ANN-based Modeling of Sunflower Threshing Process and Defining the Optimal Operation Point for Separation Efficiency

P. Ghiasi[1*], A. Masoumi[2], A. Hemmat[2], G. Najafi[3]

Abstract

Harvesting is one of the most important field operations in sunflower production. Seed damage and low separation efficiency are the top concerns of harvesting sunflower. In this study, a threshing cylinder with rubber teeth and a concave for harvesting sunflower were designed and evaluated. The variable parameters were threshing cylinder speed (TCS), threshing space (TS) and moisture content (MC) of sunflower head. Azargol variety was used to evaluate the threshing unit. The tests were performed at three cylinder speed levels (280, 380 and 480 rpm), two threshing spaces (8 and 10 cm) and two moisture content of sunflower head based on the crop condition (20% and 45% wet basis). An ANN model was developed to predict the amount of materials in each part of the concave. Results showed that the sunflower seeds had no damage during the threshing process and the presented model could predict the amount of materials in each part of the concave with a regression coefficient $R^2=0.95$. Based on the ANN model, with a decrease in MC and TS, and an increase in TCS, the separation efficiency was increased. Furthermore, optimal parameters for the threshing unit which were suggested by Design Expert software to maximize the separation efficiency were 18% w.b, 450 rpm and 10.5 cm for MC, TSC, and TS, respectively and in this condition separation efficiency was determined to be 94.92%.

Keyword: Sunflower harvesting, Threshing model, Threshing unit

Introduction

Oilseeds are one of the most important agricultural crops that are used as raw materials for providing oil and supplying the needs of fat, protein, and vitamins for human and living organisms. Oil production has been increased recently and most of this increase has been related to the sunflower seed oil (Inna, 2010). Sunflower planting is mostly for two main purposes; oil production and direct consumption (Schneiter and Miller, 1981). Harvesting is often done manually in Iran because mechanized harvesting is very expensive and is not still economical. Mechanized harvesting methods are conducted with rasp bar drum and concave and can make a seed loss of 46% during the threshing operation in the threshing unit (Farokhi *et al.*, 2013). Although the seed damage is not very important in oilseeds, mechanical damage leads to weakening germination and reduces the storage and grain growth potential (KhajePor, 2012). The damage to sunflower seeds in fresh market results in reducing the crop price significantly. Harvesting operation when the moisture content is not reduced enough, would reduce the sunflower seeds quality and increases the possibility of disease outbreaks (Giner and Gely, 2005). The mechanized harvesting of sunflower has been studied by several researchers (El-khateeb and Saad, 2008; Ghiasi *et al.,* 2016; Sudajan *et al.*, 2002). In all of these studies, separation efficiency and sunflower seed damage have considered as two important parameters for evaluation of the threshing unit which express how materials were spread through the threshing unit and to what extent threshing unit was able to chop the crop into appropriate pieces.

1- PhD candidate, Department of Biosystems Engineering, Tarbiat Modares University,Tehran, Iran
2- Faculty Member, Department of Biosystems Engineering, Isfahan University of Technology, Isfahan, Iran
3- Faculty Member, Department of Biosystems Engineering, Tarbiat Modares University,Tehran, Iran
(*- Corresponding Author Email: p.ghiasi@modares.ac.ir)
DOI: 10.22067/jam.v10i1.76264

The effects of the threshing parameters have been studied for several crops to optimize the threshing condition. The proposed models can be offered for simulating the behavior of the threshing unit (Miu and Kutzbach, 2007). In this case, they modeled the kinematic behavior of the material into the threshing unit with a regression coefficient of $R^2 = 0.9$. The dynamical model of materials in the threshing unit was presented by (Ning *et al.*, 2015) then through fuzzy control, the forward speed of the combine harvester was controlled. Among the statistical and mathematical models, intelligent systems were better to predict nonlinear behavior because of the use of complex algorithms. The effect of concave clearance, cylinder speed, feed rate, and moisture content was studied on the percentage of grain damage, separation efficiency, and percentage of germination for chickpea threshing (Salari *et al.*, 2013). Results showed that with an increase in the cylinder speed and decrease in the moisture content, the feed rate, and the concave clearance as well as the threshing efficiency were increased. The number of lost seeds in paddy harvester were simulated by Hiregoudar *et al.* (2011) using artificial neural networks and the minimum amount of lost seeds for the harvester. Mirzazadeh *et al.* (2012) used an artificial neural network (ANN) to model wheat behavior in a threshing unit. The results showed that the neural network with 7 neurons can simulate the behavior of wheat in the threshing unit with a regression coefficient of $R^2 = 0.81$.

Providing a proper model for threshing can be a powerful tool for optimizing and managing the threshing process. The study of some researches about the modeling of materials behavior in the threshing unit showed that the behavior of the materials in the threshing unit not only depended on the type, physical and rheological properties of crops but also can be completely different in each crop. Generally, to mechanistically harvest new crops and design other sections of the combine harvester, it is necessary to analyze the behavior model of materials. In this study, the behavior of the sunflower head

in the threshing unit with robber teeth was modeled by using ANN. The present study aimed to predict the behavior of the sunflower head in the threshing unit with an ANN model and to define the optimal point of the threshing unit to maximize the separation efficiency.

Material and Methods

Threshing cylinder and concave

A threshing unit was designed and developed on a chassis to join a conveyor. The schematic design of the machine units is shown in Fig.1, which includes threshing cylinder, concave, flanges, rubber grips, and shaft. The diameter and width of the threshing cylinder were both 50 cm. As shown in Fig.1, the threshing unit has four rows of rubbers, two rows had four and the other two rows had five rubbers, and all of them were fixed on a shaft with a diameter of 30 mm. The concave's arc was 135 degrees and was divided into five sections to collect the seeds and MOG[1] of each part and also to record the amount of them. After the threshing process, the remaining materials of each part were checked carefully by three adult persons to check the surface damages on sunflower seeds. Then, broken and cracked seeds were separated and weighted to calculate the surface damages.

The machine was evaluated with Azargol sunflower variety. Variable parameters including TCS[2] in three levels (280,380 and 480 rpm), MC[3] in two levels (45 and 20 w.b), TS[4] in two levels (8 and 10 cm which were the distance between threshing cylinder and concave in front of the threshing unit and distance between threshing cylinder and concave in the back of the threshing unit was 5 cm) and constant feed rate (670 kg.h^{-1}) were selected. The study was conducted based on a 2×3×2 factorial design with three replications, and the experiment was a completely randomized design with three factors including MC, TSC, and TS. For each test, the input

---

1- Material Other than Grain
2- Threshing Cylinder Speed
3- Moisture Content
4- Threshing Space

weight of the threshing unit and the weight of the threshed sunflower head under the concave and behind it were measured. Note that, in numbering the different sections of the concave, the behind section was named "part 6".

Artificial neural network

The artificial neural network is one of the computational methods that strives to recognize the relationships between the input and output data using the process of learning and neuron. Artificial neural networks were implemented with 4 inputs including the number of parts, moisture content, threshing cylinder speed, and threshing space and one output includes the separation efficiency (Fig.2). The tan-sigmoid transfer function was used for the nodes in the hidden layer as it was a powerful configuration for complex non-linear function approximation (Zurada, 1992).
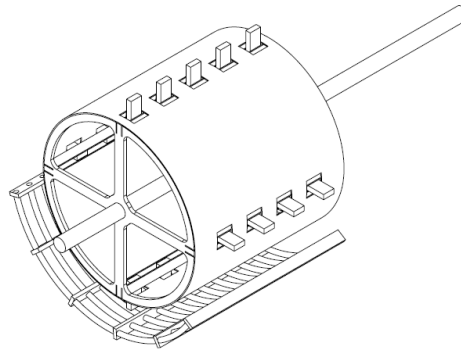

Fig.1. Schematic of the threshing unit

A network model is characterized by an error space representing the error of the system for every possible combination of the weights and biases (Uno *et al.*, 2005). Mean Sum-squared Error (MSE) was used as the performance function, and the batch training was used in which the weights and biases were updated in the direction of the negative gradient of the performance function only after the entire training samples (epoch) had been applied to the network. The gradients calculated at each training sample were added together to determine the change in the weights and biases. The performance of the neural network was evaluated with MSE and the correlation coefficient of R^2, which are presented in equations 1 and 2, respectively.

$$MSE = \frac{\sum_{i=1}^{n}(y_{O,i} - y_{M,i})^2}{n} \qquad (1)$$

$$R = \frac{\sum_{i=1}^{n}(y_{O,i} - y_{O,mean})(y_{M,i} - y_{M,mean})}{\sqrt{\sum_{i=1}^{n}(y_{O,i} - y_{O,mean})^2(y_{M,i} - y_{M,mean})^2}} \qquad (2)$$

Where n is the number of data, $y_{O,i}$ and $y_{M,i}$ are the output value predicted by the model and the measured output value, respectively, $y_{O,mean}$ and $y_{M,mean}$ are the measured average output value and the predicted average value by the model.

In this study, the Neural Network Toolbox of MATLAB R2016a software was used to predict the percentage of materials in different concave parts. For this research, 70% of the data were used for training, 15% for testing and 15% for validation of network (Shahgoli *et al.*, 2018). The number of neurons obtained during the test and error was 15 neurons for the network. The number of neurons in the output layer depends on the number of output parameters. In this research, the output of the model was the percentage of material deposited in different parts of the concave, so the number of neurons in the outer layer was one.
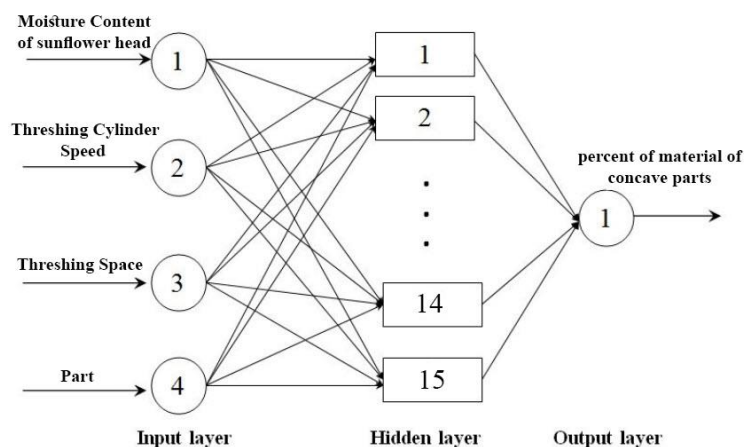
Fig.2. The artificial neural network structure

Optimal point of the threshing unit

The model was presented and the suitability of the model was ensured for predicting the amount of material. In each part before obtaining the amount of material in different parts of the concave, the range of each independent parameter for the moisture content of sunflower head was expanded. The minimum and maximum moisture content of sunflower head were determined based on seed handling, then 5 levels of MC were selected. The maximum level of the threshing cylinder speed was limited by input power in the threshing unit and due to mechanical constraints in the threshing unit, the range of distance between the threshing cylinder and the concave was defined. The moisture content of sunflower head in 5 levels (18, 28, 38, 48 and 58 w.b.), the threshing cylinder speed in 4 levels (250, 450, 650 and 850 rpm) and the threshing space in 4 levels (7.5, 8.5, 9.5 and 10.5 cm) as the new inputs were entered to the model. The data for the parts of 1 to 5 were related to the materials which had passed through the concave and the data for the part of 6 was related particularly to the materials that had not passed through the concave. Based on the separation efficiency equation for the concave, (Equation 3) (El-khateeb and Saad, 2008), the more material passed into the concave, the more separation efficiency of the concave was increased. Accordingly, the optimum operating conditions were obtained when the percentage of the material

accumulated in section 6 was minimized (Griffin *et al.*, 1981). For this purpose, design expert 7.0.0 software and the general factorial choice were used.

$$\eta_{SE} = \frac{\frac{mass\ of\ material\ passed\ into\ the\ concave}{total\ material\ input}}{\times 100} \quad (3)$$

ANN model validation

After developing the model, training process was done by using 70% of experimental data and tested by using 15% of experimental data. The variable parameters of the experimental test, were entered to the model as new inputs and compared with the actual results. The correlation coefficient between actual results and output of the ANN model for separation efficiency was calculated by using Microsoft Excel 2016 software.

Result and Discussion

Threshing efficiency

The threshing unit with different levels of MC, TCS, and TS was tested and then the analysis of variance was done. The analysis of variance was performed in the completely randomized design on three factorials. Obtained results are tabulated in Table 1. Results indicated that the effects of MC, TCS, and TS on the percentage of material in part 6 were significant at 1% level of confidence. The interaction between the first degree of MC*TCS was not significant at 5% level and the interaction effect of the first degree of MC*TS and TCS*TS was significant at 5%

level. The interaction between the second degree of MC*TCS*TS was not significant at 5% level.

Fig. 3a shows the percentage of material for the concave parts in MC levels of 20% and 45% w.b in the primary parts of the concave. In the MC level of 45% w.b , the amount of separated material was low; because of a smaller space and high sunflower head density, the amount of material passed through the concave parts was increased. In the MC level of 20 w.b %, because of the fragility of sunflowers head and rheological properties, the material passed through the concave was increased in the primary parts. Sudajan *et al.* (2002) reported that the attaching force between seed and flower head reduced and hence seeds might be separated easily. This might result in a higher separation efficiency in the lower MC. The effect of TCS on the percentage of material in each part is shown in Fig. 3b. An increase in TCS caused the threshing unit to break the sunflowers head at the primary parts so less material went to the last parts. Then, either the part 6 or back of the concave received less amount of material. These findings are in line with Vejasit and Salokhe (2006) study that increasing TCS led to increasing separation efficiency. The distance between the threshing cylinder and the concave affected the material density. Furthermore, the density of the material between the threshing cylinder and the concave was increased and the amount of material in the primary parts was increased in the low TS as well (Fig. 3c). Seidirad and Javadi (2011) reported a similar result for decreasing the TS.

Table 1- Analysis of variance to evaluate the effects of MC, TCS and TS and the interaction between them on the amount of material in part 6

S.V	DF	Sum of squares	F Percent of material
MC	1	1184.74	86.93^{**}
TCS	2	1101.68	40.42^{**}
TS	1	387.96	28.46^{**}
MC*TCS	2	69.21	2.54^{ns}
MC*TS	1	114.13	8.37^{*}
TCS*TS	2	114.38	4.2^{*}
MC*TCS*TS	2	4.28	0.16^{ns}
Error	24	327.10	

* * Highly significant at 1% level; * significant at 5% level; ns, not significant; df, degrees of freedom

Seed damage

In the threshing process of the sunflower head, the force which was applied by the threshing teeth on sunflower seeds, did not catch the fracture force. Therefore, seeds crossed the concave without any damage or spot and seed damage amount was zero. Because of the lack of data for seed damage, it was not considered in the output of the ANN model and there were maybe a small amount of seed damage in expended input data.

The most important factors that kept seeds intact were: 1- the open space of the concave, 2- bars diameters 3- flexible teeth of the threshing cylinder 4- closed threshing cylinder which prevented seeds from striking to the metal parts.

Modeling

After the formation of the input and output matrix, the most suitable artificial neural network was chosen to simulate the amount of material accumulated in the concave parts. Fig.4 shows the correlation coefficient of the proposed artificial neural network model to simulate the amount of material accumulated in concave parts in the validation sections. The correlation coefficient for prediction of separation efficiency was 0.95 and the mean squared error for the network was 0.56, with the minimum value obtained during the trial and error. By rotating the threshing cylinder, sunflower heads were under the influence of impact and abrasion in the space between the threshing cylinder and the concave. Then the seeds were separated from sunflower head.

Since the distance between the threshing cylinder and the concave in the front part was long enough, seeds in this area were separated and passed through the concave, then the impact force would be more effective than abrasion on the threshing process. In the back parts of the concave, because of a higher material density, seeds were separated by abrasion of other sunflower heads and bars and cans of the concave (Lizhang *et al.*, 2013). Understanding what action is more effective during the threshing process, can be useful.

(A)

(B)

(C)
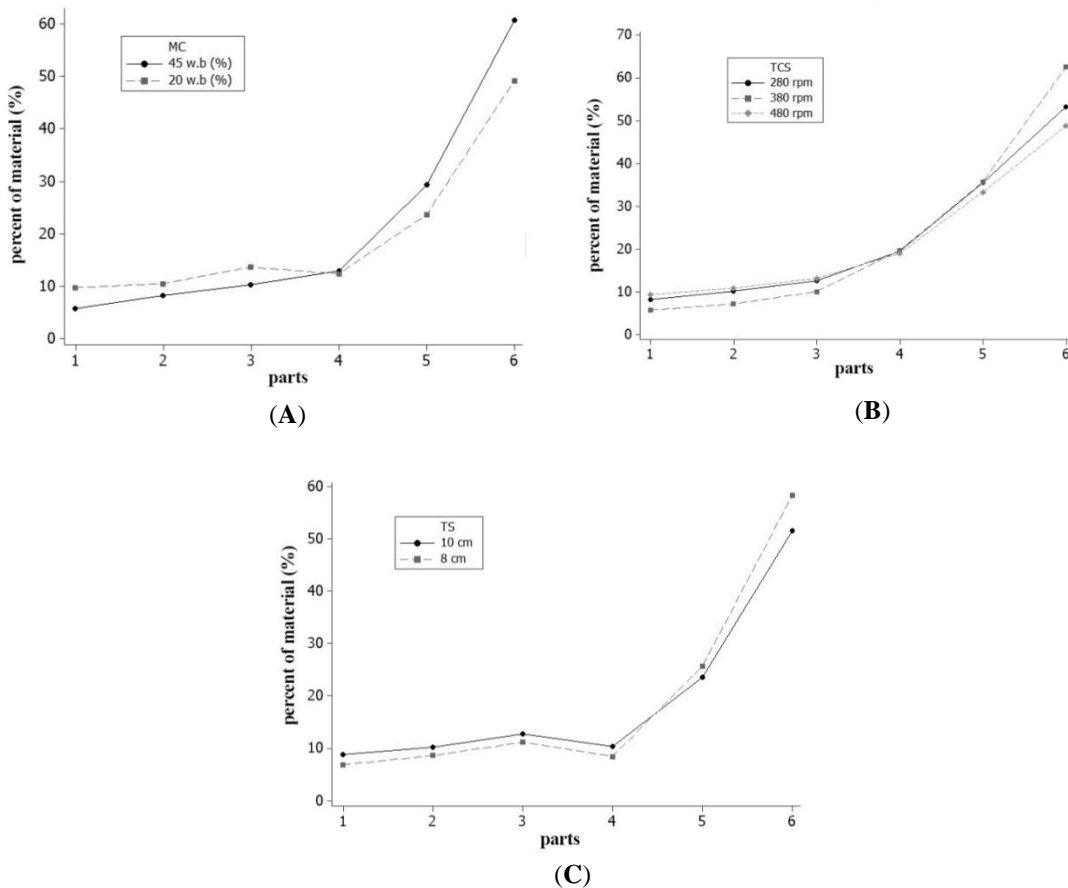
Fig. 3. (**A**) Effect of MC on MOG (**B**) Effect of TCS on MOG (**C**) Effect of TS on MOG

$Y=0.943x + 3.33$

$R^2=0.95$
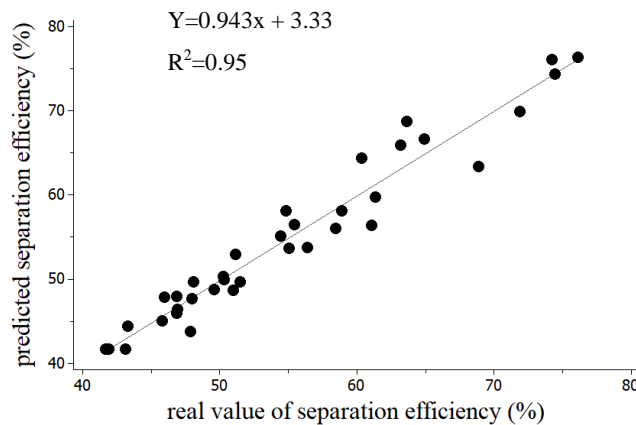
Fig. 4. Artificial neural network performance

Results of the artificial neural network model related to the effect of MC on the percentage of the material existent in the concave parts are shown in Fig. 5a. The decrease in MC changed rheological properties of sunflower head to fragility, increased the amount of material in the primary parts of the concave and reduced the volume of the remaining materials in the last part. In a higher moisture content, due to the impact of the rubber component on sunflower head, the head was torn and cut into smaller pieces at the last parts by abrading other sunflower heads, bars, and cans of the concave, and passing through the concave. Under this circumstance, the concave separation efficiency was increased in lower moisture content. El-khateeb and Saad, (2008) achieved similar results for two sunflower thresher machines that decreasing in MC of sunflower head led to increasing the separation efficiency but seed damage increased in both thresher machines by decreasing in MC.

Fig. 5b shows the results of the ANN model for the effect of the threshing cylinder speed on the percentage of material in the concave parts. With increase in TCS, the effect of impact force on the threshing process was increased, so it caused more materials to drop into the primary part of the concave. With increase the threshing cylinder speed, not only the intensity of the threshing process was increased which was because of the increase in the impact effect, but also the passage of material was increased in the primary part. As a result, the separation efficiency of concave was increased. These findings are in consistent with Sudajan *et al.*, (2002), El-khateeb and Saad, (2008) and Seidirad and Javadi (2011) for threshing sunflower seeds and cumin.

The effect of the threshing space on the percentage of material in the concave parts based on the artificial neural network modeling is presented in Fig. 5c. Accordingly, the more open space of threshing unit, the more chance for unthreshed sunflower head to drop into the back parts of the concave. The reduction in the threshing space led to an increase in the density of the material which consequently increased the effect of abrasion on the threshing process. Based on the results reported by Seidirad and Javadi (2011), decreasing in the TS in lower MC was more effective on the threshing efficiency than higher MC. According to Fig. 5c, with a decrease in the TS, the percentage of the material was decreased in section 6 and as a result, the separation efficiency was improved.

Optimal working point

The experiment data was exported from the ANN model. Because of significant interaction between MC*TS and TCS*TS, Design Expert software was used for defining the optimal point. Then the optimum point was determined to maximize the concave separation efficiency. The concave parts included 6 sections: parts 1 to 5 were specifically for those materials that passed into the concave open area and section 6 was a place for the accumulation of materials that did not pass into the concave open area. Therefore, according to equation 3, the percentage of the material had to be minimized in Section 6 to achieve the maximum concave separation efficiency. The optimum points with utility index are given in Table 2. The optimal point of the threshing unit was obtained in 18% w.b of MC, 450 rpm of TCS and 10.5 cm of TS.

Conclusions

The results of the ANN model showed that the trends of separation efficiency with MC of sunflower head, TCS and TS, had a good agreement with those which were obtained from the real tests. Because of the design property, the sunflower seeds were not damaged. With a decrease in MC from 58% to 18% w.b, the separation efficiency was increased from 71.67% to 74.2% and also an increase in TCS from 250 rpm to 850 rpm improved the concave separation efficiency from 67.5% to 72.25%. With the reduction in TS from 10.5 cm to 7.5 cm, the concave separation efficiency was increased from 70.6% to 77.26%. Finally, to maximize the separation efficiency of the threshing unit, three optimal conditions were proposed with a utility index of 1, 0.977 and 0.873.

(**A**)

(**B**)

(**C**)
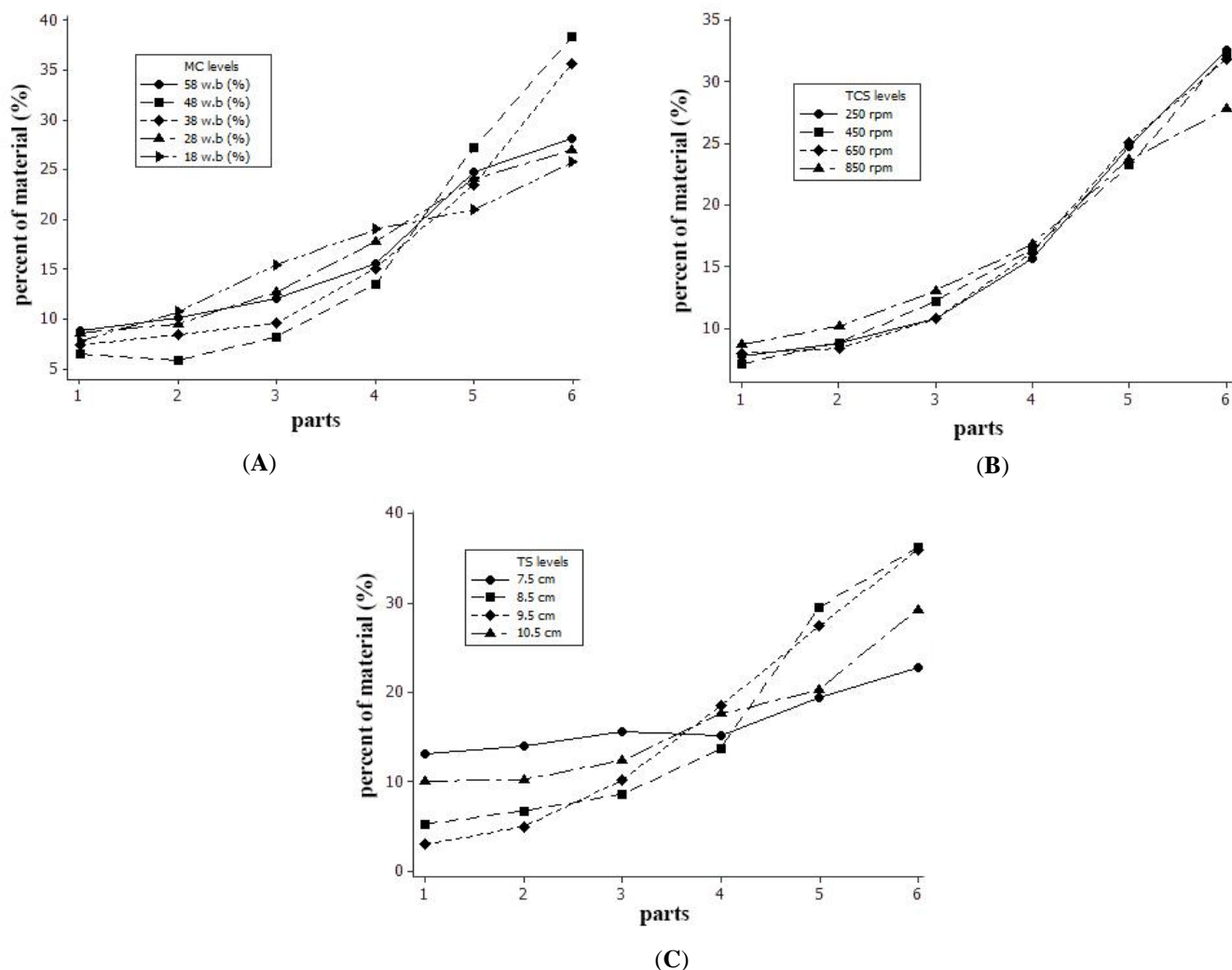
Fig.5. (**A**) Effect of sunflower head MC on the percentage of material in the concave parts (**B**) Effect of TCS on percentage of material in the concave parts (**C**) Effect of TS on the percentage of material in the concave parts

Table 2. Optimal conditions of threshing unit

	MC(% w.b)	TCS (rpm)	TS (cm)	Separation efficiency (%)	Desirability
1	18	450	10.5	94.92	1
2	58	250	7.5	93.75	0.977
3	48	850	7.5	88.35	0.873

References
1. El-khateeb, H., and M. I. Saad. 2008. Operating factors affecting using two different threshing machines for threshing sunflower heads. Agricultural Mechanization and Engineering 251-270.
2. Farokhi, E., A. Nabipor, and J. Daneshian. 2013. Guidelines sunflower production in different regions of the country. Agricultural and Natural Resource Research and Education Center. Tehran. Iran. (In Farsi).

3. Ghiasi, P., A. Masoumi, and A. Hemmat. 2016. Design, development, and evaluation of a threshing cylinder and concave for harvesting sunflower. The 10th national congresss on biosystems Eng. (Agr. Machinery). Mashhad, Iran. (In Farsi).
4. Giner, S. A., and M. C. Gely. 2005. Sorptional parameters of sunflower seeds of use in drying and storage stability studies. Biosystems Engineering 92: 217-227.
5. Griffin, G. A., and Deere and Company. 1981. Combine harvesting. Deere & Co.
6. Hiregoudar, S., R. Udhaykumar, K. T. Ramappa, B. Shreshta, V. Meda, and M. Anantachar. 2011. Artificial Neural Network for Assessment of Grain Losses for Paddy Combine Harvester a Novel Approach. Control, Computation and Information Systems 140: 221-231 Springer, Berlin, Heidelberg.
7. Inna, P. 2010. Agribusiness handbook: Sunflower refined and crude oils. FAO Investment Centre Division: 40-40.
8. KhajePor, M. 2012. Industrial plants. first edition. Isfahan University of Technology Publication Center. Isfahan. Iran. (In Farsi).
9. Lizhang, X., L. Yaoming, M. Zheng, Z. Zhan, and W. Chenghong. 2013. Theoretical analysis and finite element simulation of a rice kernel obliquely impacted by a threshing tooth. Biosystems Engineering 114: 146-156.
10. Mirzazadeh, A., Sh. Abdollahpour, A. Mahmoudi, and A. Ramazani. 2012. Intelligent modeling of material separation in combine harvester ' s thresher by ANN. International Journal of Agriculture and Crop Sciences 23: 1767-1777. (In Farsi).
11. Miu, P. I., and H. D. Kutzbach. 2007. Mathematical model of material kinematics in an axial threshing unit. Computers and Electronics in Agriculture 58: 93-99.
12. Ning, X., J. Chen, Y. Li, K. Wang, Y. Wang, and X. Wang. 2015. Kinetic model of combine harvester threshing system and simulation and experiment of speed control. Nongye Gongcheng Xuebao/Transactions of the Chinese Society of Agricultural Engineering 31: 25-34.
13. Saeidirad, M., and A. Javadi. 2011. Study on machine-crop parameters of cylinder threshers for cumin threshing. Agricultural Engineering International: CIGR Journal 13.
14. Salari, K., R. Amiri Chayjan, J. Khazaei, and J. Amiri Parian. 2013. Optimization of Independent Parameters for Chickpea Threshing Using Response Surface Method (RSM). Journal of Agricultural Science and Technology 15: 467-477.
15. Schneiter, A. A., and J. F. Miller. 1981. Description of sunflower growth stages. Crop Science.
16. Shahgoli, G., H. GhafouriChyane, and M. Tarahom. 2018. Modeling of Soil Compaction Beneath the Tractor Tire using Multilayer Perceptron Neural Networks. Journal of Agricultural Machinery 8: 105-118. (In Farsi).
17. Sudajan, S., V. M. Salokhe, and K. Triratanasirichai. 2002. PM-Power and Machinery: effect of type of drum, drum speed and feed rate on sunflower threshing. Biosystems Engineering 83: 413-421.
18. Uno, Y., S. O. Prasher, R. Lacroix, P. K. Goel, Y. Karimi, A. Viau, and R. M. Patel. 2005. Artificial neural networks to predict corn yield from Compact Airborne Spectrographic Imager data. Computers and Electronics in Agriculture 47: 149-161.
19. Vejasit, A., and V. Salokhe. 2004. Machine-Crop Parameters Affecting Performance of an Axial-Flow Soya Bean Thresher. Agricultural Engineering International: The CIGR Journal of Scientific Research and Development, Manuscript PM 04, 004.
20. Zurada, J. M. 1992. Introduction to artificial neural systems. West.

تعیین نقطه بهینه کاری برای بیشینه کردن بازده جداسازی کوبش آفتابگردان بر اساس مدل عصبی

پدرام قیاسی ‌*۱، امین اله معصومی۲، عباس همت۲، غلامحسن نجفی۳

چکیده

برداشت آفتابگردان یکی از فرآیندهای مهم در زراعت آفتابگردان می‌باشد. آسیب دانه‌ای و بازده جداسازی کم از مشکلات برداشت آفتابگردان می‌باشند. در این مطالعه، سیلندر کوبنده با دندانه‌های لاستیکی و ضد کوبنده برای برداشت آفتابگردان طراحی و ساخته شد. سرعت سیلندر کوبنده، فضای کوبنده و رطوبت طبق آفتابگردان، پارامترهای مستقل در ارزیابی واحد کوبش تعیین شد. از رقم آفتابگردان آذر گل برای ارزیابی استفاده شد. آزمون‌ها در سه سطح سرعت سیلندر کوبند (۲۸۰، ۳۸۰ و ۴۸۰ دور در دقیقه)، دو سطح فضای کوبنده (۸ و ۱۰ سانتی‌متر) و دو سطح رطوبت طبق آفتابگردان (۲۰ و ۴۵ بر اساس ماده تر) انتخاب شد. برای پیش‌بینی مقدار مواد جمع‌شده در هر بخش ضد کوبنده، شبکه عصبی مصنوعی ارائه شد. نتایج حاکی از آن است که دانه‌های آفتابگردان بدون آسیب توسط واحد کوبش، کوبیده می‌شود و مدل ارائه شده برای کوبش با ضریب همبستگی ۰/۹۹ می‌تواند مقدار مواد ریخته شده در هر بخش ضد کوبنده را پیش‌بینی کند. بر اساس مدل عصبی ارائه شده با کاهش رطوبت طبق آفتابگردان و فضای کوبنده و افزایش سرعت سیلندر کوبنده، بازده جداسازی واحد کوبش افزایش می‌یابد. نقطه بهینه کاری بر اساس مدل شبکه عصبی مصنوعی برای بیشینه کردن بازده جداسازی، رطوبت طبق آفتابگردان ۱۸٪ بر اساس ماده تر، سرعت سیلندر کوبنده ۴۵۰ دور بر دقیقه و فضای کوبنده ۱۰/۵ سانتی‌متر تعیین شد.

واژه‌های کلیدی: برداشت آفتابگردان، مدل‌سازی کوبش، واحد کوبش

۱– دانشجوی دکتری، گروه مهندسی مکانیک بیوسیستم، دانشگاه تربیت مدرس، تهران، ایران
۲– عضو هیئت علمی، گروه مهندسی مکانیک بیوسیستم، دانشگاه صنعتی اصفهان، اصفهان، ایران
۳– عضو هیئت علمی، گروه مهندسی مکانیک بیوسیستم، دانشگاه تربیت مدرس، تهران، ایران
(Email: p.ghiasi@modares.ac.ir :نویسنده مسئول –*)