Engineering and Applied Science Research
https://www.tci-thaijo.org/index.php/easr/index
Published by the Faculty of Engineering, Khon Kaen University, Thailand

Multi-objective optimization of a threading machine for tobacco leaves

Ranaporn Senasutham[1)], Sujin Bureerat[2)], Juckamas Laohavanich[1)], Cherdpong Chiawchanwattana[1)] and
Suphan Yangyuen*[1)]

[1)]Postharvest Technology and Agricultural Machinery Engineering Research Unit, Mechanical Engineering, Faculty of Engineering, Mahasarakham University, Maha Sarakham 44150, Thailand
[2)]Department of Mechanical Engineering, Faculty of Enginrring, Khon Kaen University, Khon Kaen 40000, Thailand

Received 23 March 2021
Revised 11 July 2021
Accepted 21 July 2021

Abstract

The threading of Turkish or Oriental tobacco leaves is part of the sun drying process prior to cigarette production. In Thailand, tobacco leaves tend to be threaded manually by farmers, resulting in low production capacity due to insufficient labor being available. Therefore, the aim of this research is to analyze the tangential velocity of conveyor trays and the number of tobacco leaves pressed into needles, thereby affecting the working capacity of the machine. The machine comprises three main units. A programmable logic controller (PLC) is applied to control the machine's operation. The factors under study include the tangential velocity of conveyor trays (0.13, 0.15, and 0.18 m/s) and the number of tobacco leaves pressed into needles using either seven or eight trays each time. The results of multiple-objective optimization for the tobacco threading machine are analyzed using the weighted sum method, revealing a tray tangential velocity of 0.15 m/s, while the use of eight trays per time produces the maximum capacity of 3,887 leaves per hour. In addition, analysis of the percentage minimum leaves lost indicates that the tangential velocity of the trays is 0.13 m/s, while pressing prior to gathering seven trays per time prevents 0.91 and 0.61% of the leaves from falling and tearing, respectively, during the threading process. Moreover, 1.30 and 2.21% of the leaves experienced falling and tearing, respectively, after the threading process. Furthermore, the analysis shows that the machine generated twice as much productivity than human labor.

Keywords: Threading machine, Turkish tobacco leaves, Weighted sum, Response surface methodology

1. Introduction

Tobacco is one of the most valuable non-food crops. Tobacco leaf is used as an ingredient in cigarettes and cigars. At least 124 countries around the world grow tobacco, about 90% of which have warm climates, with 64.3% of such land being located in Asia [1]. The Tobacco Authority of Thailand, previously known as the Thailand Tobacco Monopoly, reported revenues of $1.66 from cigarette sales, both domestically and internationally. Moreover, it received a profit of 86 million Thai baht from selling tobacco leaves [2]. According to the data from the Excise Department, Ministry of Finance, around 34,000 households in Thailand farm tobacco as a career. Oriental tobacco, frequently referred to as "Turkish tobacco", is widely grown by 14,900 farming families in the northeastern region of Thailand, earning average incomes of more than $324/rai [3]. Since each variety of tobacco leaf has different amounts of dominant chemical compounds, the Turkish tobacco leaves have the highest volatile content. The Turkish tobacco leaf needs to be sun-cured, producing a strong, unique odor, unlike Virginia and Bailey tobacco which need to be smoke-cured in an incubator [4]. The tobacco leaves must be threaded into strings prior to the sun drying process which normally takes about seven days [5].

The cultivation of tobacco usually takes place after the farmers have harvested their rice. Curing is the process by which the harvested tobacco leaves are prepared for sale to the market. First, leaves aged 40-60 days are collected from the tobacco trees by harvesting from the bottom, taking 3-4 leaves at a time. The leaves are then threaded onto a needle measuring 1.5 m in length, which can accommodate around 400 leaves per bunch (medium-sized Turkish tobacco leaves). The dried leaves are subsequently moved for sun drying and later incubated indoors before being packaged. Finally, the products are sold to private companies authorized by the Thai government as well as government-owned companies [5].

The process of threading tobacco is still conducted manually since there are no tools or machines to aid the process. Since human labor is required, only around 1,557 leaves may be threaded per hour, which is considered a slow threading rate. Workers usually become tired during the process or waste time doing other activities rather than focusing on their work. Another obstacle is that the industry often lacks sufficient manpower, although in the past, a private company attempted to invent a threading machine for tobacco leaves on a commercial scale. However, the machine was not widely used by farmers due to the difficulties involved in its use, low capacity, and lack of mobility.

To date, no proper research has been conducted on tobacco leaf threading. Most of the existing research concerns the process after the leaves have been threaded, for example, the incubation of tobacco leaves [6, 7]. However, a study in 1964 consists merely of an abstract article on the invention of the stringer machine and the testing of its operation in comparison with threading by hand. The

---

*Corresponding author. Tel.: +08 0412 5684
Email address: suphan.y@msu.ac.th
doi: 10.14456/easr.2022.24

results revealed that the machine was approximately 21% more efficient than the manual process while producing similar work quality [8]. In 2019, research was carried out on the design and devolvement of a tobacco threading machine, with the test results revealing that the machine could thread 4,570 leaves per hour (nine bunches per hour). According to a review of the previous research, only a few studies have been conducted in this field. Further improvement is required to the existing research by Sanasutham et al. who designed and developed a tobacco threading machine that has already been tested in the laboratory [9].

This current research is an extension of that conducted by Senasutham et al. which involved a field test on a threading machine. After the experiment, the data were analyzed using response surface methodology (RSM), to study the influence of the tangential velocity of conveyor trays and the number of tobacco leaves pressed into needles, thereby affecting the working capacity of the machine. Additionally, multi-objective optimization is conducted to find suitable variables for adjusting the threading machine according to each different performance to match the needs of the farmers and could provide better results than when using human labor.

2. Materials and methods

2.1 Preparation of materials

2.1.1 Tobacco leaves

For this study, a variety of medium-sized Turkish tobacco leaves were collected from the middle of trunks in Roi Et Province, Thailand (Figure 1). The moisture content was 86.80% wet basis (wb), with the leaves measuring approximately 73.27 mm in width and 147.17 mm in length [10].

Figure 1 Turkish tobacco leaves

2.1.2 Components of the testing unit

The examination of the threading machine performance in this work represents an extension of the previous research, when a field test was conducted. The machine comprises the three main units: conveying, threading, and gathering as illustrated in Figure 2.

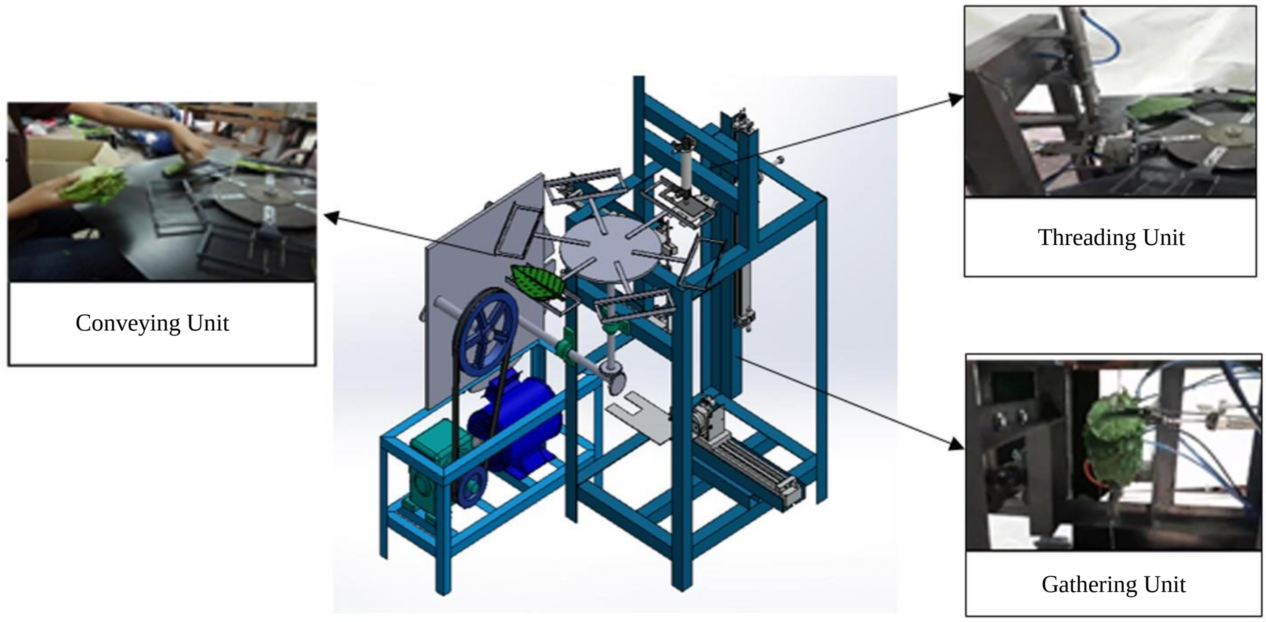


Figure 2 The three main units of the tobacco leaf threading machine.

The system is controlled by the programmable logic controller (PLC), globally known as the "work horse" of industrial automation, making it easier to improve the productivity and maintenance of the machine [11]. The PLC uses solenoid valves and pneumatic actuators, motors, heaters, and buzzers as output devices to drive the industrial process [12]. A control system function automated by the PLC is used as a cylinder controller for threading and gathering tobacco leaves. The conveyor unit is powered by a 1 hp single phase electric motor, transmitting power through the shaft which connects with the pinwheel gear of the tobacco tray. A Geneva mechanism is used as a tool for continuous step movements. A tobacco leaf conveyor containing six trays is used for the test. The tobacco leaves are then transported to the threading unit. Once in the threading unit, a pneumatic gripper holds the needle at the bottom of the leaves with cylinders used to press the leaves on to it. To press the leaves to the needle using the cylinder, there is a limit switch which inputs the signal to the PLC. The limit switch is activated when the edge of the tray touches it. When the leaf count reaches its limit, the gathering unit begins to gather the leaves from the needle to form a bunch. Figure 3 illustrates the operating steps of the tobacco leaf threading machine.

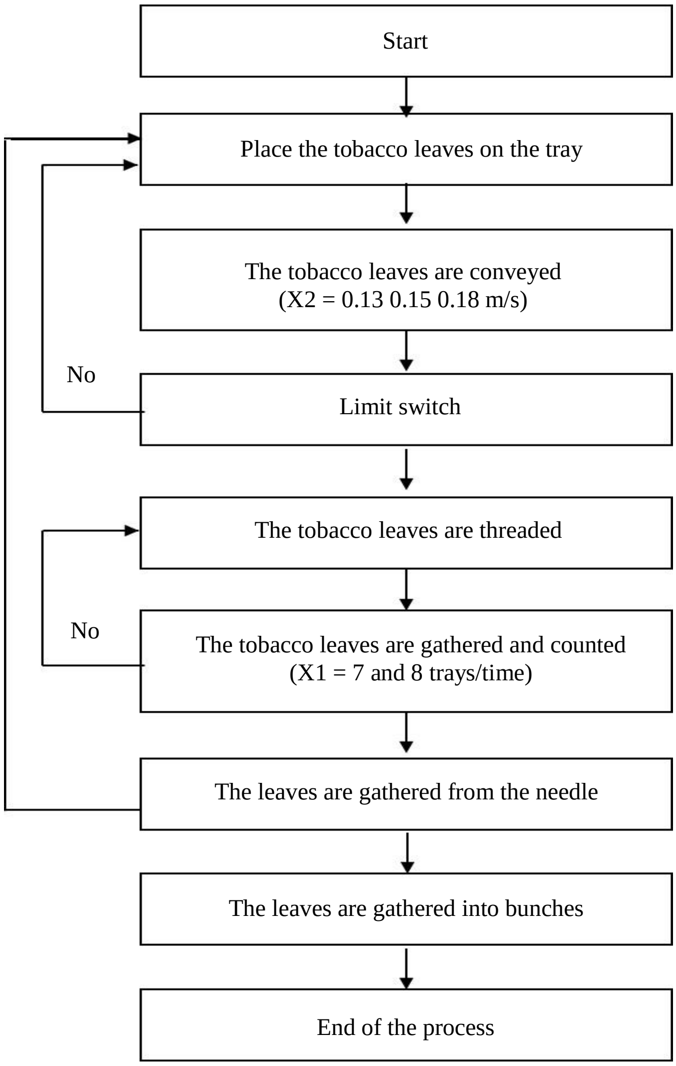


Figure 3 Operating steps of the threading machine.

2.2 Testing and evaluation

The test sample in this study consists of a group of farmers who work in the tobacco industry and have no experience of using a threading machine. Prior to testing, the farmer must practice placing the leaves onto a tray. The farmer testing the equipment requires a comprehensive manual to learn how the threading machine works and how to operate it. The variable parameters in this study are the constant tangential velocity of trays (X_2) and the number of times the leaves are threaded prior to gathering (X_1). The X_2 is set to 0.13, 0.15, and 0.18 m/s by adjusting the tray tangential velocity using an electrical current inverter, while the X_1 is set to seven and eight trays per time. The tests are replicated three times for each condition, with the results then used to calculate the working capacity (leaves per hour), as shown in Equation (1). The quality of tobacco leaves is subsequently assessed following completion of the threading process.

$$C_1 = \frac{L}{T} \tag{1}$$

Where C_1 is working capacity (leaves per hour), L is the number of leaves threaded (leaves), and T is the testing time (hour)

2.3 Analysis of multi-objective optimization

2.3.1 Response surface methodology

The influential factors affecting the capacity of the threading machine and the quality of the threaded leaves are then analyzed. These factors consist of the number of threads pressed prior to leaf gathering (X_1) and the tangential velocity of the trays in the conveying unit (X_2). The data from the test is then collected to analyze the response surface methodology (RSM). The RSM is a statistical technique for improving the study equation [13-15] with the purpose of optimizing a response [16], as demonstrated by the following quadratic Equation (2) [17, 18].

$$Y = a_0 + \sum_{i=1}^{n} a_i x_i + \sum_{i=1}^{n} a_{ii} x_i^2 + \sum_{i=1}^{n} \sum_{j=i+1}^{n} a_{ij} x_i x_j \tag{2}$$

Where Y represents the model response variable, a_0 is a constant, a_i is the linear term coefficient, a_{ii} is the quadratic term coefficient, a_{ij} is the interaction term coefficient, and X_i and X_j are the independent variables.

2.3.2 Weighted sum approach

Since this research has multiple objectives, the multi-objective optimization problem (MOOP) method is applied, consisting of special numerical techniques such as the weighted sum presented in Equation (3). The weighted sum method is commonly used for multi-objective optimization [19-21]. It varies the weights to achieve the multi objectives and combines them into a single optimal set [22].

$$F(x) = \sum_{i=1}^{p} w_i f_i (x) = w_1 f_1 (x) + \ldots + w_p f_p (x) \tag{3}$$

$$\text{When } \sum_{i=1}^{p} w_i = 1, w_i \in [0,1] \tag{4}$$

The objective functions considered in this study are the capacity of the machine (f_1), percentage of the falling leaves during the process (f_2), percentage of leaves tearing during the process (f_3), percentage of the fallen leaves after threading (f_4), and percentage of leaves tearing after threading (f_5). Using dimensionless variation factors, the weighted sum is measured according to the formula in Equation (5):

$$F = w_1 \frac{1}{f_1} + w_2 \frac{f_2}{100} + w_3 \frac{f3}{100} + w_4 \frac{f_4}{100} + w_5 \frac{f_5}{100} \tag{5}$$

This research consists of three case studies and uses the weighted sum method (Table 1). Firstly, case “A” involving optimization, focuses on the capacity of the threading machine. Case “B” focuses on the percentage of leaves lost during the threading operation. Finally, case “C” focuses on the percentage of leaves torn, both during and after the threading process. The objective of the study is to ascertain the optimal values of the factors affecting the desire of the tester to use the machine.

Table 1 Conditions for optimization

Case	**Weighted sum**				
	f_1	**f_2**	**f_3**	**f_4**	**f_5**
A	0.80	0.05	0.05	0.05	0.05
B	0	0.25	0.25	0.25	0.25
C	0	0	0.50	0	0.50

3. Results and discussion

3.1 Testing the tobacco leaves processed by the threading machine

3.1.1 Operational capacity

According to Table 2, the tangential velocity of the trays is 0.15 m/s when pressing the leaves at the rate of eight trays per time. The highest capacity is 3,887 leaves per hour while the tangential velocity of the trays is 0.18 m/s when pressing seven trays per time. The lowest capacity achieved is 2,712 leaves per hour.

The results show that when the tangential velocity of the trays increases from 0.13 to 0.15 m/s, the capacity of the machine increases to produce seven and eight trays of pressed leaves per time, respectively. This result is consistent with the performance evaluation of a multi-tuber peeling machine, in that an increase in the tray speed leads to greater capacity [23]. However, when the tangential velocity of the trays in the conveying unit increases to 0.18 m/s, pressing seven and eight trays per time, the machine’s capacity decreases. This is because the conveying of the trays affects the place where the tester can put the leaves, making it difficult to get them on the tray in time. This is consistent with the findings of other researchers, who revealed that when using different feed rates at higher speeds, the operator is unable to feed the material at a faster speed while remaining within the limits of human working conditions [24, 25].

Table 2 Threading tobacco leaves with the threading machine

Threading press count (trays per time)	**Tangential velocity of the trays (m/s)**	**Capacity**	
		(leaves per hour)	**(bunches per hour)**
7	0.13	3091	6.18
	0.15	3780	7.56
	0.18	2712	5.42
8	0.13	3823	7.65
	0.15	3887	7.77
	0.18	3454	6.91

Note: Six conditions were tested, each replicated three times.

3.1.2 Quality of the thread

When the tangential velocity of the trays is raised from 0.13 to 0.18 m/s, respectively, the percentage of lost leaves increases, as shown in Figures 4 and 5. This is due to the tester placing the leaves on the tray too quickly. Sometimes, the tester places the leaves in the wrong position or stacks them too high, resulting in many leaves falling off the trays during the conveying, threading, and gathering processes. This finding aligns with the existing research on cassava peeling and shelling and peanut machines, in that an increase in machine speed leads to high losses [26, 27].

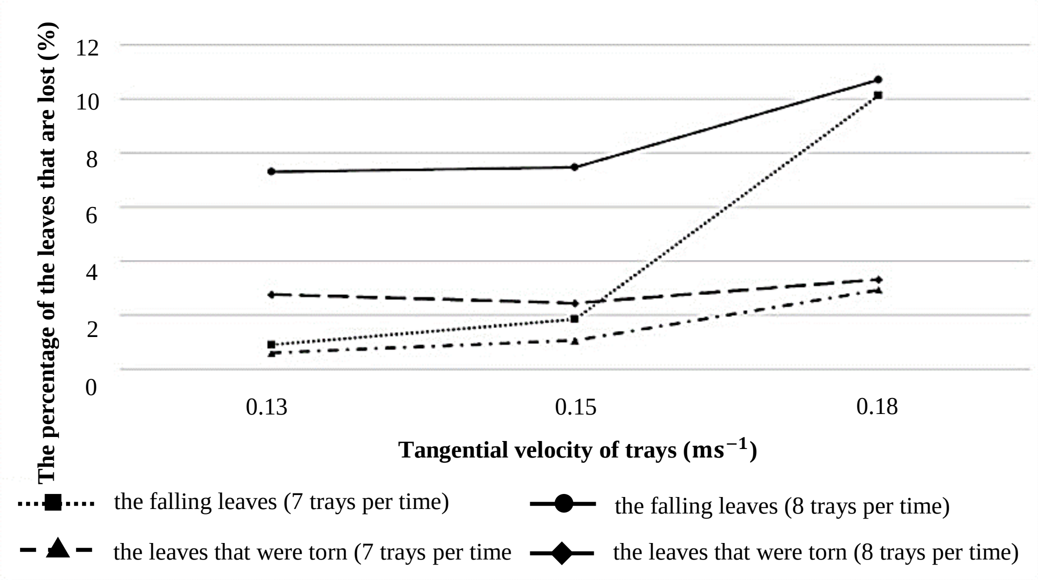


Figure 4 Effect of tray tangential velocity on leaf quality during the threading process.

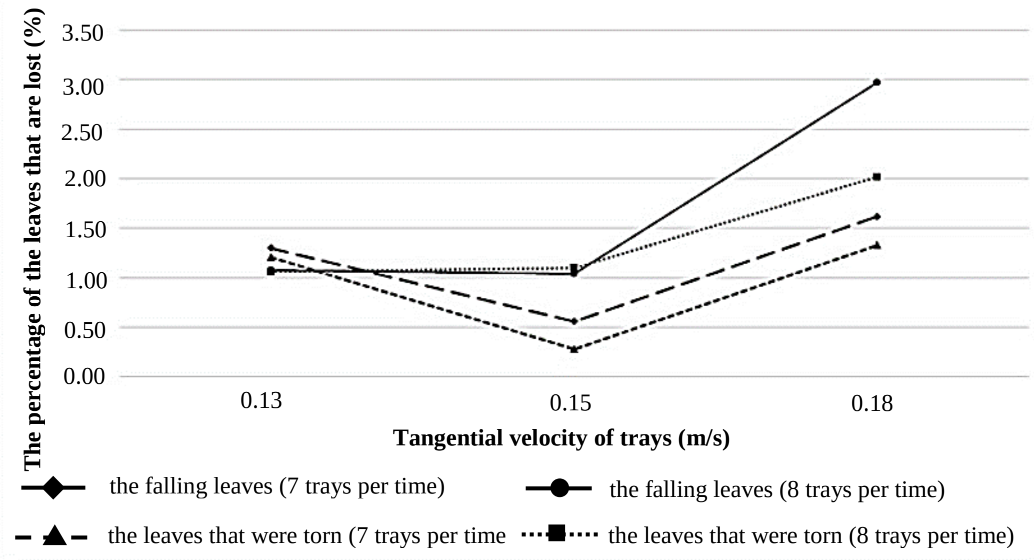


Figure 5 Effect of tray tangential velocity on leaf quality after threading.

3.2 Result of multi-objective optimization

The influential factors affecting the capacity and quality of the tobacco leaves produced by the threading machine are analyzed. The relationship between these factors and the dependent variables is examined using the RSM: capacity and quality of the tobacco leaves produced by the threading machine following a quadratic equation associated with the experimental design. According to Equations (6)-(10), an R-squared indicator with a high value means that the quadratic equation is suitable for applying to the dataset [28].

$$f_1 = -1141.448 - 4241.484X_1 + 250080.868X_2 + 298.844X_1^2 - 875949.999X_2^2 + 1864.684X_1X_2 \quad (6)$$

$(R^2 = 0.8828)$

$$f_2 = -1.437 - 5.240X_1 + 13.152X_2 + 1.861X_1^2 + 3280.000X_2^2 - 120.473X_1X_2 \quad (7)$$

$(R^2 = 0.9908)$

$$f_3 = -0.528 - 1.932X_1 + 33.670X_2 + 0.579X_1^2 + 846.666X_2^2 - 35.631X_1X_2 \quad (8)$$

$(R^2 = 0.9998)$

$$f_4 = 3.148 + 11.684X_1 - 641.845X_2 - 1.062X_1^2 + 1386.666X_2^2 + 31.210X_1X_2 \quad (9)$$

$(R^2 = 0.9995)$

$$f_5 = 2.189 + 8.130X_1 - 444.203X_2 - 0.666X_1^2 + 1101.666X_2^2 + 15.131X_1X_2 \quad (10)$$

$(R^2 = 0.9152)$

These equations are then used to create a surface plot for analyzing the influential factors affecting the capacity and quality of the tobacco leaves produced by the threading machine. Figure 6 shows the surface plots of responses and the predicted capacity values (f_1), plotted as functions for counting the trays before gathering (X_1) and their tangential velocity (X_2). According to the surface plot shown in Figure. 6, the capacity (f_1) tends to increase according to the number of trays prior to gathering (X_1). Based on the tangential velocity of the trays (X_2), the response reached the maximum level of actual velocity at about 0.15 m/s. These results indicate that capacity is affected by speed. This is consistent with other research findings, in that increased peripheral and rotational speed leads to greater efficiency [29, 30]. However, the capacity tends to decrease when the tangential velocity is too high [31] due to the tester being unable to place the leaves on the tray in time.

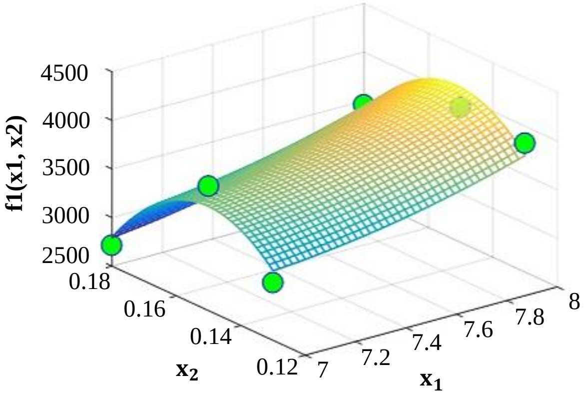
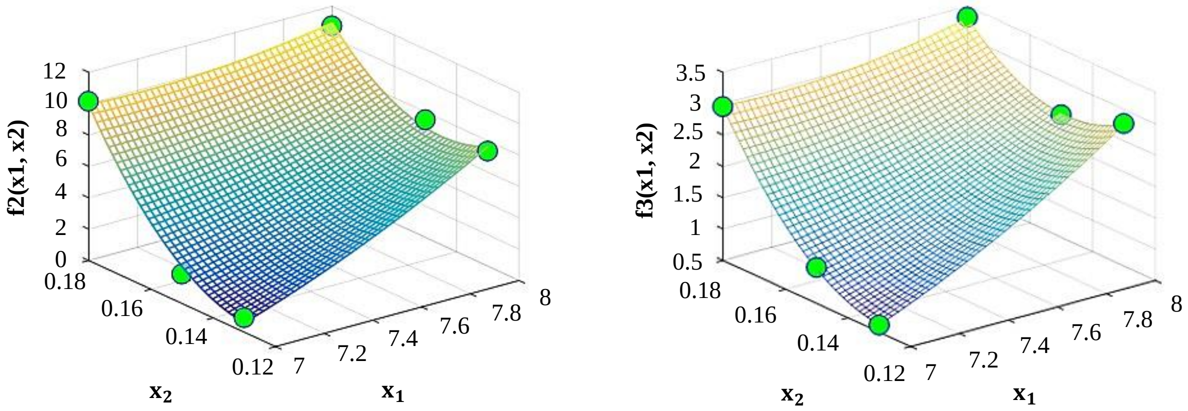


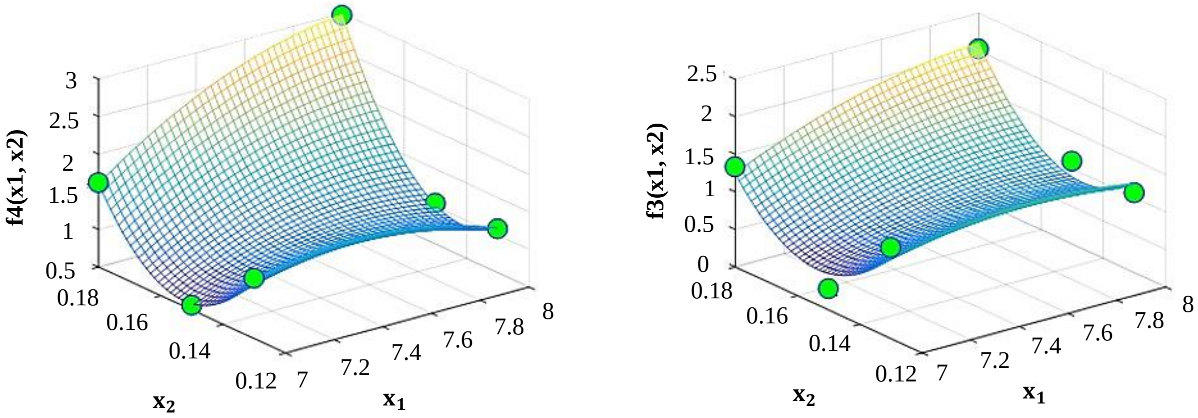
Figure 6 Surface plot for capacity (f_1) as a function of X_1 versus X_2.

The surface plots showing the percentage of falling and torn leaves during the process are shown in Figure 7a and 7b. The trays were counted prior to gathering (X1) with their tangential velocity (X2) increasing to a high level, causing a rise in the percentage of leaves falling or tearing during the process. A surface plot showing the percentage of fallen and torn leaves after threading is presented in Figure 7c and 7d. The tray count before gathering (X_1) had less impact on the percentage of fallen and torn leaves after threading. However, when the tangential velocity of the trays (X_2) increases to a high level, the percentage of fallen and torn leaves after threading tends to increase. This is consistent with the research of Adeshina Fadeyibi et al., who claimed that increasing the tangential velocity results in a higher percentage loss [32]. Since the conveying of the trays affects the place where the tester can put the leaves, they are unable to get the leaves on the tray in time.



(a) Surface plot of f_2 vs X_1, X_2

(b) Surface plot of f_3 vs X_1, X_2



(c) Surface plot of f_4 vs X_1, X_2

(d) Surface plot of f_5 vs X_1, X_2

Figure 7 Surface plots showing the percentage of leaves falling (f_2) and tearing (f_3), during the process, and leaves falling (f_4) and tearing (f_5) after threading as a function of X_1 versus X_2.

The results of surface analysis reveal that the dependent variables are influenced by the initial variables. However, during operation, it is necessary to consider both the capacity and quality produced by the machine. Therefore, by using the weighted sum approach, suitable values for all five variables (F) are obtained. Table 3 demonstrates how the most suitable values can be obtained under multiple conditions using the weighted sum approach. The variables are divided into three cases according to their level of importance.

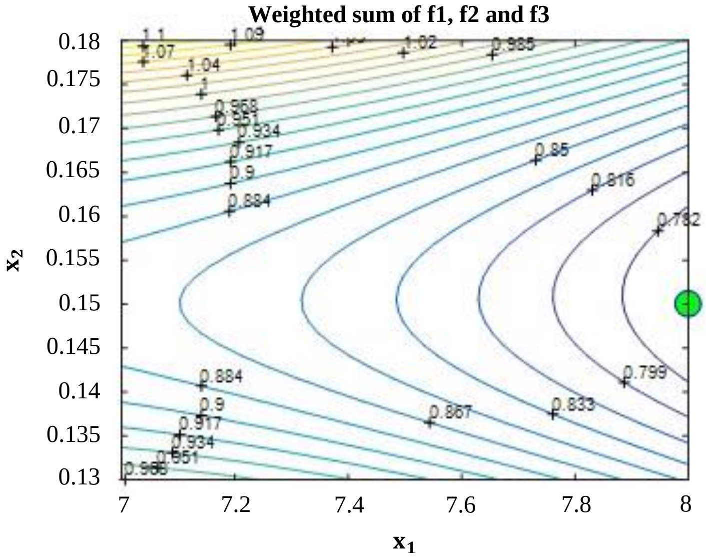
Table 3 Results of multiple-objective optimization

Case	**Weighted sum**					**Factor value**	
	f_1	**f_2**	**f_3**	**f_4**	**f_5**	**X_1**	**X_2**
A	0.8	0.05	0.05	0.05	0.05	8	0.15
B	0	0.25	0.25	0.25	0.25	7	0.13
C	0	0	0.50	0	0.50	7	0.14

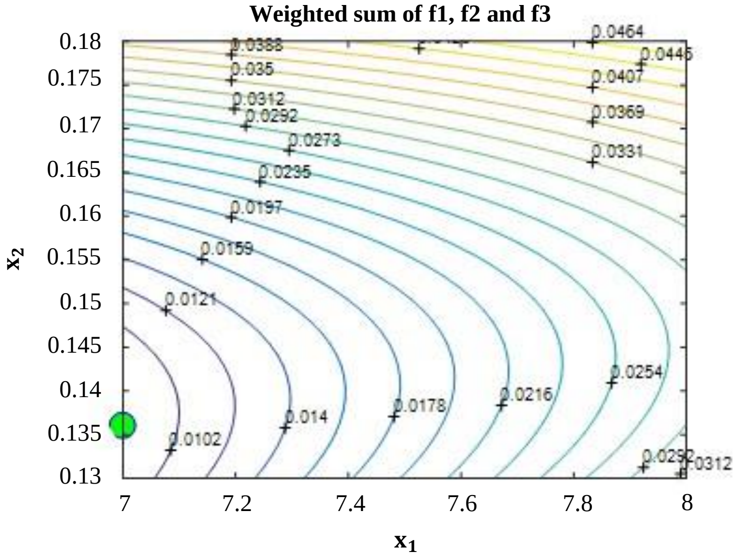
The weighted sum for the factors in case A, focusing on the capacity of the machine is shown in Figure 8 (a). The optimum tray count values prior to gathering (X_1) and the tangential velocity of the trays (X_2) as X_1 is equal to eight trays per time while X_2 is equal to 0.15 m/s. Therefore, when a user needs to achieve high capacity with a threading machine, conditions of case A must be considered.

The weighted sum for the factors shown in case B, focusing on leaf quality during and after the threading process, is shown in Figure 8(b). The optimum tray count values prior to gathering (X_1) and the tangential velocity of the trays (X_2) are X_1 equal to seven trays per time while X_2 is equal to 0.13 m/s Therefore, when the user requires the lowest percentage of fallen and torn leaves during and after the process while somewhat ignoring the capacity of the machine, the optimum factors of case B must be considered.

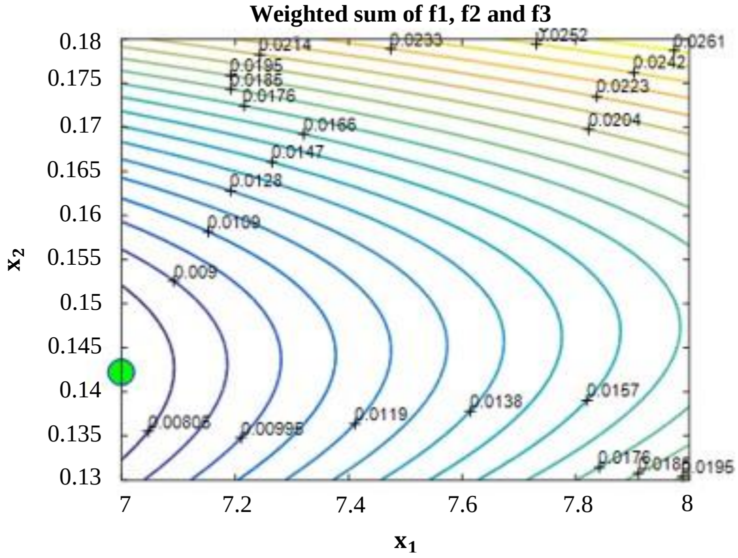
Figure 8(c) shows the weighted sum for the factors in case C, focusing on the leaf quality and the percentage of torn leaves during and after the threading process. The optimum tray count value of the trays prior to gathering (X_1) and the tangential velocity of the trays (X_2) as X_1 are equal to seven trays per time while X_2 is equal to 0.14 m/s. As a result, when the user requires the lowest percentage of torn leaves during and after the process without paying attention to the capacity of the machine and number of fallen leaves, the optimum factors of case C must be considered.



(a) Contour plot in case A



(b) Contour plot in case B



(c) Contour plot in case C

Figure 8 Contour plots showing the optimized factor values in cases A, B, and C.

4. Conclusions

The weighted sum analysis method for multi-objective optimization of the threading machine reveals that the percentage loss is not significant since farmers tend to focus on capacity. Therefore, it can be concluded that the tangential velocity of the trays is 0.15 m/s while pressing prior to gathering eight trays at a time gives a maximum capacity of 3887 leaves/hour. Tobacco leaf loss from tearing and falling during the process equated to 7.49 and 2.45%, respectively, while 1.04 and 1.1% of leaves were lost from tearing and falling after threading, respectively. The analysis revealed the minimum percentage loss for tangential velocity of 0.13 m/s, with a pressing capacity prior to gathering seven trays per time of 3,091 leaves per hour. Tobacco leaf loss from tearing and falling during the process equated to 0.91 and 0.61%, respectively, while 1.30 and 1.21% of leaves were lost from tearing and falling, respectively. When comparing the operating results between the threading machine and human labor, the former was found to be approximately twice more efficient than the latter.

5. Acknowledgments

This research was supported by the Faculty of Engineering, Mahasarakham University and Research and Researchers for Industry (RRi).

6. References

[1] Barla FG, Kumar S. Tobacco biomass as a source of advanced biofuels. Biofuels. 2016;10(4):1-12.

[2] Ministry of Finance. Thailand Tobacco monopoly. Annual report 2018 [Internet]. 2018 [cited 2019 Nov 25]. Available form: http://www.thaitobacco.or.th/th/category/annual-report. (In Thai)

[3] Rojanaporntip J. Tobacco leaf [Internet]. 2017 [cited 2019 Feb 25]. Available form: https://www.technologychaoban.com/agricultural-technology/article_10759. (In Thai)

[4] Ishida N. Expanded separation technique for chlorophyll metabolites in Oriental tobacco leaf using non aqueous reversed phase chromatography. J Chromatogr A. 2011;1218(34):5810-8.

[5] Adam International. Good agricultural practices for oriental tobacco. Thailand: Adam International Co. Ltd; 2012.

[6] Cao G, Bao Y, Wu C, Wang Y. Analysis on efficiency optimization of tobacco leaf flue-curing process. Procedia Eng. 2017;205:540-7.

[7] Bao Y, Wang Y. Thermal and moisture analysis for tobacco leaf flue-curing with heat pump technology. Procedia Eng. 2016;146:481-93.

[8] Sujinda B. Tobacco piercing tool. Third National Conference on Agriculture and Biology: Plant and Biological Science; 1964 Jan 29-31; Kasetsart University Bangkhen Campus, Thailand. Bangkok: Kasetsart University; 1964. p. 34.

[9] Senasutham R, Yangyuen S, Laohavanich J, Bureerat S, Chaiwchanwattana C. Design and development of a threading machine for tobacco leaves. 2018 Third International Conference on Engineering Science and Innovative Technology (ESIT); 2018 Apr 19-22; Bangkok, Thailand. New York: IEEE; 2018. p. 1-4.

[10] Senasutham R, Yangyuen S, Laohavanich J, Chaiwchanwattana C. Design concept of threading machine for tobacco leaves. RMUTI J Spec. 2015:167-71.

[11] Netto R, Bagri A. Programmable logic controllers. Int J Comput Appl. 2013;77:27-31.

[12] Hudedmani MG, Umayal RM, Kabberalli, SK, Hittalamani R. Programmable logic controller (PLC) in automation. Adv J Grad Res. 2017;2(1):37-45.

[13] Shoesmith E, Box G, Draper N. Empirical model-building and response surface. New York: Wiley; 1987.

[14] Singh B, Panesar PS, Nanda V, Gupta AK, Kennedy JF. Application of response surface methodology for the osmotic dehydration of carrots. J Food Process Eng. 2006;29(6):592-614.

[15] Rith M, Arbon NA, Biona JBM. Optimization of diesel injection timing, producer gas flow rate, and engine load for a diesel engine operated on dual fuel mode at a high engine speed. Eng Appl Sci Res. 2019;46(3):192-9.

[16] Myers RH, Montgomery DC, Anderson-Cook CM. Response surface methodology: process and product optimization using designed experiments. 4th ed. New York: John Wiley & Sons; 2016.

[17] Khuri AI, Cornell JA. Response surfaces: designs and analyses. New York: Marcel Dekker; 1987.

[18] Tiojskens LMN, Hertog MLATM, Nicolai BM. Food process modelling. Cambridge: Woodhead; 2001.

[19] Bureerat S. Multi-objective optimization problem. The optimization of mechanical engineering systems. Khon Kaen: Khon Kaen University; 2013. (In Thai)

[20] Janardhan M, Gopala KA. Multi-objective optimization of cutting parameters for surface roughness and metal removal rate in surface grinding using response surface mythology. Int J Adv Eng Tech. 2012;3(1):270-83.

[21] Marler RT. A study of multi-objective optimization methods for engineering application. Saabrucken: VDM Verlag; 2009.

[22] Marler RT, Arora JS. The weighted sum method for multi-objective optimization: new insights. Struct Multidisc Optim. 2010;41(6):853-62.

[23] Fadeyibi A, Ajao F. Design and performance evaluation of a multi-tuber peeling machine. AgriEngineering. 2020;2(1):55-71.

[24] Yangyuen S. Laohavanich J. Development of a semi-automatic macadamia cracking machine. Eng Appl Sci Res. 2018;45(4): 256-61.

[25] Marey SA, Kable AE, Sayed-Ahmed IF. Performance evaluation of two different seed cotton trash extractors. AMA Agric Mech Asia Afr Lat Am. 2013;44(3):7-13.

[26] Nathan C, Wadai J, Haruna IU. Comparative analysis of type 3 and type 4 cassava peeling machines. Niger J Technol. 2017;36(4):1088-94.

[27] Helmy MA, Abdallah SE, Mitrroi SE, Basiouny MA. Modification and performance evaluation of a reciprocating machine for shelling peanuts. AMA Agric Mech Asia Afr Lat Am. 2013;44(3):18-24.

[28] Saikaew C, Chillapat N. Experimental design for product and process improvement: an application in bottle glass crushing machine. KKU Eng J. 2006;33(4):415-30. (In Thai)

[29] Gupta RK, Das SK. Performance of centrifugal dehulling system for sunflower seeds. J Food Eng. 1999;42(4):191-8.

[30] Ndukwu MC, Ekop IE, Etim PJ, Ohakwe CN, Ezejiofor NR, Onwude DI, et al. Response surface optimization of Bambara nut kernel yield as affected by speed of rotation, and impeller configurations. Sci. Afr. 2019;6:1-11.
[31] Daniyan IA, Adeodu AO, Azeez TM, Dada OM, Olafare AO. Optimization of peeling time and operational speed for cassava peeling using central composite design and response surface methodology. Int J Eng Res Sci Technol. 2016;5(9):630-9.
[32] Singh KP, Saha S, Mishra HN. Optimization of barnyard millet dehulling process using RSM. AMA Agric Mech Asia Afr Lat Am. 2010;41(2):15-20.