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Full Factorial Design of Experiment Approach to Design and Optimize the Performance of Industrial Coconut Testa Peeling Mechanism for Sri Lankan Manufacturing Industry

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Abstract:- Sri Lanka has the fourth largest coconut export market in the world. Desiccated coconut, brown fiber, virgin coconut oil, and coconut water are some popular exports among number of export products. Coconut testa should be peeled off in most of the coconut product manufacturing processes. Although testa peeling is common for a many coconut products, manual peeling method is still used in Sri Lankan manufacturing industry. Freezing, boiling, baking, and specialized machines are different methods that can be used except manual peeling. In this research the best mechanism for testa peeling to replace manual peeling is identified and the identified process is optimized by conducting number of experimental runs. Automation the manual peeling mechanism has been identified the well suited solution for the current requirements in the Sri Lankan coconut manufacturing industry. A Prototype was fabricated and experiments were conducted to identify the best parameter settings for coconut testa peeling. The effect of Grater thickness, Contact angle and Grater rotational speed were considered and the thickness of the peeled testa were observed as the output parameter. Full Factorial Design of Experiment (DOE) was conducted by changing parameters in different levels. Grater thickness and Contact angle show significant impact on the thickness of testa while grater rotational speed does not show a significant impact at 5 % significance level. Thickness of the testa can be optimized by setting Contact angle in high level and Grater thickness in the lower level.

Keywords:- *Coconut Manufacturing Industry; Testa peeling; Design of Experiments*

I. INTRODUCTION

Sri Lanka is renowned for its agricultural potential, characterized by fertile soil and diverse climates suitable for plant cultivation. Among the country's agricultural commodities, coconut holds a significant position, particularly in the western and southern lowlands where commercial coconut plantations thrive. A specific region, known as the coconut triangle, stands out for its optimal soil quality and favorable dry and intermediate climatic conditions, making it ideal for coconut cultivation. The coconut triangle alone contributes an annual production of 3000 million coconuts, with 200 million earmarked for export and the remainder consumed domestically [1].

Sri Lanka is famous in world export market for desiccated coconut, brown fiber, virgin coconut oil and coconut water [2]. Coconut testa peeling is required in coconut product manufacturing processes. Although there are different methods are available for testa peeling, manual peeling method is used in Sri Lankan manufacturing industry [3]. Manual peeling will lead to low production rate. Skilled labors are required to this process and it has become a challenge to find required amount of manpower. This study is conducted to get maximum efficiency and to reduced manpower usage to peeling process by selecting a suitable mechanism for testa peeling process for Sri Lankan coconut product manufacturing industry.

II. LITERATURE REVIEW

Testa is the part that protects the flesh of the fruit with a shell [4] approximately, 18 % of the coconut kernel is composed of testa [5]. De-husked coconuts weigh about 500 g and have 100 g endosperm, 120 g shell, and 250 g juice [6]. The highest bulk density value was observed for coconut testa is 0.67 g/ml while the lowest 0.54 g/ml [7]. The thickness of the coconut testa is no wider than 1.5mm.

Oil refined from coconut testa contained more natural antioxidants compared to coconut kernel oil and may confer health benefits [8]. Testa flour formulation is for two Sri Lankan traditional food items, roti and pittu and to determine their nutritional properties [9]. Testa flour can be successfully incorporated into refined wheat flour to improve nutritional properties with acceptable sensory properties up to 20% level for making roti and pittu [9]. And also, coconut testa flour is a rich source of dietary fiber. Fiber helps regulate the body's sugar and control hunger. To get high-quality desiccated coconut, coconut testa should be removed. There are many methods can be identified in literature for removing coconut testa such as,

- Semi-automatic testa removal machine [10]
- Freezing method [11]
- Boiling method [12]
- Baking method [13]
- Developed coconut husk peeling machine [14]
- Coconut testa skin peeling machine [4]

1st machine is a power tool like a hand grinder to peel the coconut testa. This mechanism needs both electro power and manpower. 2nd, 3rd and 4th are not machines. Those are methods. The hardness of the coconut testa can be reduced using a freezer, boiler and oven and remove the testa layer. However, manpower is required for those methods peel coconut testa. Because, those methods only assist to the peeler. According to above methods, 4th and 5th methods are the physically fabricated machines. They concluded that 6th machine is a failed product. Each method listed above are required labour force. This study aims to identify and optimize a mechanism for removing coconut testa replace manual methods to use in Sri Lankan coconut product manufacturing industry.

III. METHODOLOGY

Background of the study and research gap were identified as the initial step of the study. Suitable methods that can be used to peel coconut testa in Sri Lankan coconut product manufacturing industry were identified and tested using a prototype. Fig. 1 shows the flow chart of the methodology followed in this study.

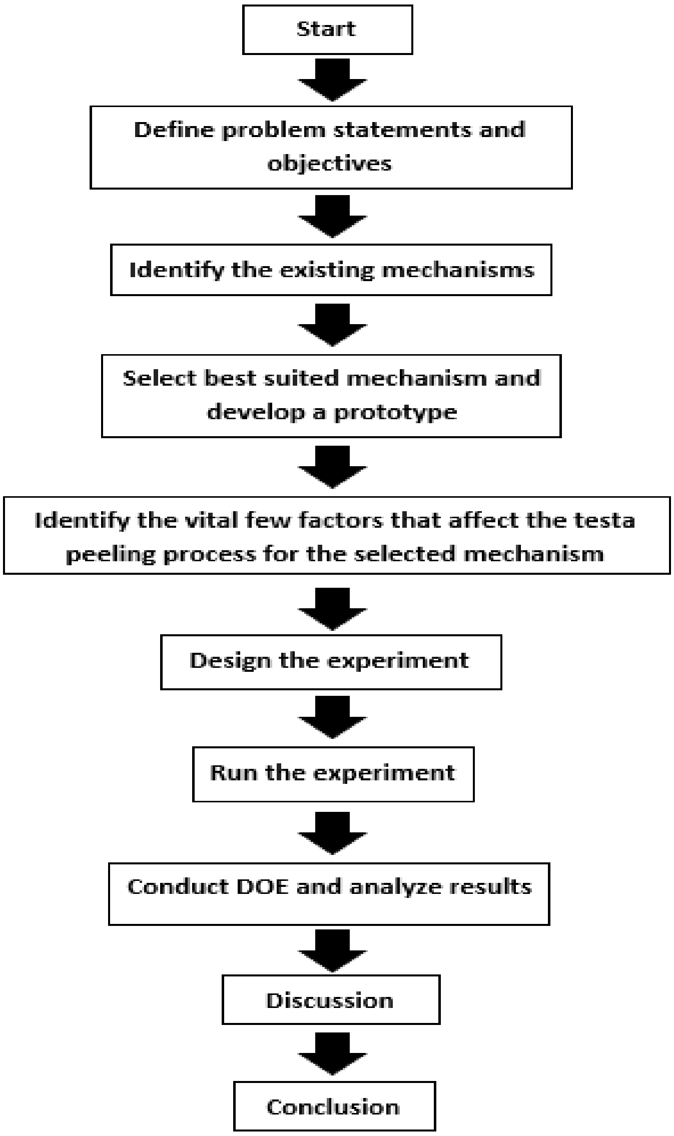

Fig 1 Flow chart of the Methodology

Table 1 shows the comparison between suitable methods by considering key parameters, time, initial cost, regular cost and productivity of the testa peeling process. According to the comparison, manual peeling method shows the lowest time to take peeling process. But it requires more laborers to increase the productivity.

Flash freezing is the most time taking method. As well as the costly process. Because flash freezer takes about 10 – 12 minutes to freeze coconut fruit. The number of coconuts peeling at a time will depend on the capacity of the freezer.

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The boiling method is consumed low time than flash freezing. When comparing both boiling and freezing methods boiling method is better than flash freezing. But both boiling and freezing methods need manpower or a machine to remove coconut shells with testa. Also, the productivity of the boiling method is depended on the boiling limit.

Automated mechanism is better than the other methods by considering both time and productivity, Further, it will reduce the effect of the worker skill factor for the final outcome when using automated mechanism.

Table 1 Compression between Alternative Methods

	Manual peeling	**Flash freezing**	**Boiling**	**Automated machine**
Time	About 1 minute for a coconut	About 25 minutes for a coconut	About 8 minutes for a coconut	Initial coconut takes 113 seconds. The rest of the coconuts peeled within 11 seconds
Initial Cost	Less	Very High	High	High
Regular cost	Only labour cost	High (Liquid Nitrogen)	High (Combustion fuel)	Only maintenance costs and electricity
Productivity	Depend on labours	Depend on freezer	Depend on boiler	318 coconuts per hour

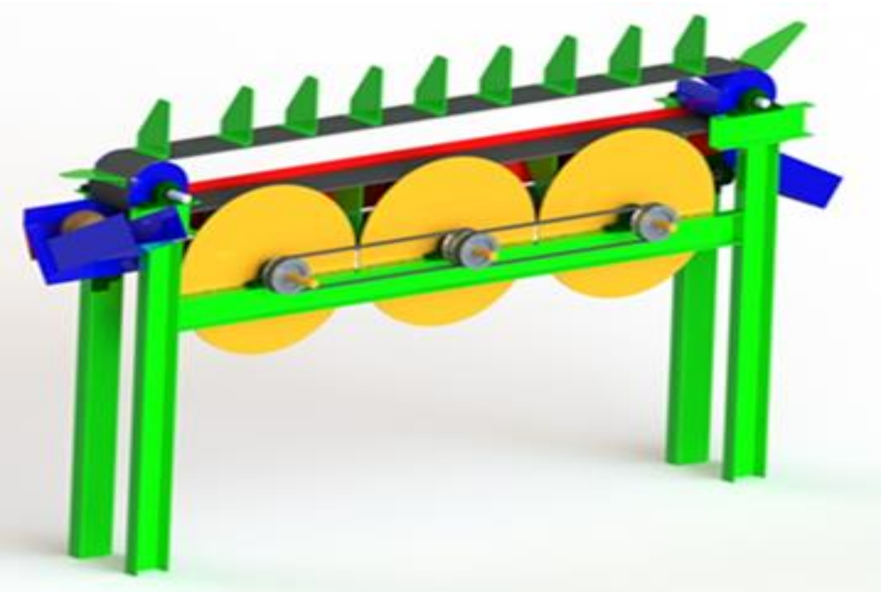

Fig 2 Automated Test a Peeling Mechanism CAD Design

The Fig. 2 shows the CAD (Computer Aided Design) model of the automated mechanism for the testa peeling machine. Machine contains three (03) cutting plates, a conveyor belt, feeding hopper and a product hopper. The machine peels off the testa from coconut with the help of three graters having spikes on their periphery. The coconut is moving along three (03) cutters using a conveyor. The peeler rotated with the help of an electric motor.

Fig 3 Fabricated Prototype

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Fig. 3 shows the fabricated prototype that represents the selected peeling mechanism. Experiments are conducted using the fabricated prototype. One coconut fruit is peeled off at a time with a given pressure in the developed prototype.

Table 2 Factors and their Levels used in the Experiment

Factor	Low level	Middle level	High level
Grater RPM	1000RPM	1250RPM	1500RPM
Grater thickness	1.5mm	-	2.5mm
Contact angle	30°	-	45°

Table 2 shows the three (03) factors and their levels which have been used in this experiment to optimize the thickness of coconut testa. Twelve (12) experimental runs were conducted as shown in Table III by changing three (03) factors simultaneously as a Full Factorial Design of Experiment (DOE).

Table 3 Experimental Plan of the Study

Testing Number	Grater RPM	Grater thickness	Contact angle	Thickness of testa
01	1000 RPM	1.5mm	30°	0.744mm
02	1000 RPM	1.5mm	45°	0.628mm
03	1000 RPM	2.5mm	30°	1.020mm
04	1000 RPM	2.5mm	45°	0.904mm
05	1250 RPM	1.5mm	30°	0.728mm
06	1250 RPM	1.5mm	45°	0.642mm
07	1250 RPM	2.5mm	30°	1.032mm
08	1250 RPM	2.5mm	45°	0.916mm
09	1500 RPM	1.5mm	30°	0.772mm
10	1500 RPM	1.5mm	45°	0.668mm
11	1500 RPM	2.5mm	30°	1.028mm
12	1500 RPM	2.5mm	45°	0.908mm

IV. RESULTS AND DISCUSSION

Fig. 4 shows the ANOVA (Analysis of Variance) results for the final model at 5 % confident interval after removing all insignificant terms. Main factors, Grater thickness (P < 0.001) and Contact angle (P < 0.001) have highly significant impacts on the thickness of peeled testa. There is no any interaction among factors (P > 0.05) according to the ANOVA results.

General Factorial Regression: Peeled testa versus Grater RPM, Grater thick, Contact angle

Factor Information

Factor	Levels	Values
Grater RPM	3	1000 RPM, 1250 RPM, 1500 RPM
Grater thickness	2	1.5 mm, 2.5 mm
Contact angle	2	30 degrees, 45 degrees

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	9	0.258432	0.028715	509.73	0.002
Linear	4	0.257257	0.064314	1141.67	0.001
Grater RPM	2	0.000854	0.000427	7.58	**0.117**
Grater thickness	1	0.220323	0.220323	3911.06	**0.000**
Contact angle	1	0.036080	0.036080	640.48	**0.002**
2-Way Interactions	5	0.001175	0.000235	4.17	0.205
Grater RPM*Grater thickness	2	0.000878	0.000439	7.79	0.114
Grater RPM*Contact angle	2	0.000121	0.000060	1.07	0.483
Grater thickness*Contact angle	1	0.000176	0.000176	3.13	0.219
Error	2	0.000113	0.000056		
Total	11	0.258545			

Fig 4 ANOVA Results

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The p-value, 0.200 (>0.05) suggests that there is no strong evidence to reject the null hypothesis of the results being normally distributed according to the results of the AD (Anderson Darling) test shown in the Fig. 5. It indicates that the data does not significantly deviate from normality.

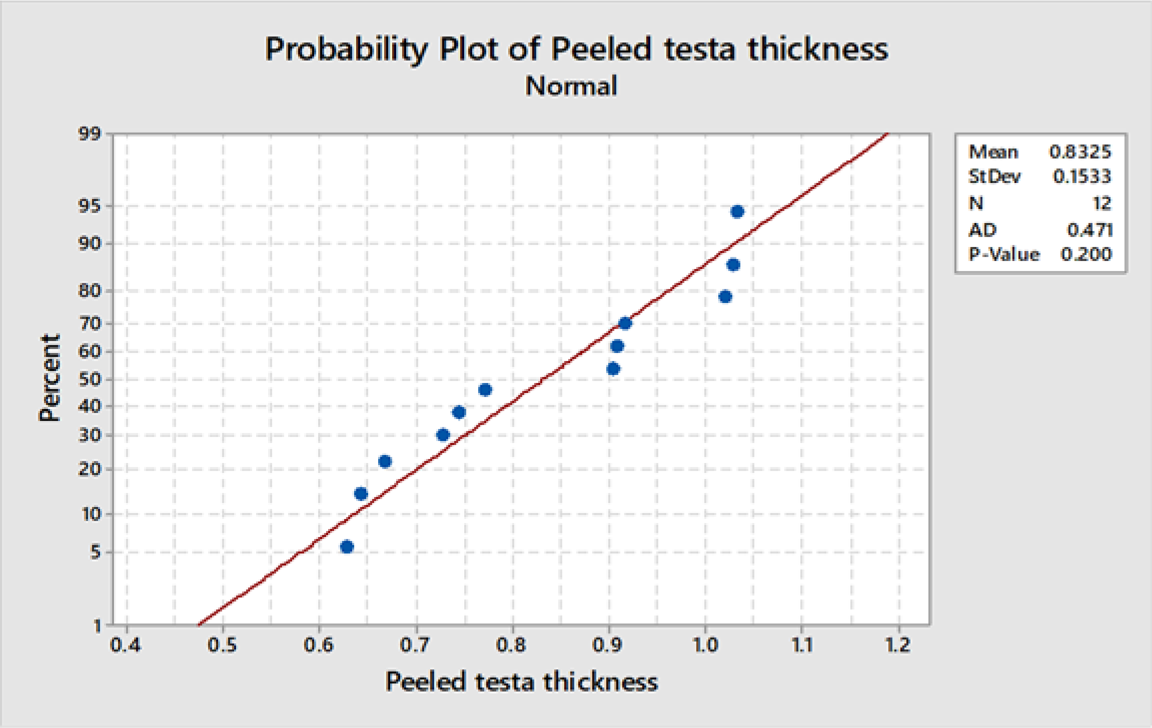

Fig 5 Normality Test Results of Residuals

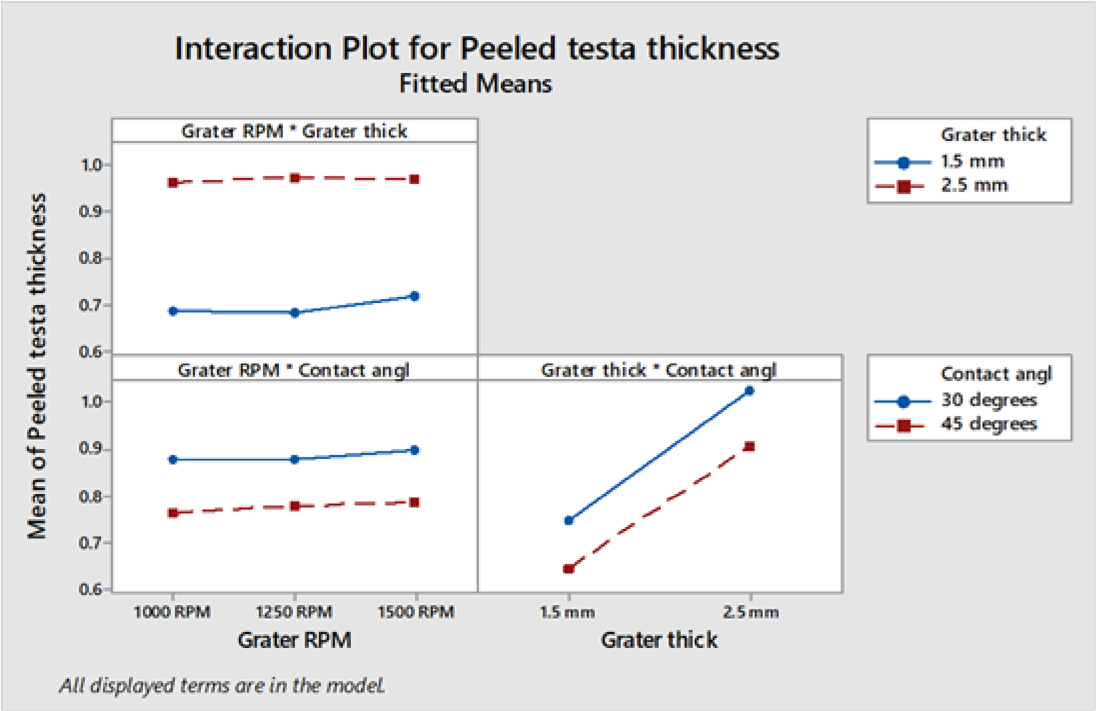

Fig 6 Tow-Way Interaction Plots Among Each Parameter

Interaction plot shown in Fig. 6 describe that there is no any interaction between main factors. The thickness of testa can be minimized using 45° contact angle with 1.5 mm grater thickness.

Fig. 7 shows the main effect plot for peeled testa thickness with the main three (3) factors. Grater thickness is practically the most significant factor, Contact angle is the second most significant factor and Grater RPM is the least affected factor on the thickness of peeled testa.

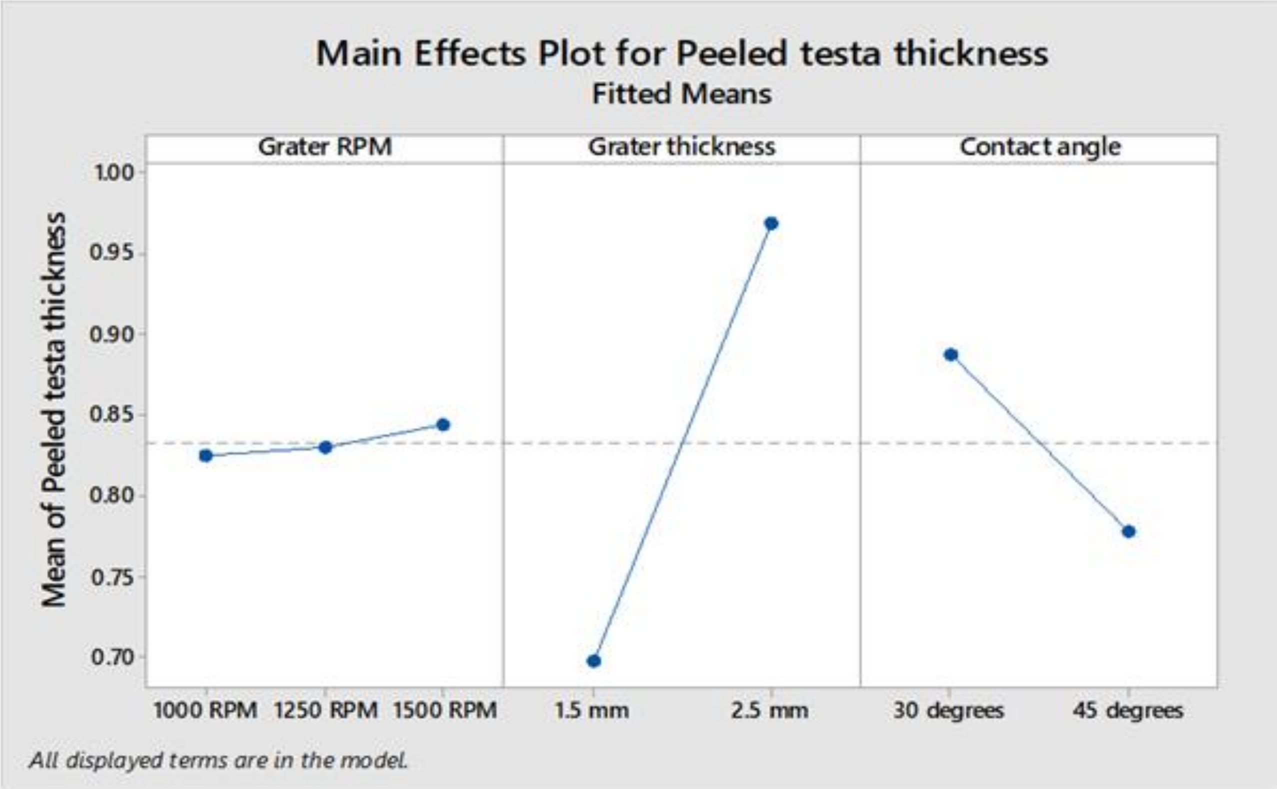

Fig 7 Main Effect Plots of Main Factors

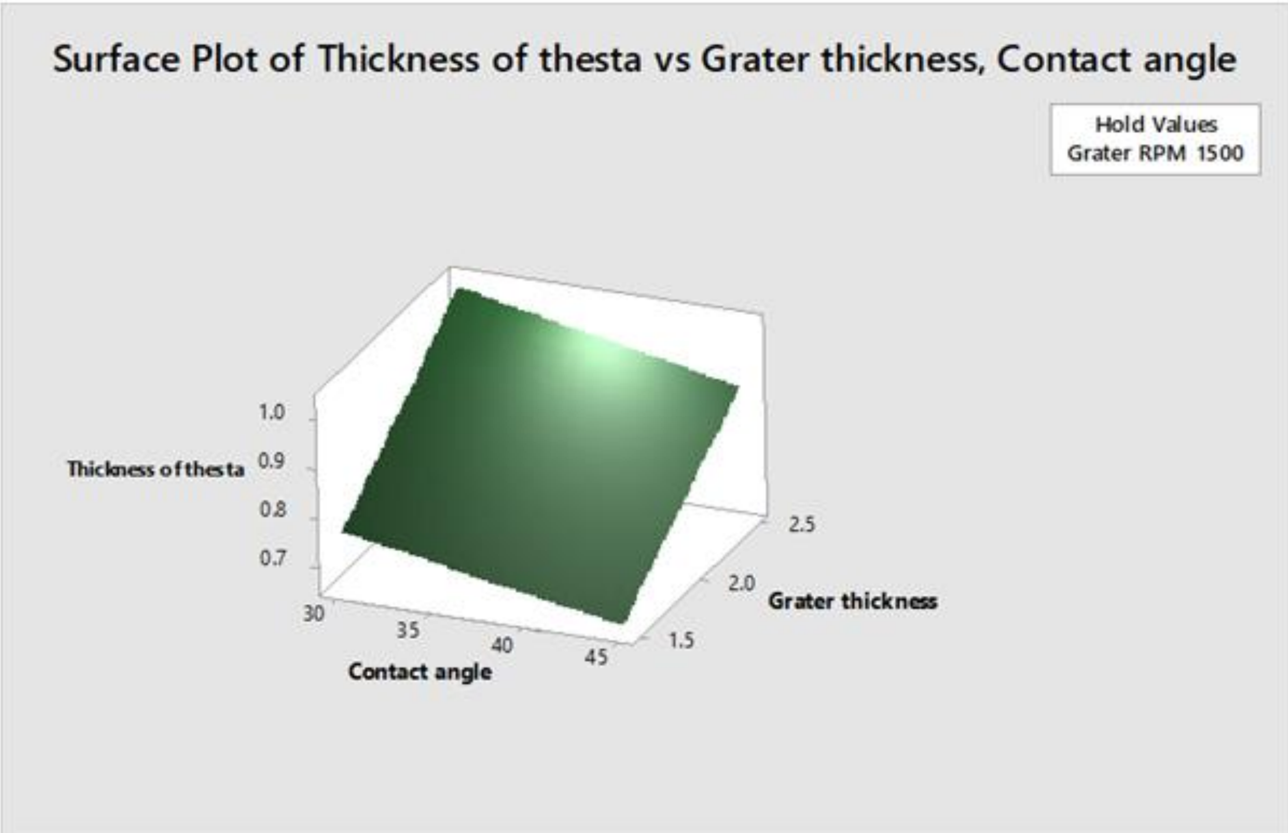

Fig 8 Surface Plot of Main Factors

Surface plot in Fig. 8 shows when the contact angle is increasing from 30° to 45° and grater thickness is decreasing from 2.5mm to 1.5mm. The graphical representation shows that the thickness of peeled testa can be decreased by increasing the contact angle.

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V. CONCLUSION

The study was carried out to identify the best mechanism for coconut testa removing to use in Sri Lankan coconut manufacturing industry and find the best parameter settings for the identified mechanism. Manual peeling methods were found to be costly, leading to the design of an industrial testa peeling machine using rotating graters. A prototype was fabricated and tests were conducted to identify the key parameters affecting the peeling process. The results showed that the Grater thickness and Contact angle has significant impacts on the thickness of the peeled testa, while Grater rotational speed did not show a significant effect. Thickness of the coconut testa can be minimized by setting the Contact angle at a high level and Grater thickness in low level. The designed machine with specific parameter levels, a higher production rate of 318 coconuts per hour could be achieved. Therefor the process efficiency can be increased. The automation of the manual process reduces labour costs and increases productivity. Table IV shows the optimum factor setting for the effective coconut testa peeling mechanism.

Table 4 Optimum Factor Setting

Factor	Optimum factor setting
Grater RPM	1500RPM
Grater thickness	1.5mm
Contact angle	45°

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