to modeling the percentage of wheat quality loss in harvesting with a straw collecting combine, it can also be optimized (minimized). Optimum operating conditions were investigated with the aim of minimizing the quality loss of wheat (Azar2 variety) in harvesting with a straw collecting combine under the influence of spike density per m^2 and forward speed of the combine, using response surface method (RSM) numerical optimization technique. The results obtained from this optimization process are presented in Figure 5.

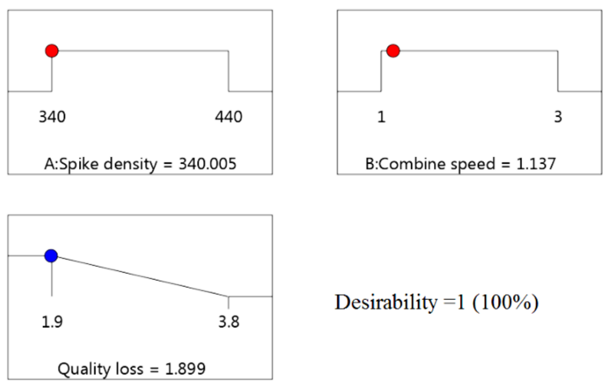

Figure 5. Optimum values to minimize the percentage of quality loss of wheat under the influence of advancing speed and spike density

The desirability index (DI) indicates the accuracy of the model in determining the combination of the investigated treatments to obtain the optimal dependent variables. The closer the value of this index is to one, it indicates the high accuracy of the model in simulating the value of dependent variables under the influence of independent variables. The value of this index was obtained according to the goal of minimizing the percentage of wheat quality loss in harvesting with a straw collecting combine harvester equal to one or 100%, based on which the high accuracy of the model in simulating the value of the dependent variable (quality loss of wheat) was observed. The optimum amount has been obtained with the minimum percentage of wheat loss (approximately 1.9 %) in the spike density of approximately 340 spikes per m^2 and approximately 1.1 km speed of the straw collecting combine (Figure 5).

CONCLUSION

In this research, the response surface method was used to model and optimize the percentage of quality loss of wheat (Azar2 variety) in rainfed conditions, under the influence of the combine forward speed and wheat spike density per m^2. Process variables in the form of quadratic regression models were significant for this answer (percentage of quality loss). By increasing the speed of straw collecting combine (from 1 to 3 km/h) and spike density per m2 (from 340 to 440), the percentage of wheat quality loss increased from 1.9 to 3.8%. Optimum conditions (the minimum amount of 1.9 %) for the percentage of quality loss of wheat in harvesting with a straw collecting combine occurred at 1.1 km/h of combine forward speed and 340 of wheat spike density per m2. The results of this research showed that the response surface method is an effective method for modeling and optimizing (minimizing) the percentage of wheat quality loss in harvesting with a straw collecting combine under the influence of spike density per m^2 and combine forward speed.

REFERENCES

Ahmadi Chenarbon, H., Ebrahimzadeh, M. R., & Rouhi, R. (2009). The study of wheat harvesting losses by combine harvester in Varamin region. *Journal of Plant and Environment*, *5*(17), 70-57.

Amiri, H., Asakereh, A., & Soleymani, M. (2022). Economic analysis and evaluation of grain losses of two common straw collecting combine harvester: a case study, Azna county, Lorestan, Iran. *Journal of Agricultural Machinery*, *12*(4), 613-626.

Eriksson, L., Johansson, E., Kettaneh-Wold, N., Wikstrom, C., & Wold, S. (2008). *Design of Experiment: Principales and Applications* (third ed.). Umetrics.

Felegary, M., Jafarinaeimi, K., & Akhavan, H.-R. (2023). Developing and Evaluating a Hot Water-Assisted Extractor for Making Instant Drink from Date Kernels Powder. *Biomechanism and Bioenergy Research*, *2*(1), 84-98.

Ghari, M., Parmah, A., Chaghasefidi, A., & Yeganeh, R. (2013). *Determination and evaluation of losses in two combine John Deere 1055 and John Deere 1165 during wheat harvest* The 6th Agricultural Research Conference, University of Kurdistan. Sanandaj.

Ghasemi Nejad Raeini, M., Faramehr, M., & Abdeshahi, A. (2018). Investigating the effect of field and crop conditions on combine performance in wheat harvesting. *Biosystem Engineering*, *49*(3), 513-524.

Hosseinpour, T., Bahari, M., & Ghorbani, K. (2014). *Characteristics of different crop varieties in Lorestan province* (First ed.). Rashedin

Khosravani, A., & Rahimi, H. (2005). Investigating wheat harvesting losses with combine harvester in Fars province. *Agricultural Engineering Research Journal*, *6*(25), 113-130.

Mandal, K., & Mukhopadhyay, D. (2015). Effects of inorganic phosphorus fractions under different tillage practices on wheat (Triticum aestivum) in an acid soil of west Bengal (India). *Tropical Agricultural Research & Extension*, *18*(3), 106-102. https://doi.org/10.4038/tare.v18i3.5332

Mirzazadeh, A., Abdollahpour, S., & Moghadam, M. (2011). Effect of design parameters on separation of grain in thresher to minimize separation loss of combine. *Journal of Agricultural Science and Sustainable Production*, *21*(3), 1-11.

Motiei, M., Shahbazi, F., & Hizbawi, I. (2016). *A five-year study of the effect of different factors on the amount of rainfed wheat waste in harvesting with a combine harvester* 10th National Congress of Agricultural Machine Engineering (Biosystem) and Mechanization of Iran, Mashhad https://civilica.com/doc/563490

Myers, R. H., Montgomery, D. C., & Anderson-Cook, C. M. (2016). *Response surface methodology: process and product optimization using designed experiments*. John Wiley & Sons.

Rostami, S., Lotfalian, M., & Hoseinzadeh-Samani, B. (2018). Assessment and comparison of conventional and straw walker combines harvesting losses in Fars province. *Agricultural Mechanization and Systems Research*, *19*(70), 85-96.

Shaker, M., & Zare, A. (2010). *Technical and economic comparison of the performance of new wheat combines with common combines in Fars province* The 6th National Congress of Agricultural Machinery and Mechanization Engineering, University of Tehran. Karaj. https://civilica.com/doc/155980

Tabaei, A., Hazbavi, I., & Shahbazi, F. (2020). Modeling and optimization of persimmon drying using response surface methodology. *Journal of food science and technology (Iran)*, *17*(98), 109-119. https://doi.org/10.29252/fsct.17.01.10