Development of an Eri Cocoon Cutting and Separating Machine

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Abstract. *The fibers of eri silk are light, fluffy, sweat-absorbing, and have a unique characteristic. The process of producing eri fiber consists of cutting the cocoon to remove the pupa from the cocoon, degumming and carding. In general, to separate the pupa from the cocoon, farmers use scissors to cut the cocoon by cutting one end of the cocoon. From surveying, it found that the average cutting rate is only 1.5 kilograms per hour per person. Other than that, there is a shortage of labor. For these reasons, agriculture is unable to produce enough eri silk to meet market demand. The purpose of this research was to develop the eri cocoon cutting and separating machine to cut cocoons and to separate the pupa from the cut eri cocoon. The size of the eri cocoon cutting machine is 0.85 meters in width, 1.50 meters in length and 0.80 meters in height. It consists of three conveyor belts that are made into a groove for placing cocoons by hand. The cutter set uses a blade that can adjust the degree of cutting. The separation of the pupa from the cocoon uses vibrations driven by a slider-crank mechanism. From the experiment results to find the most suitable conditions of the machine, it was found that if the blade was tilted at an angle of 50 degrees to the horizontal level and the conveyor speed was set at 2.2 meters per minute, the machine gave the best results. When the speed of the pupa separator is 250 rpm, the cutting machine gave the average cutting rate of 6.424 kilograms per hour and the percentage of pupa separated from the cocoon was 100 significantly. From this operating result, it can be concluded that an eri cocoon cutting and pupa separating machine developed from this research can increase the cutting and separating rate of eri cocoon and tend to be used in the group of eri silk farmers*

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1. Introduction

Samia ricini (Eri silk) is a silk that is resistant to diseases and insects. Eri can be fed throughout the year or about 4-5 generations per year. Eri silkworm eats castor leaves and cassava leaves as food [1]. Eri 's cocoon is long, slender, white and quite flat. The average size is 2.1 cm wide, 4.8 cm in length. The fibers of eri are loosely woven together. The end of the cocoon is quite pointed and the other end of the cocoon has a small hole to allow butterflies to leave the cocoon. Silk thread eri is a short line [2]. The characteristics of the Eri silk yarn are glossy, light white, lightweight. The eri silk fabrics are unique, beautiful like wool. The eri fabric is thick, soft, fluffy and lightweight. It is also suitable for making blankets, duvets, curtains, bedspreads, tablecloths, carpets and other products. The products obtained from eri silk are in great demand in the market. Besides, the eri fiber production process does not have a process to kill pupa, which does not conflict with the feeling of users who do not want to kill silk [3].

In the production of eri fibers or silk yarns begins by cutting the cocoon, separating the pupa from the cocoon or waiting for the butterfly to penetrate from the cocoon and then cutting the cocoon to remove the pupa stains. Before the degumming process, it must be cleaned as it will prevent the fibers from discoloring in the dyeing process. There are 3 types of cutting in the cocoon: cutting at one end of the cocoon at an angle of 45 degrees, cutting in the middle of the body and cutting along the length of the cocoon. The cutting process takes a long time because the cocoon is tough. From the interviews with farmers that raise eri silk threads and sell eri silk cocoon in Ban Pong Pong, Udonthani Province (Mrs. Boonmee Bun-apai), it is found that the silk cocoons are cut using scissors and have the rate of cutting and separating the silk cocoons around 6 kilograms per person per day. In general, the price of cocoons depends on the integrity of the cocoon. The

complete silk cocoon costs 200 baht per kilogram whereas the defective silk cocoons (twin silk cocoons, dirty silk cocoons etc.) [4] cost 180 baht per kilogram. Pupa can be sold for 20 baht per kilogram. Eri yarn can be sold for around 1900-2000 baht per kilogram, depending on the quality of the yarn [5].

From the study of the problem of the pupa separation process from the silkworm cocoon, it is found that it takes a long time. This process is an important part of the production of eri silk. When the first step which is the process of cutting and separating the pupa is slow, then the production of fibers and yarn will also slow, resulting in the product is not enough to meet the needs of the weaving industry. Therefore, the development concept in this research is to design and build a machine to cut and separate the pupa from the cocoon for eri silk. The machine consists of the section to cut the cocoon and section to separate the pupa from the cocoon. The design condition is that the eri cocoon cutter must be easy to use, durable, and easy to maintain. It is expected that the developed machine for cutting and separating the pupa from the cocoon could support the small eri silk industry.

2. Materials and Method

2.1 Study the physical properties of eri cocoon

This research studied the size measurement of eri cocoon using vernier caliper (Resolution 0.25 mm.). Measurement definition is as follows: Length (L) is the side with the longest diameter. Width (W) is the longest diameter perpendicular to L. Thickness (T) is the longest centerline which is perpendicular to W and L (details are shown in Fig. 1).

The study of the size of these cocoons is to be used to design the cocoon filling. From the sampling test, measuring the size of 1,000 cocoon samples, the results showed that the average length was 3.617 ± 0.341 cm; the average width was 1.634 ± 0.187 cm; the average thickness is 1.593 ± 0.121 cm (mean ± SD).

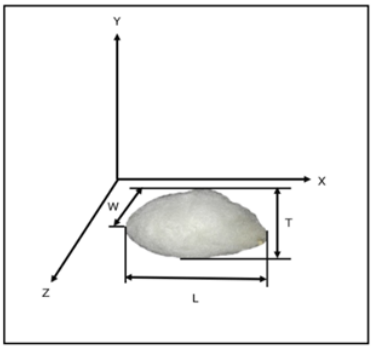

Fig. 1: Definitions of length, width, and thickness of the cocoons.

2.2 Design of the eri cocoon cutting and separating machine

The design applies knowledge and principles of mechanical and agricultural machinery design [7,8,9]. The design condition of the eri cocoon cutting machine is that a machine consisting of three conveyor belts made into grooves. The cutter set uses a blade, which can adjust the cutting angle and the pupa separator. This separator uses vibrations driven by a slider-crank mechanism. Eri cocoon cutting machine is designed to be 85 cm in width, 150 cm in length and 80 cm in height (details shown as Fig. 2). The machine frame is made of angle steel that is 3 cm wide, 3 cm long and 0.3 cm thick. The components of the machine are as follows: 1) Three sets of cocoon conveyor belts made into grooves. The angles on both sides of the groove have an angle of 20 degrees to tilt cocoon body and 60 degrees to shirk the blades. 2) The cocoon press is made of 0.5 mm thick stainless steel to press the cocoons to not bounce off from the groove while cutting. 3) The cocoon cutter, which uses an industrial blade to cut the cocoon [10]. These blades can be tilted to the cutting degree from 40 degrees to 60 degrees to cut the end of the cocoon which is transported on a conveyor belt. 4) The cocoon brush is a round plastic brush used to brush the cocoon cut and 5) the next part is the pupa separation kit from the cocoon. It serves to separate the pupa from the cocoon after cutting [11]. 6) The control cabinet consists of a button to turn on and off the indicator light. There is also an inverter and DC motor speed controller. The procedure of the cocoon cutter and the pupa separator starts from feeding the cocoon onto the groove of the conveyor belt that is made for laying the cocoon. The cocoon will move with the belt to the cocoon cutter set, which is equipped with a cocoon press kit to help support the cocoon and prevent the cocoon from splitting while cutting. After the cocoon is cut at one end, the brush will remove the cocoon from the conveyor. From then on, the cocoon will fall into the pupa separation set. In this separation set, install a sieve of the pupa from the cocoon. The pupa will fall through the sieve down to the bottom of the separation set.

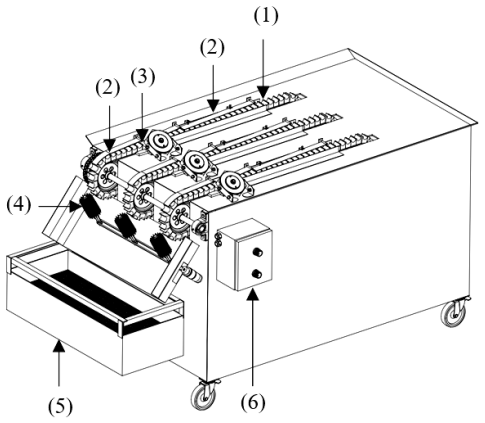

Fig. 2: Components the eri cocoon machine: (1) Cocoon conveyor belt, (2) Cocoon press set, (3) Cocoon cutting set, (4) Cocoon brush, (5) Papa separator and (6) Control cabinet.

2.3 Experimental design

Kamphaeng Saen eri cocoon was selected as raw material for experimentation. The size of the eri cocoon used in the experiment is between 1.6 - 2.0 centimeters in width and 3 - 3.5 centimeters in length. The experiment is divided into 2 parts. The first part is to find the rate of cocoon transportation by placing the cocoons at the conveyor belt. In this experiment cocoons were laid continuously for 1 hour. The second part was to find the efficiency of cocoon cutting and pupa separation efficiency. Each test will find the time needed to cut the cocoons in the amount of 0.1 kilograms that are placed on a conveyor (approximately 180 cocoons). Every experiment will repeat 3 times. Besides, the factors that are considered in the experiment are the conveyor belt speed and blade inclination degree. The belt speed is adjusted at 0.7, 1.4, 2.2, 2.8 and 3.6 meters per minute. The blade degrees are adjusted to 40, 45, 50, 55 and 60 degrees, respectively. In addition, the motor speed drives the slider-crank mechanism of the pupa separation unit was adjusted the speed at 150, 200 and 250 rpm respectively. From the experimental results, it can be calculated to find the cocoon feed rate, cocoon cutting efficiency and cocoon separation efficiency from the following equation;

- Cocoon feed rate (kg / hour)

$$Cocoon\ feed\ rate = \frac{Cocoon\ weight(kg)}{Total\ time\ spent(hour)} \quad (1)$$

- Cocoon cutting efficiency (%)

$$Cocoon\ cutting\ efficiency = \frac{weight\ cut\ cocoon(kg)}{weight\ of\ total\ cocoon(hour)} \quad (2)$$

- Cocoon separation efficiency (%)

$$Cocoon\ separation\ efficiency = \frac{separation\ cocoon\ (kg)}{weight\ of\ total\ cocoon\ (kg)} \quad (3)$$

2.4 Statistical analysis

In this research, Design-Expert 7is the program used to analyze data. The analysis consists of an analysis of variance (ANOVA) based on P-value, R-Square (R-Square) analysis and Response surface methodology (RSM). All these analyses are used to predict the optimum values for cutting at a 95 percent confidence level [12].

3. Results and discussion

The developed eri cocoon cutting and separating machine is shown in Fig. 3. There are three conveyor belts that make grooves for placing cocoons. The cutting blades, which are industrial blades (shown in Fig. 4), consist of three blades. All blades can adjust the degree of cutting. Pupa separating set uses vibrating driven by slider-crank mechanism. The experiment results of the cocoon feeding rate finding are shown in Table 1. From the results, it is found that the maximum feed rate of the cocoon on the conveyor is 6.424 kilograms per hour with the conveyor speed at 2.2 meters per minute. When the speed of the conveyor belt is slow, resulting in the cocoon feed rate to decrease accordingly. Likewise, when the conveyor speed is too fast, causing the cocoon cannot feed on the conveyor belt in time. The cocoon feed rate was then decreased. The experiment results of the cutting efficiency finding of and separation efficiency finding when adjusting the blade tilt angle 40 45 50 55 and 60 degrees are shown in Table 2 to Table 6 respectively. The results of cutting the cocoon when adjusting the inclination of the blade to 40, 45, 50 and 55 degrees are shown as Fig. 4

Statistical analysis to find the optimum conditions for predicting the efficiency of cocoon cutting and separating pupa from the cut cocoon will be done by using the responsive surface area method in the quadratic model. Factors studied are blade inclination degree, conveyor speed and revolving speed of the pupa separation unit. The analysis of variance using the regression model at the reliability level of 95% found that the P-value is less than 0.0001 and the coefficient of decision-making (R-Sq) is 0.78.

From the data of experiment results shown in Table 2 to Table 6, the regression model equation can be written to show the correlation between cocoon cutting efficiency and pupa separation efficiency as in Equation 4 and Equation 5. From Equation 4 and Equation 5, Y_1 means the efficiency of cutting cocoons; Y_2 means the pupa separation efficiency; X_1 is the tilt angle of the blade (degrees); X_2 is the speed of the conveyor (meters per minute); X_3 is the rotational speed of the pupa separation (rpm).

$$Y_1 = 103.56 + 4.06X_1 + 0.33X_2 + 0.36X_3 - 3.82X_1X_2 - 1.09X_1X_3 + 0.50X_2X_3 - 20.62X_1^2 - 4.50X_2^2 - 0.22X_3^2 \quad (4)$$

$$Y_2 = 96.93 + 8.63X_1 - 0.061X_2 + 2.99X_3 - 3.47X_1X_2 - 0.70X_1X_3 - 0.032X_2X_3 - 28.36X_1^2 - 3.26X_2^2 - 0.068X_3^2 \quad (5)$$

Regression model models (Equations 4 and 5) can be plotted as a response surface graph in three and two-dimensional graphs (Fig. 6 and Fig. 7). Both graphs are used to describe the influence of blade degrees and conveyor speed on cocoon cutting efficiency and pupa separation efficiency. The orange-red area shows that it has a great influence on the efficiency of cocoon cutting and pupa separation. From the experiment, when the blade angle is constant whereas the conveyor speed is changed, it is found that the increasing speed makes the percentage of cocoon cutting tend to continuously decrease as quadratic decrease. The optimize conditions to make the 100%of efficiency of cocoon cutting and the pupa separation is to adjust the blade tilt at an angle of 50 degrees, speed of the pupa separator is 250 rpm and the conveyor speed is 2.2 meters per minute.

Although all three variables affect the percentage of cutting and the percentage of separation, therefore the overall satisfaction of the response (desirability) is measured to find the appropriate value. The graph of desirability value is shown in Fig. 8. When setting the constant speed of the pupa separator, it is found that the blade angle of the blade should be between 50 and 55 degrees. The conveyor speed can be adjusted from 0.7 to 3.6 meters per minute, resulting in high efficiency in both cutting and separation. At the same time If the blade angle is adjusted too much or too little, it will result in both cutting and separation efficiency decreasing statistically.

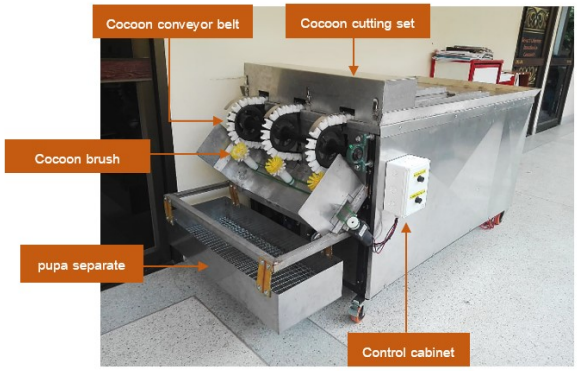

Fig. 3: Eri cocoon cutting machine

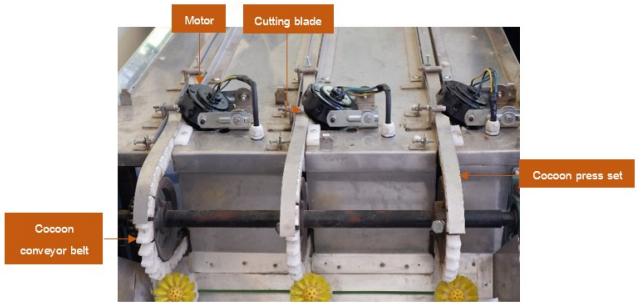

Fig. 4: Cocoon cutting set

Fig. 5: Results of cocoons cutting when angle of blade was adjusted to of 40, 45, 50 and 55 degrees

Conveyor speed (meters per minute)	Cocoon feed rate (kilograms per hour)
0.7	5.747
1.4	6.224
2.2	6.424
2.8	6.143
3.6	5.844

Table 1 Rate of cocoon feeding

Angle degree of blade	Conveyor belt speed (meters per minute)	Separation speed (RPM)	Cutting percentage	Separation percentage
40	0.7	150	78.24	68.04
		200	75.32	54.19
		250	70.02	59.71
	1.4	150	81.98	61.39
		200	79.42	62.84
		250	72.21	65.1
	2.2	150	82.78	60.52
		200	81.52	72.18
		250	81.48	70.32
	2.8	150	65.32	58.03
		200	82.48	62.6
		250	75.38	65.04
	3.6	150	70.38	50.84
		200	73.69	54.42
		250	78.81	55.82

Table 2 Percentage of cocoon cutting and percentage of pupa separation when angle degree of blade is 40

Angle degree of blade	Conveyor belt speed (meters per minute)	Separation speed (RPM)	Cutting percentage	Separation percentage
45	0.7	150	84.62	60.64
		200	75.04	64.84
		250	92.55	74.92
	1.4	150	75.93	61.87
		200	86.06	66.75
		250	99.52	84.85
	2.2	150	100	73.70
		200	100	80.32
		250	100	84.97
	2.8	150	100	77.99
		200	100	83.35
		250	100	90.96
	3.6	150	99.51	76.75
		200	100	86.97
		250	99.17	87.68

Table 3 Percentage of cocoon cutting and percentage of pupa separation when angle degree of blade is 45

Angle degree of blade	Conveyor belt speed (meters per minute)	Separation speed (RPM)	Cutting percentage	Separation percentage
50	0.7	150	100	90.28
		200	100	94.76
		250	100	97.97
	1.4	150	100	96.98
		200	100	98.42
		250	100	99.18
	2.2	150	100	97.34
		200	100	99.35
		250	100	100
	2.8	150	100	97.75
		200	100	96.24
		250	100	100
	3.6	150	100	97.77
		200	100	98.73
		250	99.05	99.05

Table 4 Percentage of cocoon cutting and percentage of pupa separation when angle degree of blade is 50

Angle degree of blade	Conveyor belt speed (meters per minute)	Separation speed (RPM)	Cutting percentage	Separation percentage
55	0.7	150	100	98.58
		200	99.3	96.06
		250	100	99.50
	1.4	150	100	95.66
		200	100	98.85
		250	100	99.98
	2.2	150	100	97.23
		200	100	98.26
		250	100	96.98
	2.8	150	99.48	95.28
		200	100	95.09
		250	100	96.22
	3.6	150	99.02	87.15
		200	95.67	95.02
		250	100	97.35

Table 5 Percentage of cocoon cutting and percentage of pupa separation when angle degree of blade is 55

Angle degree of blade	Conveyor belt speed (meters per minute)	Separation speed (RPM)	Cutting percentage	Separation percentage
60	0.7	150	84.3	77.75
		200	80	79.32
		250	82.04	80.42
	1.4	150	96.67	76.08
		200	99.36	78.49
		250	90.3	84.40
	2.2	150	82.18	50.28
		200	85.32	61.81
		250	81.54	70.72
	2.8	150	90.42	83.63
		200	87.3	81.39
		250	81.96	81.42
	3.6	150	70.34	63.82
		200	75.15	68.21
		250	74.81	62.40

Table 6 Percentage of cocoon cutting and percentage of pupa separation when angle degree of blade is 60

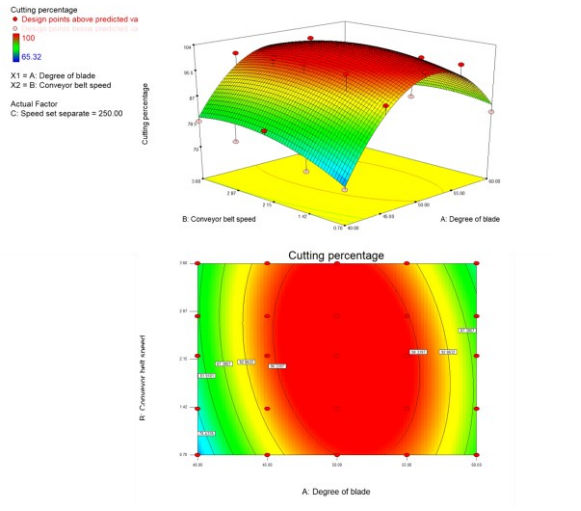

Fig. 6: Graph between Angle of blade (degree) and Conveyor belt speed (meters per minute) to cocoon cutting percentage

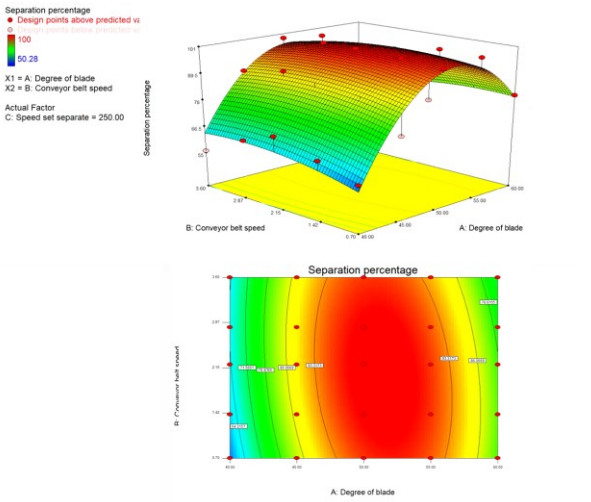

Fig. 7: Graph betw een Angle of blade (degree) and Conveyor belt speed (meters per minute) to cocoon separation percentage

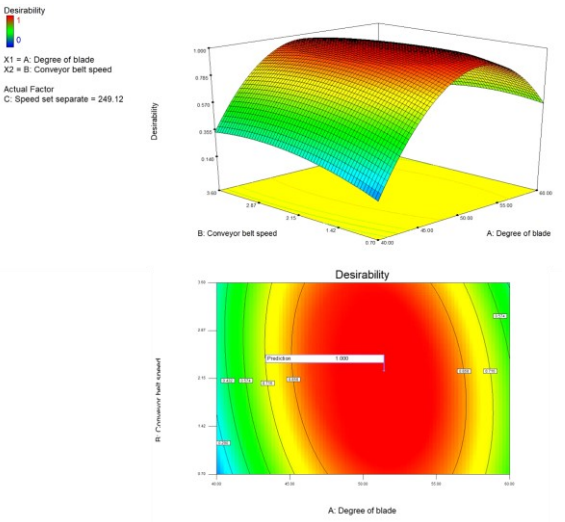

Fig. 8: Graph between Angle of blade (degree) and Conveyor belt speed (meters per minute) to desirability

4. Conclusions

From the results of the development of the eri cocoon cutting and the pupa separating machine, it can be summarized as follows eri cocoon can be cut with an average maximum cutting rate of 6.424 kilograms per hour and the efficiency of the pupa separation from the cocoon is 100%. The operating conditions are to adjust the blade tilt at an angle of 50 degrees of the horizontal. The speed of the pupa separator is 250 rpm and the conveyor speed is set at 2.2 meters per minute. The eri cocoon cutting and the pupa separating machine developed in this research can increase the rate of cocoon cutting and pupa separation and tend to be used in small industries in the eri silk producers.

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