PROTOTYPE GINGER SLICING MACHINE WITH PARAMETER CONTROL FOR IMPROVED PRODUCTION EFFICIENCY

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Abstract

This research aimed to design and develop a ginger slicing machine with appropriate parameter control suitable for the Tid-Mai-Tid-Mue Community Enterprise. The study employed the principles of Design of Experiment (DoE) using a 2^k Full Factorial Design to investigate the factors affecting the machine's performance. The experimental results revealed that the coefficient of determination (R-sq) was 99.61% and the adjusted R-sq was 98.23%, indicating excellent model fit. A two-tailed hypothesis test was conducted with the null hypothesis H_0: $\mu = 78.63$ and the alternative hypothesis H_1: $\mu \neq 78.63$. The P-value was 0.809 at a significance level of 0.05 indicated that the results followed a normal distribution and met statistical validity requirements. A performance evaluation comparing manual slicing with the developed ginger slicing machine showed that manual labor required 486 seconds to slice 3 kilograms of ginger, whereas the developed machine achieved an 80.38% reduction in processing time, completing the same task in approximately 95 seconds. Implementation of the machine significantly reduced labor workload, production costs, and operator fatigue while increasing productivity. Additionally, it contributed to the enhancement of herbal product processing to better meet market and community enterprise demands.

Keywords: Community Enterprise, Design of Experiment, Ginger Slicing Machine, Parameter Control, Production Efficiency

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Introduction

Community enterprises serve as primary mechanisms for strengthening the country's grassroots economy by generating income for the nation, creating employment opportunities, serving as instruments for addressing local poverty issues, and fostering entrepreneurship through the creation of occupational groups and new entrepreneurs (Watthapron et al., 2024). Community enterprises encompass business activities related to the production of goods, provision of services, or other operations conducted by individuals with established bonds who collaborate to generate income and promote self-reliance among families within communities and between communities (Sutthikhun & Jaimun, 2024).

Phetchabun Province comprises 1,022 community enterprises (Community Enterprise Promotion Division, 2024), with Khao Kho District hosting numerous community enterprises that predominantly collaborate to process agricultural products for value addition (Phueakbuakhao et al., 2021). The Tid-Mai-Tid-Mue Community Enterprise, represents one such agricultural processing enterprise within the district. Field interviews conducted with the Tid-Mai-Tid-Mue Community, revealed that the group specializes in ginger processing, leveraging the numerous therapeutic properties of ginger, including relief of gastric distension, treatment of digestive disorders, and alleviation of abdominal bloating and flatulence (Pali et al., 2020). The enterprise's primary product, brown sugar ginger, experiences substantial market demand; however, the group encounters significant challenges in developing processing technology for ginger products, resulting in production capacity that fails to meet market requirements.

In response to this identified problem, the researcher developed an interest in conducting a study to develop a prototype ginger slicing machine capable of appropriate parameter control (Thavornwat et al., 2022) through the application of analytical principles and control of variables affecting the ginger slicing process prior to processing operations (Saenjit et al., 2025). The objective was to achieve consistent quality output that aligns with community enterprise requirements, facilitating innovation analysis and design while conducting experimental studies of appropriate factors (Chanpahol & Jantana, 2022) for optimal ginger slicing machine configuration. This research employed quantitative decision-making technology based on mathematical models to implement Design of Experiment (DoE) (Puntanagornpat et al, 2024) methodology for systematic experimental planning and process control (Maneerat & Ngaoprasertwong, 2023). The study utilized a two-factor full factorial design (2^k Full Factorial Design) to examine the effects of factors influencing productivity (Kaddar et al, 2024) and to identify optimal parameters for agricultural product production and processing. This approach enables efficient development and control of production processes, ensures product quality confidence, and contributes significantly to production cost reduction while increasing productivity for the Tid-Mai-Tid-Mue Community Enterprise.

Objectives

1. To design and construct a prototype ginger slicing machine with adjustable parameter control to improve processing efficiency.

2. To find the appropriate parameters using Design of Experimental (2^k) for controlling Prototype Ginger Slicing Machine.

Research Methodology

1. Design and Construction of a Ginger Slicing Machine

The operational principle of the ginger slicing machine employs blade-based slicing mechanisms utilizing centrifugal force to propel ginger heads (ginger rhizomes) into contact with cutting blades according to predetermined theoretical assumptions.

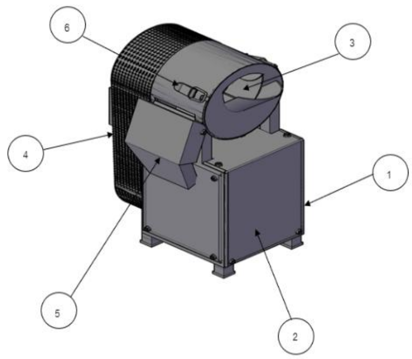

Figure 1. Structural design of the ginger slicing machine

As illustrated in Figure 1, the design of the principal components of the ginger slicing machine comprises the following equipment specifications: Component 1 represents the main structural framework of the ginger slicing machine; Component 2 consists of the electric motor and electrical control circuit housing; Component 3 encompasses the impeller and shaft assembly; Component 4 includes the pulley system, bearing cartridge assembly, belt installation mechanism, and protective belt cover; Component 5 comprises the cutting blades and ginger discharge channel; and Component 6 incorporates the ginger rhizome input chamber equipped with a locking cover for machine maintenance operations. The design methodology utilized computer-aided engineering software to facilitate the design process. The machine's main structural dimensions are depicted in Figure 2. The researcher selected stainless steel sheet material with a thickness of 2 mm, which was formed into a circular cylindrical configuration with a radius of 230 mm and welded to a base constructed from 1×1-inch stainless steel square tubing. The overall dimensions measure 313 mm in width, 210 mm in length, and 584 mm in height. The internal blade mounting assembly features an adjustment slot measuring 150 mm in length and 40 mm in height. The cutting blade assembly for ginger slicing incorporates blades measuring 141 mm in length and 25 mm in width, designed to perform the cutting and slicing functions of ginger rhizomes. The system includes a ginger separator plate positioned at the discharge end, measuring 217 mm in width, 149 mm in length, and 102 mm in height, which functions to contain the processed ginger and direct the output flow to prevent material dispersion. Additionally, a control cabinet is provided for machine operation control, as demonstrated in Figure 3.

Figure 2. Machine Structural Configuration

Figure 3. Prototype Ginger Slicing Machine

2. Experimental design

This research divided the experimental design into two principal components:

2.1 The identification of factors influencing the experimental process and factors affecting ginger slicing performance through factor screening utilizing a 2^k factorial experimental design to eliminate non-significant main factors and retain the remaining significant main factors for further investigation to determine optimal conditions.

2.2 Experimentation to determine optimal factor levels through analysis of input parameters of the ginger slicing machine, which can be illustrated as a flowchart depicting the sequential steps of the experimental design procedure, as presented in Figure 4.

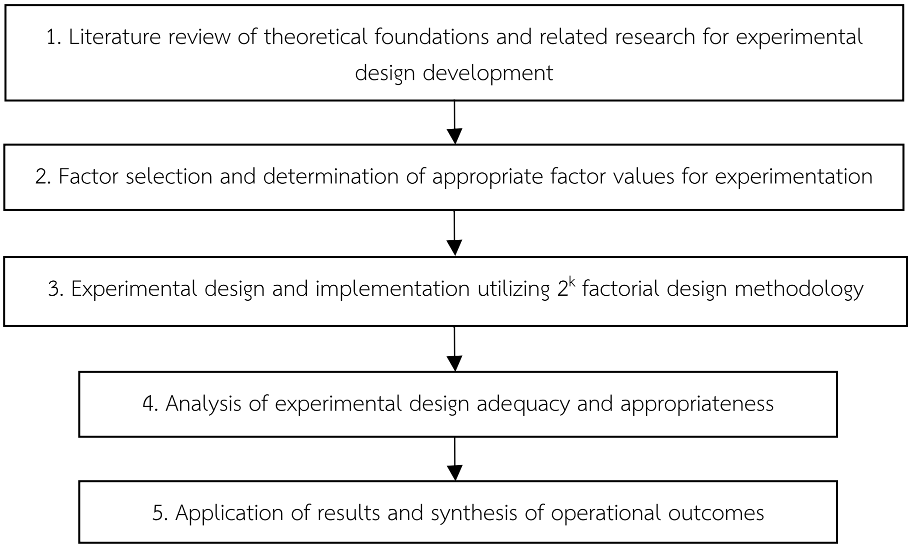

Figure 4. Experimental design flowchart

The experimental design for ginger slicing aims to achieve the predetermined target dimensions, whereby the ginger slices produced by the prototype machine must maintain a thickness ranging between 20-26 mm, as illustrated in Figure 5, to satisfy the specifications required for processing into value-added products within the ginger-based confectionery community enterprise.

Figure 5. Sample of ginger slices produced by the machine

3. Experimental Factor Selection

Five experts evaluated and scored the input factors influencing the ginger slicing performance to identify significant experimental variables. The evaluation revealed that the factors affecting ginger slicing performance include motor speed, blade angle, ginger size, blade length, and ginger moisture content. The assessment employed a scoring system and utilized a cause-and-effect matrix (Cause and Effect Diagram or Fishbone Diagram) (Pyzdek, 2003) to illustrate the relationships between quality characteristics and associated factors. Upon identification of the experimental input variables, the determination of principal factors for experimentation through factor analysis based on Pareto principles, applying the 80:20 rule to classify the relationships between factors in the experimental design process, as demonstrated in Figure 6.

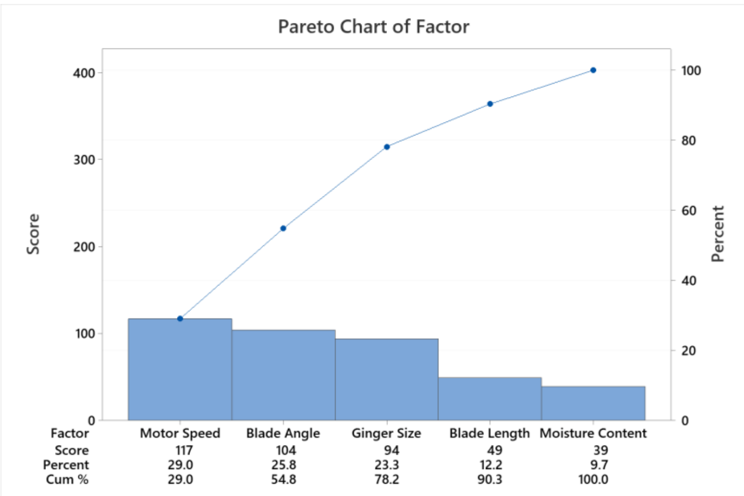

Figure 6. Pareto chart illustrating the relationship between factors for experimentation

Based on this rationale, the researcher concluded that the factors with the highest scores represent the input variables that are interrelated in the operation of the ginger slicing machine. Three primary factors were identified: motor speed, blade angle, and ginger size, which constitute controllable input variables. The motor speed for slicing ginger ranges from 210 to 310 rpm. Operating below this range results in incomplete slicing, while excessive speeds produce slices that do not meet the desired thickness. The selected motor speed aligns with the findings reported by (El-Haq et al, 2016). Each factor was designated to comprise two levels to achieve the desired output values, as presented in Table 1.

Table 1: Factors representing input variable relationships for experimental design

Factors	Level of Factors	Unit
Blade Angle	17 - 25	Degree
Motor Speed	210 – 310	Rpm
Ginger Size	100 - 200	Millimeter

4. Design of Experiments for Optimizing Ginger Slicing Parameters

Although various experimental design techniques exist, this research employed a full factorial experimental design (Palaphan, 2017) for the investigation of two-level factors (2^k Full Factorial Design) Which is suitable for experiments involving a small number of factors and up to three levels per factor, due to its capability to simultaneously examine both main factor effects and interaction effects within a single experimental framework.

The experimental response variable (Pawaree et al., 2023) was defined as the processing time required for ginger slicing using the prototype machine. The objective was to control and optimize parameter settings for appropriate machine configuration in production operations. Experiments were conducted using 3 kg of ginger rhizomes per trial, with a total of 10 experimental runs, representing a cumulative quantity of 30 kg of ginger.

5. Hypothesis Testing

Hypothesis testing is the statistical process employed to verify the parameters obtained from ginger slicing machine adjustments derived from experimental design. This process utilizes sampling techniques and statistical methods to assess the reliability of these values. The objective is to confirm whether the obtained values are accurate and consistent with statistical principles. The hypothesis framework is divided into two primary components:

1) Null Hypothesis (H_0)
2) Alternative Hypothesis (H_1 or H_a)

If the hypothesis test results reject the null hypothesis (H_0), the alternative hypothesis (H_1) must be accepted by implication (Palaphan, 2017).

Results and Discussion

The full factorial experiment investigated three factors at two levels each. The experimental design consisted of $2^3 = 8$ factorial runs, supplemented by 2 center point (Ct Pt) experiments to enhance experimental accuracy through the identification of central values for analyzing design relationships appropriately using Minitab software version 19. The total experimental runs comprised 10 trials. The results of the factor correlation analysis are presented in Table 2.

Table 2: Results factor to analysis of variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	7	3963.97	566.28	72.48	0.014
Linear	3	3830.37	1276.79	163.43	0.006
Blade Angle	1	120.13	120.13	15.38	0.059
Motor Speed	1	3655.13	3655.13	467.86	0.002
Ginger Size	1	55.13	55.13	7.06	0.117
2-Way Interactions	3	63.37	21.12	2.70	0.281
Blade Angle*Motor Speed	1	15.12	15.12	1.94	0.299
Blade Angle*Ginger Size	1	3.13	3.13	0.40	0.592
Motor Speed*Ginger Size	1	45.13	45.13	5.78	0.138
Curvature	1	70.22	70.22	8.99	0.096
Error	2	15.62	7.81		
Lack-of-Fit	1	3.12	3.12	0.25	0.705
Pure Error	1	12.50	12.50		
Total	9	3979.60			

Analysis of Table 2 revealed that the main effects comprise blade angle, motor speed, and ginger size. It can be concluded that among the main effects, the motor speed factor significantly influences the response variable, as evidenced by a P-value less than 0.05. Table 3 demonstrates that the variance analysis from the designed experiment yielded an R-squared value of 99.61% and an adjusted R-squared value of 98.23%, both exceeding 70% (Palaphan, 2017), indicating that this experimental design is accurate and appropriate. Consequently, the researcher determined that the motor speed factor exerts the greatest influence on the experimental response.

Table 3: Model summary analysis results

S	R-sq	R-sq(adj)	R-sq(pred)
2.79508	99.61%	98.23%	93.72%

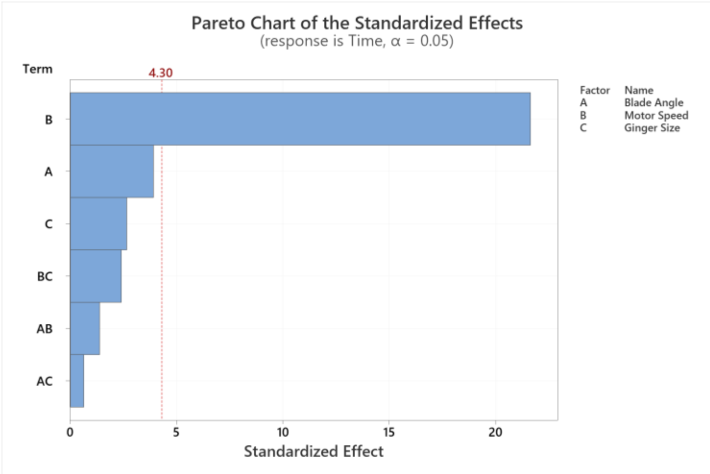

Figure 7. Pareto chart displaying factor terms

From Figure 7, the Pareto chart demonstrates that the effect value of the rotational speed factor substantially exceeds the critical line, indicating that the rotational speed factor significantly influences the response. However, second-order interactions must also be considered. The central position of the main factor lies within the linear range, the result indicates no significant curvature, thus the linear model is adequate. The primary factor of rotational speed demonstrates a significantly greater effect on the response compared to other factors. Low rotational speed results in extended production time, while high rotational speed leads to reduced production time, as illustrated in Figure 8.

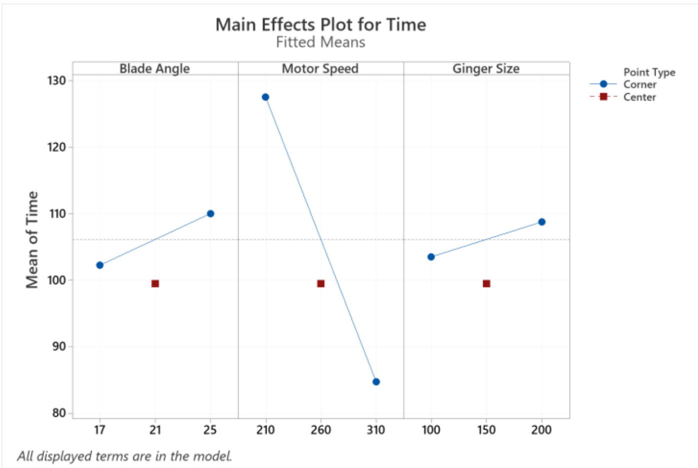

Figure 8. Main effects influencing the outcomes

Based on the examination of the interaction plot between two factors, as presented in Figure 9, it can be explained that the terms Blade Angle*Motor Speed, Blade Angle*Ginger Size, and Motor Speed*Ginger Size represent factor interactions that exhibit significant combined effects between each respective term.

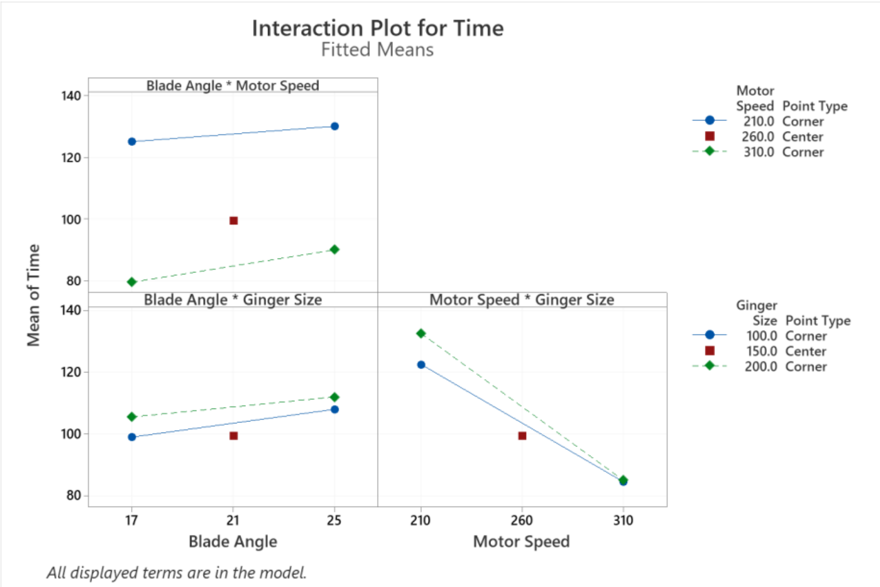

Figure 9. Effects of factor interactions on outcomes

Table 4: Results of multiple response prediction analysis

Variable	Setting			
Blade Angle	17			
Motor Speed	310			
Ginger Size	100			
Response	**Fit**	**SE Fit**	**95% CI**	**95% PI**
Time	78.63	2.61	(67.38, 89.87)	(62.16, 95.09)

From Table 4, the experimental results obtained through the Minitab program yielded optimal parameter settings for maximizing the efficiency of the ginger slicing prototype machine. The optimal configuration was determined to be: blade angle of 17 degrees, ginger size of 100 mm, and motor speed of 310 rpm. As demonstrated in Figure 10, the experimental outcome yielded a processing time of 78.63 seconds, which enabled the experimental design results to achieve ginger characteristics that satisfied the aforementioned hypothesis requirements while maximizing ginger throughput per operational cycle.

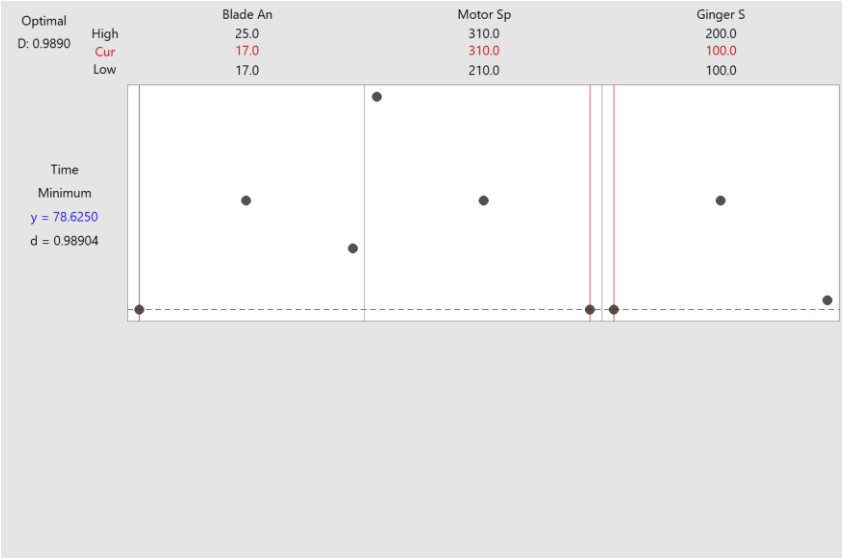

Figure 10. Optimal factor level analysis (Response Optimizer)

The optimal factor level analysis (Response Optimizer) to determine parameter settings that minimize the ginger slicing time of the prototype machine. As illustrated in Figure 10, the overall satisfaction of the appropriate factor levels, expressed as Composite Desirability (D), equals 0.9890, indicating a correlation between factor values and response values of 98.90%. This value, being close to unity, is considered to represent an excellent level of optimization.

Hypothesis testing to validate the accuracy of the optimal values through a one-sample t-test. The machine was configured according to the performance-affecting factor values, and hypothesis testing was performed using a randomly selected sample size of 13 trials to determine the number of ginger slicing tests at a significance level of 0.05. The experimental results obtained through the Minitab program are presented in Figure 11.

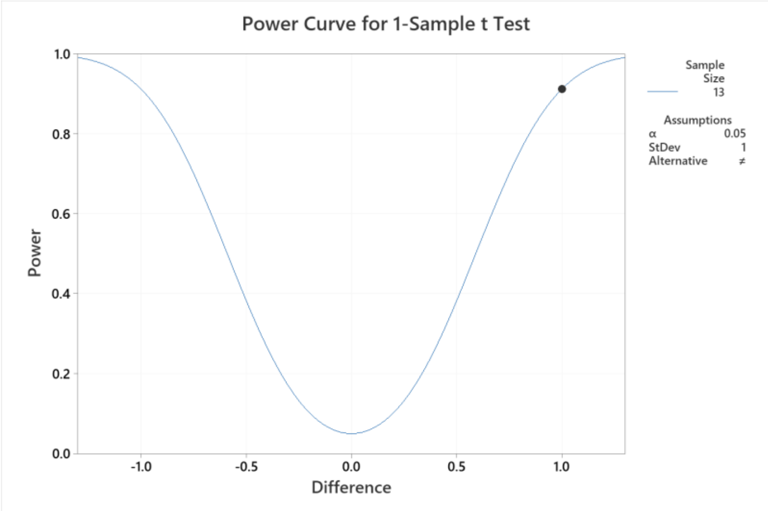

Figure 11. Sample size determination results for testing

Hypothesis testing to validate the values obtained from the ginger slicing machine configuration derived from the experimental design. The machine parameters were set to: blade angle of 17 degrees, ginger size of 100 mm, and motor speed of 310 rpm. A two-tailed hypothesis test (not equal) was employed with random sampling, targeting a processing time of 78.63 seconds per 3 kg of ginger slicing. The significance level was established at 0.05, with the following hypotheses:

Null hypothesis H_0: $\mu = 78.63$

Alternative hypothesis H_1: $\mu \neq 78.63$

A two-tailed hypothesis test was performed to confirm the experimental results. The statistical analysis yielded a sample mean of 80.385 seconds, a standard deviation of 3.070 seconds, and a 95% confidence interval ranging from 78.530 to 82.240 seconds. The results indicated that the null hypothesis could not be rejected, as demonstrated in Figures 12 and 13.

Descriptive Statistics

N	Mean	StDev	SE Mean	95% CI for μ
13	80.385	3.070	0.851	(78.530, 82.240)

μ: population mean of Sample Test

Figure 12. Hypothesis Test Result

Subsequently, the ginger slicing machine was tested using the experimental design configuration through 13 randomized trials, processing 3 kg of ginger per trial. The machine settings were adjusted according to the experimental design results, with a confidence level set at 95%. The resulting data were analyzed using the Minitab program, yielding a P-value of 0.809, which exceeds the significance threshold of 0.05. This result confirms that the dataset follows a normal distribution, as illustrated in Figure 13.

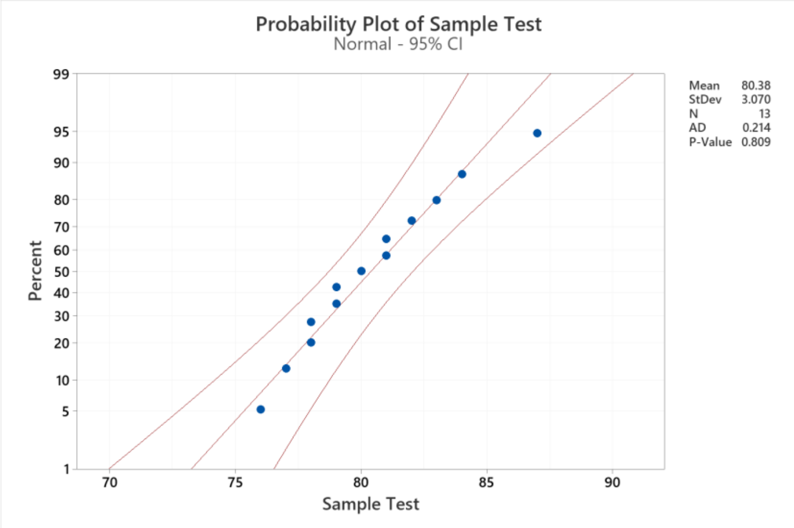

Figure 13. Normal distribution test results

Conclusions

This research successfully designed and developed a prototype ginger slicing machine equipped with adjustable parameters to enhance processing efficiency for the Tid-Mai-Tid-Mue Community Enterprise. A full factorial experimental design was applied to identify key factors-motor speed, blade angle, and ginger size-affecting machine performance. Experimental results showed that motor speed had the most significant impact, and the optimal configuration was determined to be a blade angle of 17°, ginger size of 100 mm, and motor speed of 310 rpm. The higher motor speed increases centrifugal force, enhancing cutting efficiency while maintaining slice uniformity, enabling the ginger slicing machine to slice ginger according to design specifications while achieving the most suitable ginger slicing time. The researchers conducted a two-tailed hypothesis test (Two Tail Test, Not equal) with null hypothesis H_0: μ = 78.63 and alternative hypothesis H_1: $\mu \neq 78.63$, obtaining a P-value of 0.809 at a significance level of 0.05 normality of residuals was separately verified using a probability plot, indicating that the experimental results were complete and appropriate. The machine was able to slice 3 kg of ginger in just 80.38 seconds, a six-fold improvement over manual slicing, which takes 486 seconds. This performance significantly reduces labor effort, increases production capacity, and lowers processing costs. The implementation of this machine supports the development of efficient, scalable, and cost-effective processing methods for ginger-based herbal products. As a result, it offers a practical solution for improving local agricultural processing and increasing income for community enterprises.

Recommendations

Recommendations from research findings

To ensure optimal machine performance and slicing quality, ginger rhizomes should be pre-cut to a length of 100-200 mm. This size range allows for smooth feeding into the slicing chamber and results in slices that meet product quality standards required for market distribution.

Recommendations for future research

Future design enhancements should include an integrated product collection or discharge system. Such a feature would streamline post-slicing handling, reduce material dispersion, improve hygiene, and enhance overall processing efficiency for end users.

Acknowledgments

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