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Abstract: *This study involves the design, development, and evaluation of a rotary-flash dryer for sago starch. The dryer's performance was assessed based on drying capacity, efficiency, losses, and product quality, including moisture content, color change, and fineness modulus. Experiments were conducted at varying drying temperatures (50°C, 55°C, and 60°C) and airflow rates (20 m/s, 22 m/s, and 24 m/s). The highest drying capacity (6.25 kg/hr.) and lowest losses (18%) occurred at 60°C and 24 m/s. Optimal moisture content (11.3%) was achieved at 60°C and 20 m/s, while ideal fineness modulus (1.1) and minimal color change (1.77) were observed at 50°C and 24 m/s. The best drying efficiency (55%) was at 50°C and 20 m/s. Using response surface methodology, the optimal drying conditions were determined to be 56.62°C and 24 m/s.*

Keywords: Physical Characteristics, Rotary-Flash Dryer, Sago starch.

1. INTRODUCTION

The sago palm (Metroxylon sagu) is a high-quality crop that is primarily grown in Southeast Asian nations. It is a crop of the twenty-first century with remarkable sustainability and the ability to grow in a variety of soil types. The name "sago" originated in Japanese and originally meant palm pith that contained starch. The pith, or core portion of the tree remains after the exterior layer resembling bark has been removed, which is where the edible starch known as sago is harvested. According to Singhal et al. [1], sago palms can store starch in their trunks until they flower. The peak starch concentration occurs just before the palm flowers appear. Sago starch accumulates in the pith of the sago palm stem from the base up [2]. For a very long time, people's basic diet consisted of either as a raw material or its derivatives, such as high-fructose syrup, white bread, noodles, and many more derivative products [3].

Despite having a higher yield (2000–3000 kg/Ha-Yr) than cassava (2000 kg/Ha-Yr) and corn (1000 kg/Ha-Yr), sago starch output was limited due to labor intensive processes and a lack of mechanization [4]. Chopping, cleaning, grating, sifting, settling, and conventional drying are all part of the time-consuming procedure. Therefore, developing a technology for drying sago starch is essential.

Hence, the goal of the study was to create a rotary flash-type drying machine that would be more efficient than the conventional sun drying method in terms of both production rate and product quality.

2. MATERIALS AND METHODS

2.1 Methodological Framework

The general method followed in this study is shown in Figure 1. The design specifications for the sago starch dryer included machine elements, appropriate material selection, and operational safety. The primary parameters that were assessed during the performance evaluation were the drying capacity, drying efficiency, and moisture reduction rate of the machine.

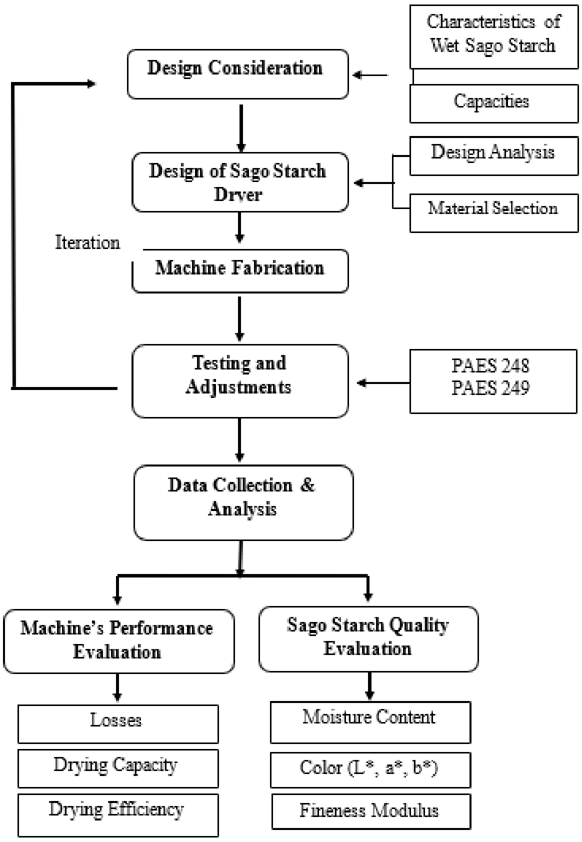


Figure 1. Process Flow Diagram

2.3 Design Considerations

In the fabrication of the Rotary-Flash Sago Starch Dryer, various considerations were taken into account: such as initial moisture content, flowability of the wet sago starch required for screw conveyor, and material balance to determine the expected output, required heat and air for drying; bulk density and particle density, for the design of the hopper, required capacity of the screw conveyor, size of drying chamber, and the carrying velocity of sago starch up to the cyclone; angle of repose, for inclination angle of the hopper; load capacity, to determine the overall design of the rotary-flash dryer.

2.3.1 Wet Sago Starch Properties

2.3.1.1 Moisture content

Approximately 72 grams of initial weight were used and were replicated five times. The samples were sun-dried, and the initial and final weights were gathered and recorded. The moisture content was computed using equation 1.

$$\mathrm{MC} = \frac{\mathrm{m_i - m_f}}{\mathrm{m_i}} \text{ X } 100 \qquad \text{Equation 1}$$

2.3.1.2 Bulk Density

The bulk density of the wet sago starch was determined by weighing the mass of materials inserted into a known volume. A digital scale with a capacity of 1kg was used during the experiment. The beaker used to contain the samples, weighs 0.394 kg and has a volume of 0.001m^3. The container was filled with the sample and weighed. The weight of the container was then deducted from the total weight recorded. The process was replicated five times, and the bulk density was determined using Equation 2.

$$\text{Bulk Density, } \rho_b = \frac{\text{mass}}{\text{volume}} \qquad \text{Equation 2}$$

2.3.1.3 Particle Density

The particle density of dried sago starch was determined by weighing the mass of materials inserted into a known volume. A precision balance with a capacity of 220 grams was used during the experiment. The pycnometer used to contain samples weighs 12.33 g and has a volume of 10 ml. The container was filled with the sample and weighed. The weight of the container was then deducted from the total weight recorded. The process was replicated five times, and the particle density was determined using Equation 3.

$$\rho_p = \frac{m_s}{V_s}; \quad V_s = \frac{[m_{pw} - m_p] - [m_{pws} - m_p - m_s]}{\rho_w} \qquad \text{Equation 3}$$

2.3.1.4 Angle of Repose

Wet sago starch is a fine-grained material with a maximum size of 240 µm or 0.24 mm [5]. To determine the angle of repose, the tilting box method was used, which is suitable for cohesionless fine-grained materials with a grain size less than 10mm [6]. The granular material is placed on the base of the box or tray, and then the tray is tilted gradually at a rate of 18°/min. The angle of repose was then measured as the material began to slide. The angle of repose was determined using Equation 4.

$$\theta = \tan^{-1}\left(\frac{H}{B}\right) \qquad \text{Equation 4}$$

2.4 Design of Rotary-Flash Sago Starch Dryer

2.4.1 Design Concept

The rotary-flash dryer was designed to remove moisture from filter cake materials, such as wet sago starch, and transform it into a dried powdered form. The process involves introducing the material using a screw conveyor into the drying chamber equipped with a rotating disc. The rotation of the disc creates a fluidized bed where hot air is introduced, rapidly drying the material as it is suspended in the air. The dryer and lighter particles will be carried with the gas and are separated using a cyclone separator. The schematic diagram for sago starch dryer is shown in Figure 2.

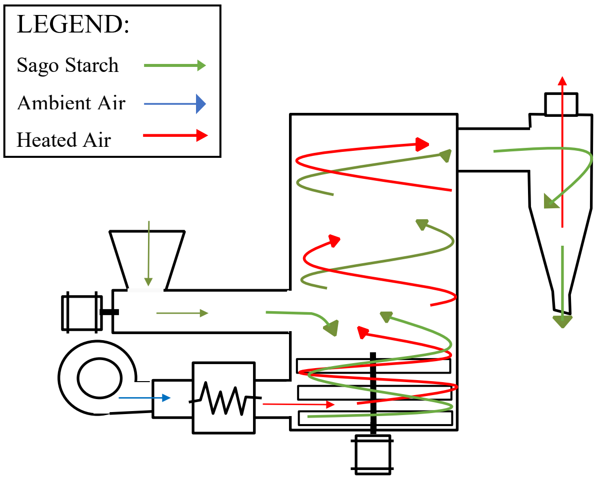


Figure 2. Schematic diagram of a rotary-flash dryer for sago starch dryer

2.4.2 Design Analysis

2.4.2.1 Material Balance

The material balance was determined using equation 5.

$$\dot{m}_a W_2 + \dot{m}_s M_{in} = \dot{m}_a W_3 + \dot{m}_p M_{out} \qquad \text{Equation 5}$$

2.4.2.2 Heat Transfer

To determine the amount of heat to raise the temperature (sensible heat) and the heat required to vaporize the moisture (latent heat), Equation 6 and 7 were used.

$$H_s = mC_p\Delta T \qquad \text{Equation 6}$$

$$H_L = m\Delta h \qquad \text{Equation 7}$$

2.4.2.2 Feeding System

In designing the hopper and screw conveyor for the feeding system, factors such as the angle of repose, density, and load capacity were considered.

a. Hopper Dimension

The volume of the hopper was obtained from the following equation with a 10% additional volume added to avoid spillage [7].

$$V_h = \frac{M_c}{\rho_b} \text{ x } 1.1 \qquad \text{Equation 8}$$

To determine the dimension of the hopper, volume of a rectangular hopper equation was used.

$$V_h = \frac{h(2L_2W_2 + L_2W_1 + L_1W_2 + 2L_1W_1)}{6} \qquad \text{Equation 9}$$

b. Screw Conveyor Design

To properly design a screw conveyor and determine the size and type of conveyor needed, type of materials to be conveyed, required flow, and length of the conveyor was considered. These parameters were achieved using charts and equations from KWS Manufacturing Company, Ltd. [8] screw conveyors engineering guide and Conveyor Engineering and Manufacturing Corporation (CEMC) [9].

Table 1. Material characteristics

Bulk Material	Max particle size (in.)	Bulk Density (lbs/ m^3)	Trough Loading %	Material Factor (F_m)	Component /Bearing Series	Flow-ability
Starch	-1/64	25-50	45	1	A1-A2-A3	I

Source: [9]

c. Drying Chamber

The diameter of the chamber was obtained considering the maximum carrying velocity of the particles and the total volumetric flow rate of air. Equation 10 was used to design the drying chamber given by Perry and Chilton [10], and equation 11 was used to determine its diameter.

$$V_m = 565.78\left(\frac{\rho_s}{\rho_s+997.95}\right) d^{0.6} \qquad \text{Equation 10}$$

$$D = \sqrt{\frac{4Q}{\pi V_m}} \qquad \text{Equation 11}$$

d. Stirrer Design

The stirrer design was obtained considering the bulk density of the wet sago starch and the capacity of the dryer with additional 50% height of the stirrer for the slurry factor of the sago starch. Equations 12 and 13 were used to design the stirrer.

$$L = n\sqrt{C^2 + P^2} \qquad \text{Equation 12}$$

$$n = \frac{H_s}{P_s} \qquad \text{Equation 13}$$

The shaft size of the stirrer was obtained considering the desired rotational speed of the stirrer, the size of the electric motor and the reduction of its speed, and the yield tensile strength of #304 stainless shaft with a safety factor of 4. Equation 14 was used to determine the shaft size of the stirrer.

$$d = \sqrt[3]{\frac{16T}{\pi\tau}} \qquad \text{Equation 14}$$

e. Cyclone Design

Cyclones could be designed for many applications, and they were categorized as high efficiency, conventional (medium efficiency), or high throughput (low efficiency). To ensure high recovery of the dried sago starch, a high-efficiency cyclone was utilized. Stairmand's high-efficiency design is shown in Table 2 and Figure 3.

Table 2. Standard cyclone dimensions

	Cyclone Type					
	High Efficiency		Conventional		High Throughput	
	(1)	(2)	(3)	(4)	(5)	(6)
Body Diameter, *D/D*	1.0	1.0	1.0	1.0	1.0	1.0
Height of Inlet, *H/D*	0.5	0.44	0.5	0.5	0.75	0.8
Width of Inlet, *W/D*	0.2	0.21	0.25	0.25	0.375	0.35
Diameter of Gas Exit, *D_e/D*	0.5	0.4	0.5	0.5	0.75	0.75
Length of Vortex Finder, *S/D*	0.5	0.5	0.625	0.6	0.875	0.85
Length of Body, *L_b/D*	1.5	1.4	2.0	1.75	1.5	1.7
Length of Cone, *L_c/D*	2.5	2.5	2.0	2.0	2.5	2.0
Diameter of Dust Outlet,	0.375	0.4	0.25	0.4	0.375	0.4

SOURCES: Columns (1) and (5) adapted from Stairmand, 1951 [11]; columns (2), (4) and (6) adapted from Swift, 1969 [12]; columns (3) adapted from Lapple, 1951 [13].

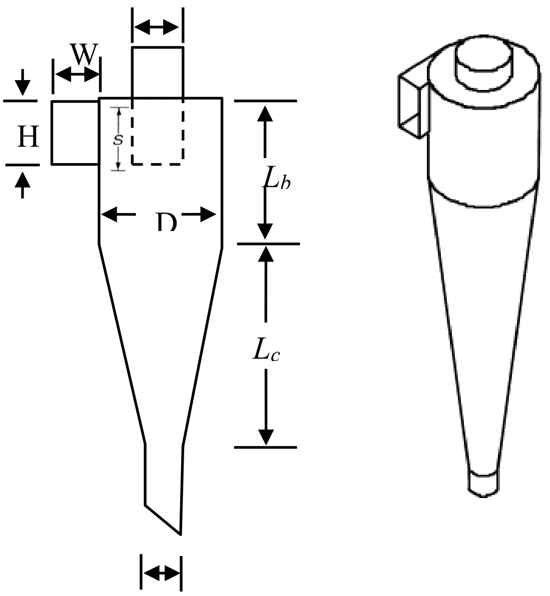


Figure 3. The cyclone configuration [11]

2.5 Sample Preparation

A total of 135 kg of wet sago starch samples were purchased in batches (loading capacities) to allow drying of the samples. The remaining samples were kept in a refrigerator at 40˚F (4.4˚C) until they were dried to prevent any changes in quality.

2.6 Experimental Setup

In data gathering, the wet sago starch was dried at three different drying temperatures of 50°C, 55°C, and 60°C with three different airflow rates. Three replications were performed for each airflow at the three different drying temperatures. The data with respect to the quality of the product, performance, and economic benefits of the machine were recorded for each treatment.

2.7 Quality Evaluation

2.7.1 Moisture Content (Wet Basis)

The samples were dried using a convective oven dryer at 105˚C. The ratio between the weight of the samples before and after drying was used to determine moisture content expressed as percentage in wet basis (%, wb.). This can be obtained using Equation 15 from PAES 202 [14].

$$MC_{wb} = \frac{W_{is} - W_{fs}}{W_{is}} \qquad \text{Equation 15}$$

2.7.2 Color Measurement

The color values of the samples were measured using a handheld colorimeter (WR-10QC, China) with a measurement caliber of 4 mm. The color was defined on the base of the chromatic coordinates, lightness (L*) a gray scale with values from 0 (black) to 100(white), green, red (a*), and blue yellow (b*) [15]. The color of wet sago starch before drying was measured, and the value was used to calculate the total amount of color change by using Equation 16 [16]. Whiteness index was also calculated using Equation 17 [17].

$$\Delta E = \sqrt{(L - L_s)^2 + (a - a_s)^2 + (b - b_s)^2} \quad \text{Equation 16}$$

$$WI = 100 - \sqrt{(100 - L_s)^2 + a^2 + b^2} \quad \text{Equation 17}$$

2.7.3 Fineness Modulus

The particle size was determined according to the guidelines outlined in the Standard INEN NTE 0517 [18]. The dried sago starch at different treatment combinations was placed onto a series of 5 sieves, each with a decreasing diameter from top to bottom: 40 mesh, 60 mesh, 100 mesh, 140 mesh, 200 mesh, and a pan collector. Mechanical vibration was applied to the sieves using sieve shaker equipment (Porter Sand, USA) for 5 minutes, and the starch retained on each sieve was meticulously gathered and weighed. The particle size was determined using the fineness modulus, calculated as the sum of the fractions of the weight retained on each sieve divided by 100, as shown in Equation 18.

$$F.M. = \frac{\Sigma(Cumulative\ percentage\ retained\ on\ specified\ sieves)}{100} \quad \text{Equation 18}$$

2.8 Performance Evaluation

2.8.1 Losses

The amount of sago starch retained and escaped in the dryer per unit time, expressed in kg/hr and can be determined using Equation 19:

$$L = \frac{(W_i - M_r) - W_f}{T_d} \quad \text{Equation 19}$$

2.8.2 Drying Capacity

The maximum capacity that the dryer can remove moisture content per unit time given can be determined using Equation 20 [19]:

$$D_c = \frac{W_i}{T_d} \quad \text{Equation 20}$$

2.8.3 Drying Efficiency

The ratio of the heat required to vaporized moisture inside fruit, to the amount of heat added to the drying air, expressed in percent, and can be determined using Equation 21 [19].

$$\text{Drying efficiency} = \frac{Q_r}{Q_d}\ x\ 100 \quad \text{Equation 21}$$

Where: $Q_r = \frac{Q_v \times m_r}{T_d}$

2.9 Data Analysis

The collected data were statistically analyzed using Central Composite Design in Response Surface Methodology (RSM) to determine the optimal combination of independent variables, i.e., drying temperatures and air velocity, and their significant effect on the actual drying capacity, efficiency, losses, color, moisture, and fineness modulus. Triplicate analyses were done for each sample, while the significant difference was determined at α= 0.005 (95% confidence level).

3. RESULTS AND DISCUSSIONS

3.1 Physical Characteristics of Wet Sago Starch

3.1.1 Moisture Content

Table 3 shows that the wet sago starch samples have an average of 45 %web moisture content after oven drying at 105 ˚C.

Table 3. Moisture content of wet sago starch

No.	**MASS OF SAMPLE, g**		**MC%**
	Initial	**Final**	
1	72	40	44
2	73	40	45
3	72	41	43
4	70	40	46
5	75	42	43
Average			**45**

3.1.2 Density

The average bulk density and particle density of wet sago starch are 728.6 kg/m^3 and 3.57 g/cm^3, respectively as shown in Tables 4 and 5.

Table 4. Bulk density of wet sago starch

No.	Mass of sample, g	BULK DENSITY, kg/m^3
1	0.693	693
2	0.714	714
3	0.779	779
4	0.699	699
5	0.758	758
AVERAGE		**738.6**

Table 5. Particle density of wet sago starch

No.	Mass of Particles, g	Volume of Particles, cm^3	Particle Density, g/cm^3
1	1.78	0.531	3.35
2	1.88	0.442	4.25
3	2.02	0.615	3.28
4	1.79	0.484	3.69
5	1.90	0.577	3.29
AVERAGE			**3.57**

3.1.3 Angle of Repose

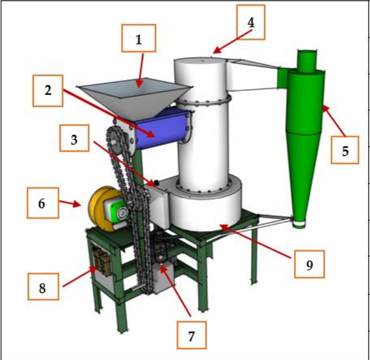
Table 6 shows that the wet sago starch samples have an average angle of repose of 48˚.

Table 6. Angle of repose of wet sago starch

No.	**Height, m**	**Base, m**	**Angle of Repose, θ**
1	0.20	0.19	46˚
2	0.204	0.187	47 ˚
3	0.20	0.194	46 ˚
4	0.21	0.19	48 ˚
5	0.21	0.18	50 ˚
AVERAGE			**48 ˚**

3.2 Design of Rotary Flash Dryer

The design and the actual rotary-flash dryer for sago starch consists of five main components: the feeding system, heating system, transmission system, drying chamber, and cyclone, are shown in Figures 4 and 5, respectively. The machine is 1.37 m high and 1.05 m long. The rotary flash dryer was designed to remove moisture from wet sago starch and transform it into a dried powdered form. The process involves introducing the material through the hopper and then conveyed by a low-speed screw conveyor into the drying chamber equipped with a high speed (290 rpm) stirrer. The stirrer creates a fluidized bed where hot air is forced by a 3-in size blower, rapidly drying the wet sago starch as it is suspended in the air. The dryer and lighter particles will be carried with the air and are separated using the cyclone.



No.	Name of Parts
1	Hopper
2	Screw Conveyor
3	Heating System
4	Drying Chamber
5	Cyclone
6	Blower
7	Transmission System
8	Control System
9.	Plenum

Figure 4. Design of the Rotary-Flash Dryer

Figure 5. Perspective view of the Rotary-Flash Dryer

3.3 Quality Evaluation of the Dried Sago Starch

3.3.1 Moisture Content Wet Basis

Table 7 shows the average moisture content of the dried sago starch after drying under three different temperature levels and air flow rates.

Table 7. Average moisture content of dried sago starch

Airflow, (m/s)	Temperature (˚C)	Average Moisture Content web (%)
24	60˚C	12.4
22		11.5
20		11.3
24	55˚C	12.7
22		11.8
20		11.8
24	50˚C	13.1
22		12.3
20		12.1

Table 7 and Figure 6 show that the moisture content of dried sago starch varied from 11.3% to 13.1%, with the highest moisture content at 50 °C and an airflow of 24 m/s and the lowest at 60 °C and an airflow of 20 m/s. These findings align with those of Mustafa Kamal et al. [20], who reported that higher temperatures result in lower moisture content in sago starch, indicating a significant effect of drying temperature on the final moisture content. Similarly, jading et al. [21] found that using a pneumatic conveying recirculated dryer, temperature and air velocity significantly reduced the moisture content of sago starch from 31% (web) to 9% (web).

According to Malaysian Standard MS 468 [22], the maximum moisture content for industrial and edible sago starch is 15% and 13%, respectively. Therefore, the treatment combinations used in this study produced favorable results for the moisture content of dried sago starch.

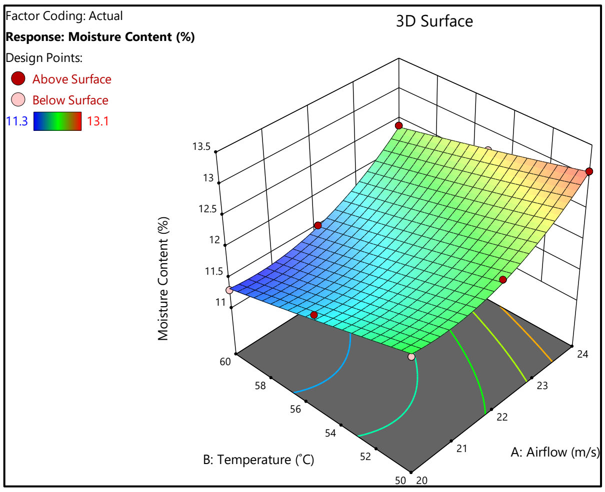


Figure 6. Effects of temperature and airflow on the moisture content of dried sago starch

3.3.2 Color (L*, a*, b*)

Both temperature and airflow significantly affected the color of dried sago starch. As shown in Table 8 and Figure 7, increased airflow decreases the color changes in dried sago starch. Sago starch dried at 50 ºC with an airflow of 24 m/s exhibited greater lightness (L) and whiteness (WI), along with less browning (ΔE) compared to starch dried at higher temperatures and lower airflows. The color changes were relatively smaller, suggesting that drying sago starch at 50 ºC is ideal for preserving its natural color properties. In contrast, sago starch dried at 60 ºC showed a slight increase in color changes (ΔE) and a decrease in whiteness (WI), with values of 3.09 and 39.56, respectively, compared to those dried at lower temperatures. Mustafa Kamal et al. [20] found that drying sago starch at 80 ºC resulted in the highest color changes (ΔE) with a value of 16.80, significantly different from the 3.09 value observed at 60ºC. This indicates that higher drying temperatures lead to decreased whiteness and increased browning.

Table 8. Average color (L*, a*, b*) values of dried sago starch

Airflow (m/s)	Temperature (˚C)	$L^*{}_s$ (42.71)		$a^*{}_s$ (2.50)		$b^*{}_s$ (3.19)		ΔE	WI
		L*	ΔL*	$a*$	Δa*	$b*$	Δb*		
24		40.16	-2.55	2.86	0.36	2.54	-0.65	2.77	40.04
22	60˚C	39.89	-2.82	2.56	0.06	2.29	-0.9	2.97	39.79
20		39.73	-2.98	3.28	0.78	3.13	-0.06	3.09	39.56
24		40.65	-2.06	2.19	-0.31	3.03	-0.16	2.17	40.53
22	55˚C	40.29	-2.42	2.15	-0.35	2.38	-0.12	2.45	40.16
20		40.21	-2.50	2.55	0.05	2.18	-1.01	2.74	40.11
24		41.18	-1.53	2.70	0.20	2.48	-0.71	1.77	41.07
22	50˚C	41.00	-1.71	2.26	-0.24	2.81	0.31	1.85	40.89
20		40.73	-1.98	2.74	0.24	2.64	-0.55	2.08	40.61

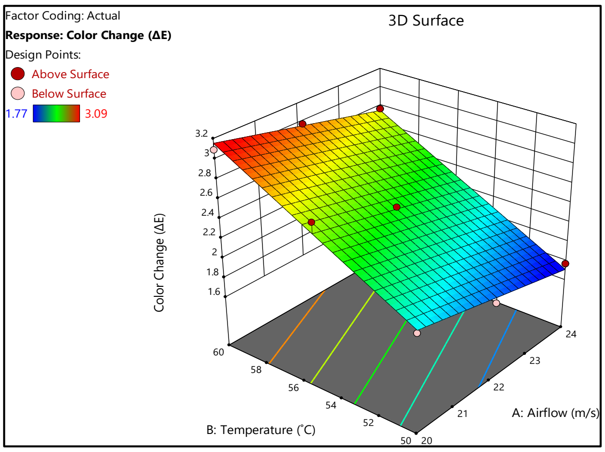


Figure 7. Effects of temperature and airflow on the color (ΔE) of dried sago starch

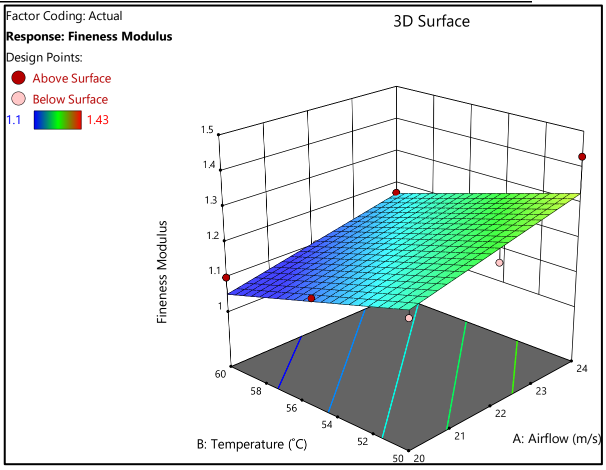


Figure 8. Surface plot of fineness modulus for dried sago starch

3.4.3 Fineness Modulus

The results revealed that airflow, temperature, and the interaction of both factors significantly affect the fineness modulus of dried sago starch, as shown in Figure 8. The relationships between temperature, airflow, and fineness modulus were inversely and directly proportional, respectively. As temperature increases, the fineness modulus decreases, while increased airflow results in a higher fineness modulus. This is due to the capability of the airflow to expel heavier and larger particles.

The fineness modulus of particles is classified as coarse (above 4), medium (2-4), and fine (0–2), with smaller FM values indicating finer material [23]. As shown in Figure 8, the lowest fineness modulus of 1.1 was obtained at a temperature of 60˚C and an airflow of 20 m/s. Conversely, the highest fineness modulus of 1.43 was observed at 50°C and an airflow of 24 m/s. The ideal particle size for industrial and edible sago starch is passed through a 120-mesh sieve, with minimum passing percentages of 60% and 90%, respectively [22]. According to the results shown in Table 9, all samples met the ideal passing rate of approximately 98% when using a 120-mesh sieve, and even with a sieve size of 200-mesh, the passing rate remained acceptable.

Table 9. Average passing percent % of dried sago starch with different size of sieve.

Airflow (m/s)	Temp ˚C	IS Sieve Size (mesh)				
		No. 40	No. 60	No. 120	No. 140	No. 200
24		100	99.19	98.49	97.81	94.41
22	60	100	99.82	98.44	97.65	93.69
20		99.99	99.89	98.79	97.87	95.01
24		99.99	99.58	98.13	96.84	87.34
22	55	99.99	99.60	97.44	96.27	90.14
20		99.99	99.58	98.24	97.31	91.07
24		99.99	99.41	96.94	95.72	65.67
22	50	99.99	99.57	98.41	97.09	82.15
20		99.99	99.47	98.55	97.29	85.14

3.4 Performance Evaluation

3.4.1 Drying Capacity

The relationship between temperature, airflow, and drying capacity is directly proportional; as temperature and airflow increase, drying capacity also increases. As observed in Figure 9, drying capacity ranged from 4.13 kg/hr. at 50˚C and 20 m/s airflow to 6.25 kg/hr. at 60 ˚C and 24 m/s airflow.

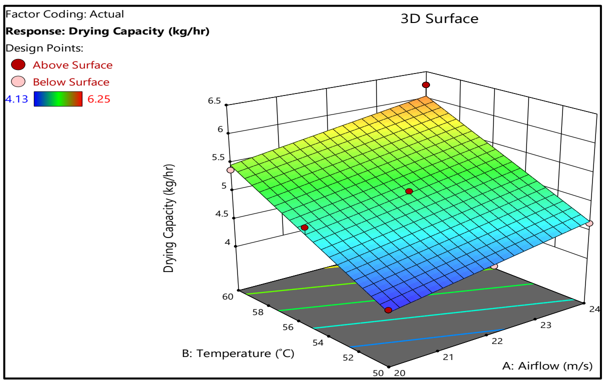


Figure 9. Effects of temperature and airflow on drying capacity of the rotary-flash dryer for sago starch

3.4.2 Losses

Figure 10 shows that losses were lower at higher temperatures and faster airflow, averaging 18% at 60 °C with a full blower control (24 m/s). Conversely, losses were higher at lower temperatures and slower airflow, averaging 31% at 50 °C with a half-blower control (20 m/s). It also illustrates this relationship, showing that losses increase as temperature and airflow decrease. Compared to PAES 201 [24], the obtained minimum loss of 18% did not meet the maximum allowable drying loss of 10%. These significant losses were observed in the feeding system, where the wet sago starch was not fully conveyed by the screw conveyor due to the large clearance size from the trough.

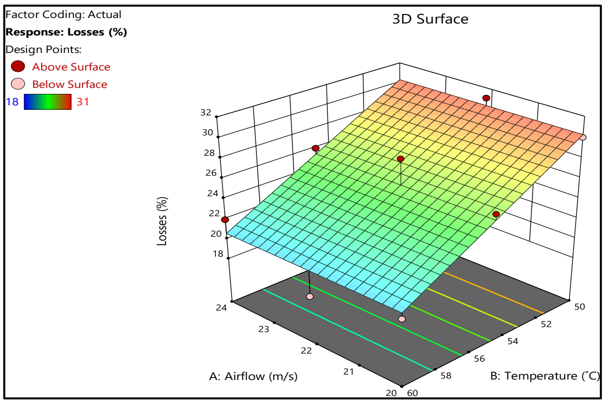


Figure 10. Effects of temperature and airflow on losses of the rotary-flash dryer for sago starch

3.4.3 Drying Efficiency

Figure 11 indicated that drying efficiency was higher at lower temperatures, ranging from 51% to 55% at 50 ˚C. In contrast, drying efficiency was lower at higher temperatures ranging from 42% to 45% at 60 ˚C.

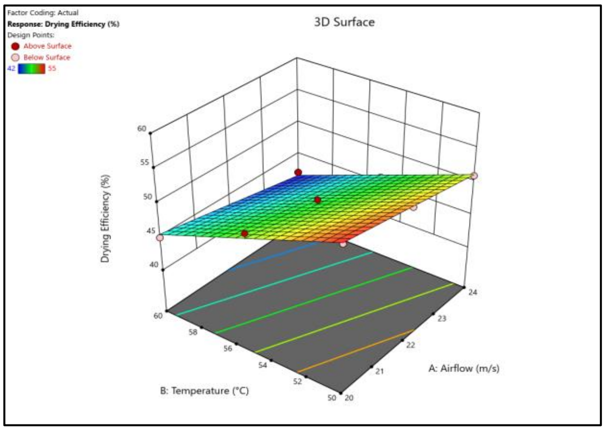


Figure 11. Effects of temperature and airflow on drying efficiency of the rotary-flash dryer for sago starch

3.4.4 Optimum Condition

The optimal performance of the dryer was achieved at a temperature of 56.63 °C and an airflow rate of 24 m/s. Under these conditions, the dryer achieved an output of 2.374 kg, an operating time of 0.902 hours, losses of 23.87%, a drying capacity of 5.581 kg/hr., a drying efficiency of 44.76%, a moisture content of 12.61%, a fineness modulus of 1.222, and a color change of 2.402. Figure 12 shows the overlay contours which were plotted as specified by the criteria. The yellow region presented in the graph interprets the acceptance values of the temperature and the airflow. It was observed that the obtained optimal condition, such as 24 m/s at 56.63 °C, was in the region of acceptance value.

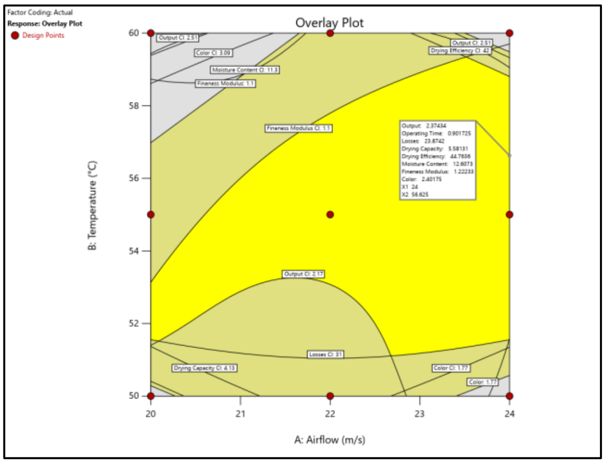


Figure 12. Optimum condition for rotary-flash sago starch dryer

3.4.5 Post Analysis

Post-analysis is essential for verifying the results obtained from the model's predictions. Table 10 illustrates the summary of the post-analysis for the optimal settings of 56.63 °C and 24 m/s. It compares the response observed during the confirmation experiment with the model’s predicted response. The table reveals that both the predicted and actual response values for the optimized dryer were within the range of the upper and lower limits. This suggests that the mathematical equations derived from the analysis were fit for predicting the response surface.

Table 10. Post-analysis summary of optimum rate combination

Responses	Predicted Mean	Predicted Median	Std Dev	n	SE Pred	95% PI low	Data Mean	95% PI high
Output	2.374	2.37	0.023	1	0.028	2.28	2.32	2.46
OT	0.902	0.902	0.023	1	0.026	0.84	0.95	0.96
Losses	23.87	23.87	1.917	1	2.182	18.5	26	29.2
DC	5.582	5.58	0.128	1	0.145	5.23	5.26	5.94
DE	44.76	44.76	0.553	1	0.629	43.2	46	46.3
MC	12.61	12.61	0.071	1	0.088	12.3	12.7	12.9
FM	1.222	1.222	0.058	1	0.066	1.06	1.18	1.38
Color	2.402	2.402	0.069	1	0.079	2.21	2.21	2.59

4. CONCLUSION

The study successfully designed, developed, and evaluated a rotary-flash dryer specifically for sago starch processing. Based on the rotary-flash dryer's performance, it was revealed that the optimal drying conditions were at 56.63°C and 24 m/s airflow, achieving an optimum output of 2.374 kg, an operating time of 0.902 hours, losses of 23.874%, a drying capacity of 5.581 kg/hr, a drying efficiency of 44.763%, a moisture content of 12.608%, a fineness modulus of 1.222, and a color change of 2.402.

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