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A PILOT PLANT SCALE OF YELLOW KONJAC (*AMORPHOPHALLUS MUELLERI* BLUME) FLOUR PRODUCTION BY A CENTRIFUGAL MILL USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT
This study aimed at investigating the effects of polishing conditions on the physicochemical properties of polished yellow konjac flour (PYKF) with a centrifugal mill using Central Composite Design-Response Surface Methodology (CCD-RSM). Micro-mill milled yellow konjac flour (MMYKF) mass and polishing cycles were the independent variables, with four observed responses (calcium oxalate, viscosity, degree of whiteness (DoW), and glucomannan). The lower limit (-1) and upper limit (+1) for MMYKF mass in this study are 10 and 15 kg, respectively, while the -1 and +1 for the polishing cycle are three times, and seven times, respectively. The optimum prediction occurred at 10 kg of MMYKF mass and six times the polishing cycle with the following characteristics: 0.52 ±0.00% w.b. calcium oxalate, 20362.00 ±16.00 cP viscosity, 62.22 ±0.01 DoW, and 69.43 ±0.02% d.b. glucomannan content, which agreed with the verification data with p-value >0.05 for all observed responses using the paired T-test. Polishing using a centrifugal mill is feasible and promises to be scaled up to industrial scale for yellow konjac flour polishing before the wet extraction process.

Keywords: Centrifugal mill; polishing; *Amorphophallus muelleri* Blume; Response Surface Methodology

INTRODUCTION
Crude yellow konjac flour (CYKF) is the flour produced by the processing of yellow konjac chips using a mechanical mill **(Widjanarko, Faridah and Sutrisno, 2014)**, including using micro-mill assisted cyclone separator and known as micro-mill milled yellow konjac flour (MMYKF). It contains ≤67.02% dry base (d.b.) glucomannan **(Faridah and Widjanarko, 2013; Witoyo et al., 2020)** and is classified as a fermentable, water-soluble, and high-viscosity food fibre **(Alonso-Sande et al., 2009)**. Hence, it is widely applied in the food industry to improve texture, as a thickener, as a gelling agent **(Zhang, Chen and Yang, 2014)**, and as a fat replacement **(Jiménez-Colmenero et al., 2013)**. However, the glucomannan content in CYKF is lower than the international standard for top and first grades (≥70 ≥90% d.b) **(Liu et al., 2002)**. The lower glucomannan content in CYKF is related to the fact that the glucomannan granules in the CYKF are still covered by impurities, such as starch, fibre, protein, fat, and ash **(Kurt and Kahyaoglu, 2017)**. The toxic substances which may be harmful to the human body also appear in CYKF. The main reason is that calcium oxalate can cause mouth and oesophagus irritation **(Kumoro, Budiyati and Retnowati, 2014)**, interference with Ca and Fe withdrawal, and other health problems **(James et al., 2013)**. Calcium oxalate content in CYKF ranged from 0.398 to 5.17% **(Faridah, 2016; Witoyo, Widjanarko and Argo, 2019)**, which was not acceptable for extensive application in food products.

Polishing is a subsequent stage aiming at removing impurities on glucomannan granules surface of yellow konjac flour after the milling process. In general, polishing removes bran in paddy during the rice milling process **(Mohapatra and Bal, 2010; Paiva et al., 2016; Reddy et al., 2017)**. This treatment is also reported as being effective in reducing anti-nutritional (tannin contents) from 1.05% to 0.09 – 0.095% and improving color in the polished sorghum grains. This process is still limited to removing impurities covering glucomannan granules in yellow konjac flour. **Wachyuningsih (2011)** and **Sary (2018)** report a polishing yellow konjac flour that uses an abrasive polisher. However, this method does not control the temperature during the process and is detrimental to the glucomannan in yellow konjac flour.

The centrifugal mill (also known as a centrifugal grinder) is one of the modified friction types of polishing machines equipped with a water-cooling system in the milling chamber to minimize heat produced during processing. This machine has the same principle as its predecessor, while the application is limited to the laboratory scale process in producing wheat and durum flour from wheat grains **(Deng and Manthey, 2017; Khalid, Manthey and Simsek, 2018)**. Polishing yellow konjac flour with a tool like that is still rare. Using a centrifugal mill for yellow konjac flour polishing was initially evaluated by **Witoyo et al. (2020)** using MMYKF as a raw material. The results showed that polishing conditions affected polished yellow konjac flour (PYKF), namely its physicochemical properties, such as calcium oxalate content, viscosity, degree of whiteness (DoW), and glucomannan content. However, the optimum conditions for the polishing of CYKF have not been determined. Thus, the Response Surface Methodology (RSM) approach is needed to obtain optimum conditions for all observed responses.

RSM is an empirical statistical modeling technique based on multiple regression analysis using quantitative data from experiments designed to solve multivariate equations **(Madamba, 2002)** simultaneously. This technique is commonly used to process and optimize biochemical and chemical processes, using fewer data **(Baş and Boyaci, 2007)**. This study aims to obtain the optimum condition of MMYKF mass and polishing cycle to PYKF using a centrifugal mill with Central Composite Design (CCD)-RSM Approach.

Scientific Hypothesis

The RSM-CCD approach can predict the optimal polishing conditions to obtain PYKF with the best characteristics.

MATERIAL AND METHODOLOGY

Samples

This study applies the optimum of MMYKF through 40 mesh sieve (13.65% w.b. moisture content) derived from yellow konjac chips milled using micro-mill assisted cyclone separator as the raw materials. Yellow konjac chips were purchased from farmers growing yellow konjac in Klangon Village, Saradan District, Madiun Regency, East Java, Indonesia (Figure 1 and Figure 2).

Chemicals

Potassium permanganate (Sigma-Aldric, USA), D-Glucose (Sigma-Aldric, USA), distilled water, H_2SO_4 (Merck KGaA, Darmstadt, Germany), NaOH (Merck KGaA, Darmstadt, Germany), HCl (Merck KGaA, Darmstadt, Germany), ammonium hydroxide (Merck KGaA, Darmstadt, Germany), methyl red (Sigma-Aldric, USA), $CaCl_2$ (Merck KgaA, Darmsadt, Germany), and other chemicals were purchased in analytical grade from Merck KGaA, Darmstadt, Germany, and used without further purification.

Instruments

Color reader (Minolta CR-10, Minolta, Japan), analytical balances (Mettler Toledo Inc., USA), Shaker water-bath (Memmert WNB14, Germany), Centrifuge (Thermo Scientific SL40R, Thermo Fisher Scientific, Inc.), viscometer (NDJ-1 rotational viscometer, China), Shimadzu UV-Visible Spectrophotometer UVmini-1240 (Shimadzu cooperation, Kyoto, Japan), Oven (Memmert, Germany), Vortex (IKA Vortex 3, ProfilLab24 GmbH, Berlin, Germany), Electrical Stove (Maspion, Indonesia), Shaker (SI-1500 Orbital-Genie Orbital Shaker, Marshall Scientific LLC)., Centrifugal mill (Workshop local made, CM 1 model, Indonesia), Disk mill (FFC 45 model, China), Micro-mill assisted cyclone separator (Workshop local made, MM 1 model, Indonesia).

Description of the Experiment

Sample preparation: The study involved the polishing process described by **Witoyo et al. (2020)** using a centrifugal mill (Figure 2) with minor modifications. The 8.96 – 16.04 kg of MMYKF from the micro-mill, assisted by cyclone separator, was weighed using the digital balance (CMOS digital scale modelDS-30k) and put into input hopper (Figure 2, (4)). The feed rate (20 Hz) and fan blower speed (10 Hz) panel were turned on for 30 seconds for conditioning, and the rotor speed was set to 30 Hz for the polishing process. Each cycle process was completed (30 seconds after CYKF run out in the input hopper). Then the PYKF (the heavy fractions) was collected (Figure 2, in front of (13)) (1^{st} polishing cycle) and put into the same input hopper for 2 to 8 polishing cycles using the same procedure as in the 1^{st} polishing cycle based on experimental design (Table 1). The final PYKF (about 250 g) from each process was collected, sampled, and stored in a dark bag for further analysis.

A number of samples analyzed: 13 samples (Table 3) and 3 samples from the verification experiment (Table 2). So there were 16 samples to be analyzed.

A number of repeated analyses: Each sample was in Duplo analyses.

A number of experiment replication: The experiment was conducted using the CCD method, whereby 13 runs for the whole experiment consisted of four replications for the correlation treatment, four replications for the axial treatment and five replications for the centre treatment. The verification experiment used three replications to validate the optimum prediction treatment suggested by Design-Expert program 10 version trials.

Determination of Calcium Oxalate

Calcium oxalate content in yellow konjac flour was evaluated based on methods described by **Iwuoha and Kalu (1995)**. Briefly, 2 g of yellow konjac flour was mixed with 10 mL of HCl and 190 mL of distilled water, followed by heating at 100 °C for 1 h. The mixed solution was cooled and diluted with distilled water to 250 mL using a volumetric flask. The mixture was filtered and divided into two portions. Each filtrate portion was added with 4 drops of indicator methyl red and ammonium hydroxide (NH_4OH) until the color turned yellow. Then, it was reheated until it reached 90 °C, cooled, and filtered again. Each final filtrate was reheated until it reached 90 °C, and 10 mL of 5% $CaCl_2$ was added. The mixed solution was stored at 5 °C overnight. Each filtrate was centrifuged at 8000 rpm for 15 min to obtain pellets. The pellets were dissolved in 10 mL of 20% H_2SO_4 to obtain 10 mL of filtrate from each filtrate. The two filtrates were mixed and diluted with distilled water to 250 mL using a volumetric flask. 125 mL of mixed filtrate solution was then heated to almost boiling and titrated with 0.05 M standardized $KMnO_4$ to form a pink color and persisted for 30 seconds. The calcium oxalate content in yellow konjac flour was calculated by Eq. 1.

$$Calcium\ Oxalate\ Content\ (\%) = \frac{T \times (Vme)(Df) \times 10^5}{(ME) \times Mf \times 1000} \quad (1)$$

Where: T is the volume of $KMnO_4$ used for titration (mL), V_{me} is the equivalent mass volume (1 cm^3 0.05 M $KMnO_4$ equivalent to 0.0025 g anhydrous oxalic acid), Df is a dilution factor, ME is the molar equivalent of $KMnO_4$ solution (0.05), and Mf is the mass of the yellow konjac flour (g).

A B C

Figure 1 The yellow konjac plants (*Amorphophallus muelleri* Blume) (A), Yellow konjac tubers (B), and the optimum of polished yellow konjac flour (OPYKF) (C).

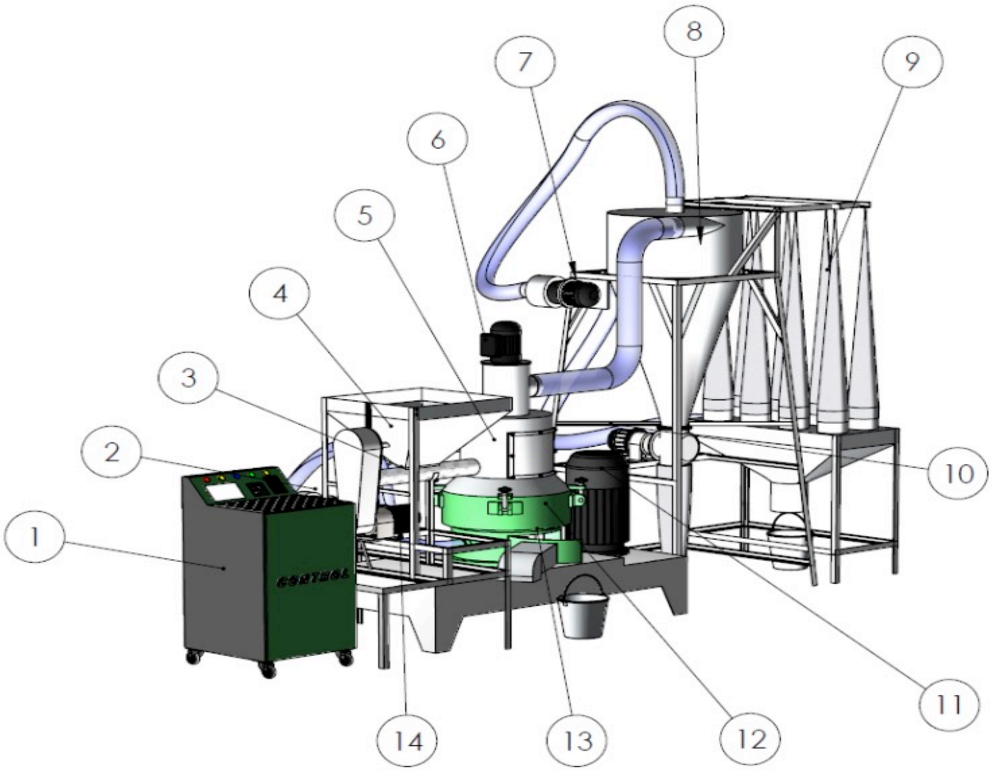

Figure 2 The schematic drawing for centrifugal Mill (1) control panel, (2) suction blower, (3) screw feeder, (4) hopper input, (5) milling room, (6) fan blower, (7) blower cyclone, (8) cyclone separator, (9) dust collector, (10) motor for valve drive, (11) 3-phase motor, (12) milling room, (13) rotors, and (14) screw feeder motor.

Determination of Viscosity

A solution (1% w/v) of yellow konjac flour was mixed using a constant temperature water-bath (75 °C) (Memmert, Germany) with a constant agitation speed (150 rpm) until perfectly hydrated **(Liu et al., 2002)**. The measurements were performed at room temperature using an NDJ-1 rotational viscometer with 12 rpm stirring speed and the spindle number 4 **(Witoyo et al., 2020)**.

Determination of Degree of Whiteness (DoW)

Yellow konjac flour color was evaluated using Minolta CR-10 (Minolta, Japan). The yellow konjac flour's surface was monitored and expressed as Hunter value (L, a, and b). The DoW was calculated based on measured Hunter value using Eq. 2 **(Witoyo, Widjanarko and Argo, 2019)**.

$$\text{Degree of Whiteness} = 100 - \sqrt{(100-L)^2 + a^2 + b^2} \qquad (2)$$

Determination of Glucomannan Content

With D-glucose as a standard curve, the spectrophotometric method was used to determine the glucomannan content in the yellow konjac flour **(Chua et al., 2012)**. In brief, 200 mg of yellow konjac flour sample was dissolved in 50 mL of NaOH-formic acid buffer, and mixed overnight at room temperature. The mixture was dissolved using a NaOH-formic acid buffer to 100 mL using a volumetric flask, and followed by centrifugation for 4000 rpm for 15 minutes to obtain glucomannan extract. The glucomannan hydrolyzate was obtained by hydrolyzing 5 mL of glucomannan extract with sulfuric acid (2.5 mL, 3 M), followed by boiling for 1.5 h in a water-bath. The mixture was cooled and added with NaOH solution (2.5 mL, 6M). The mixture was diluted again to 25 mL in a volumetric flask using distilled water. The absorbance of both the glucomannan extract and hydrolyzate was measured using a spectrophotometer at 540 nm. Compared with the D-glucose standard curve to obtained the glucose content (mg) in both samples. The calculation of glucomannan content (% d.b.) was following Eq. 3.

$$\text{GM content (\% d.b.)} = \frac{0.9 \times (5T - T_0) \times f}{m \times (100 - w)} \times 100 \qquad (3)$$

Where: m is the mass of yellow konjac flour (mg), w is water content in yellow konjac flour (%), T_o is glucose content in yellow konjac flour extract (mg), T is glucose content in yellow konjac flour hydrolysate (mg), and f is dilution factor.

All physicochemical properties of 13 samples of polished yellow konjac flour (calcium oxalate content, viscosity, DoW, and glucomannan content) were analyzed in duplicate, as shown in Table 3.

Experimental Design and Statistical Analysis

The CCD-RSM was applied in the polishing process of MMYKF using the centrifugal mill. At the same time, the MMYKF mass and polishing cycle were the independent variables. Following the report by **Witoyo et al. (2020)**, this study's central point was 12.5 kg with five times for MMYKF mass and polishing cycle, respectively. The range of independent variables used in this study is shown in Table 1. Physicochemical data of 13 randomized polishing processes were analyzed using Design-Expert 10 trial versions (State Ease, Inc.) based on multivariate analysis. The quadratic equation was used to calculate non-linear models of the observed system **(Faridah and Widjanarko, 2013)**, as shown in Eq 4. The appropriate model was determined based on R^2, adjusted R^2, lack of fit, and *p*-value of the model from the Design-Expert program's calculation **(Sugiono et al., 2019)**. The verification (Table 6) was carried out with three replications under the optimum polishing conditions prediction from the laboratory's Design-Expert program. The software predictions and verification data were analyzed and compared by paired T-test using Minitab 17 (Stat View, USA) to determine the optimum polishing conditions' accuracy.

$$Y = \beta_0 + \sum_{i=1}^{2} \beta_i X_i + \sum_{i=1}^{2} \beta_{ii} X_i^2 + \sum_{i=1,j=2}^{k-1,k} \beta_{i,j} X_i X_j + \varepsilon \qquad (4)$$

Where ε is a random error, k is the number of independent parameters, X_i and X_J are the coded independent variables of MMYKF mass and polishing cycle, β_0, β_i, β_{ii}, and β_{ij} are the regression coefficients of the intercept, linearity, quadratic, and interaction of the treatment, respectively, and Y is the observed response.

RESULTS AND DISCUSSION

Time of Polishing

The polishing time of each run of polishing is shown in Table 2. Table 2 shows that the MMYKF mass and number of polishing cycles increased the time of polishing. The longest polishing time was found at MMYKF mass of 15 kg and a polishing cycle of seven times with 59.55 minutes, whereas the shorter polishing time was found at MMYKF mass of 12.5 kg and the polishing cycle of two times with 16.25 minutes.

Model Fitting and Selection

In this study, MMYKF mass (X_1) and polishing cycle (X_2) were applied to optimizing four responses of PYKF. The four PYKF responses were calcium oxalate, viscosity, DoW, and glucomannan content (Table 3). The selection model was evaluated for each response by the R^2, adjusted R^2, lack of fit, and *p*-value. Considering the criteria, the quadratic model was suitable and adequate to represents data from all responses of PYKF with a *p*-value <0.05. Table 4 shows the fitting model, coefficient regression, and significance of the second polynomial order for all responses. The R^2 of quadratic models were 0.9680, 0.9647, 0.9469, and 0.9808 for calcium oxalate, viscosity, degree of whiteness, and glucomannan content, respectively. Moreover, the adjusted R^2 value for calcium oxalate, viscosity, DoW, and glucomannan content in the sequence were 0.9452, 0.9394, 0.9090, and 0.9672. The higher R^2 and adjusted-R^2 indicated the quadratic model's adequacy to explain all response data **(Mohapatra and Bal, 2010)**. Moreover, for all responses the lack of fit ($p \geq 0.05$) values were calculated, indicating that the quadratic model was adequate to predict all observed responses **(Faridah, 2016; Mohapatra and Bal, 2010)**. The lack of fit for calcium oxalate, viscosity, DoW, and glucomannan responses were 0.7053, 0.3746, 0.2652, and 0.0521, respectively.

Table 1 Range of polishing process.

Independent Variable	Unit	-α	-1	0	+1	+α
Micro-mill Milled Yellow Konjac Flour (MMYKF) Mass	Kg	8.96	10	12.5	15	16.04
Polishing Cycle	Number of cycles	2	3	5	7	8

Table 2 The total time polishing each run.

Std	Run	Actual Variable		Coded Variable		Total time of polishing (Minutes)
		MMYKF Mass (Kg)	Polishing Cycle (Number of cycles)	X_1	X_2	
2	1.	15.00	3.00	1.00	-1.00	27.62
13	2.	12.50	5.00	0.00	0.00	37.77
8	3.	12.50	8.00	0.00	1.41	57.78
12	4.	12.50	5.00	0.00	0.00	37.00
1	5.	10.00	3.00	-1.00	-1.00	17.88
5	6.	8.96	5.00	-1.41	0.00	24.57
10	7.	12.50	5.00	0.00	0.00	37.35
6	8.	16.04	5.00	1.41	0.00	46.92
4	9.	15.00	7.00	1.00	1.00	59.55
3	10.	10.00	7.00	-1.00	1.00	38.53
7	11.	12.50	2.00	0.00	-1.41	16.25
11	12.	12.50	5.00	0.000	0.000	36.97
9	13.	12.50	5.00	0.000	0.000	37.77
Ver.*	Ver.*	10.00	6.00	-1.00	0.586	35.56 ±0.35

Note: * Ver. means: Verification experiments.

The Effect of Independent Variables on Physicochemical Properties of PYKF

Calcium Oxalate

Calcium oxalate is one of the non-glucomannan components that is surrounding glucomannan cell granules and is toxic when consumed; thus, it needs to be removed. Calcium oxalate content in PYKF ranged from 0.45 to 1.12 % w.b. The present study results were higher than the data reported by **Faridah (2016)** and lower than the research data by **Witoyo, Widjanarko and Argo (2019)**. In this study, calcium oxalate was affected merely by the number of polishing cycles, as illustrated in Figure 3A. Calcium oxalate content decreased quadratically as a function of the polishing cycle increased. The decrease of calcium oxalate might be caused by erosion of non-glucomannan compounds covering the surface of yellow konjac flour granule during the polishing process, due to the frictional force between the rotor on the centrifugal mill and yellow konjac flour, and between yellow konjac flour, followed by the continuous fractionation process during the process **(Witoyo et al., 2020)**. According to **Nurhasanah, Antarlina and Syah (2017)** and **Nurhasanah et al. (2019)**, the polishing process can reduce the anti-nutritional compounds (tannins) in whole sorghum grains. **Wachyuningsih (2011)** stated that polishing yellow konjac flour using an abrasive polisher reduces the calcium oxalate in yellow konjac flour. Moreover, the calcium oxalate of PYKF was not affected by the MMYKF mass.

Viscosity

Viscosity is one of the important indicators in the utilization of yellow konjac flour in various applications, particularly in food products, as thickening agents, gelling agents, stabilizers, emulsifiers **(Impaprasert, Borompichaichartkul and Srzednicki, 2014)**, and fat replacers **(Jiménez-Colmenero et al., 2013)**, which require high viscosity. The viscosity of PYKF was in the range of 11.125 – 20.750 cP. This data was higher than the data reported by **Faridah (2016)** and lower than the data reported by **Xu et al. (2014)**. The data finding indicated the PYKF included in the second the first-grade classification for common konjac flour, which the Ministry of Agriculture issued, People's Republic of China **(Liu et al., 2002)**. The polishing cycle performed a quadratic effect on PYKF viscosity, as illustrated in Figure 3B. The PYKF viscosity increased five times in the polishing cycle and decreased afterward.

Table 3 Physicochemical properties of Polished Yellow Konjac Flour (PYKF) using CCD-RSM.

Std	Run	Actual Variable		Coded Variable		Responses			
		MMYKF Mass (Kg)	Polishing Cycle (Number of cycles)	X_1	X_2	Calcium Oxalate (% w.b)	Viscosity (cP)	DoW	Glucomannan Content (% d.b.)
2	1.	15.00	3.00	1.00	-1.00	0.95	15375.00	60.37	64.38
13	2.	12.50	5.00	0.00	0.00	0.73	19125.00	61.41	69.18
8	3.	12.50	8.00	0.00	1.41	0.45	17500.00	62.38	66.04
12	4.	12.50	5.00	0.00	0.00	0.61	20750.00	61.83	69.92
1	5.	10.00	3.00	-1.00	-1.00	0.89	15750.00	61.01	64.98
5	6.	8.96	5.00	-1.41	0.00	0.61	20125.00	61.78	69.19
10	7.	12.50	5.00	0.00	0.00	0.61	20125.00	61.71	69.65
6	8.	16.04	5.00	1.41	0.00	0.73	19750.00	61.65	68.84
4	9.	15.00	7.00	1.00	1.00	0.56	17843.75	61.80	66.59
3	10.	10.00	7.00	-1.00	1.00	0.50	18875.00	62.34	67.34
7	11.	12.50	2.00	0.00	-1.41	1.12	11125.00	59.94	60.72
11	12.	12.50	5.00	0.000	0.000	0.61	20500.00	61.78	69.63
9	13.	12.50	5.00	0.000	0.000	0.67	19875.00	61.84	69.43

Table 4 Fitting model, coefficient regression and significance of second polynomial order for PYKF's responses.

Coefficient Regression	Calcium Oxalate (% w.b.)	Viscosity (cP)	DoW	Glucomannan (% d.b.)
Intercept, β_0	+0.65	+20075.00	+61.71	+69.56
Linear				
β_1 (MMYKF Mass)	+0.034^{ns}	-242.07^{ns}	-0.17^{ns}	-0.23^{ns}
β_2 (Polishing Cycle)	-0.22*	+1826.17*	+0.77*	+1.51*
Quadratic				
β_1^2	+0.011^{ns}	-109.77^{ns}	-0.014^{ns}	-0.37^{ns}
β_2^2	+0.067*	-2922.27*	-0.29*	-3.18*
Interaction				
β_{12}	+7.752E-005^{ns}	-164.06^{ns}	+0.024^{ns}	-0.039^{ns}
Fitting Model				
R^2	0.9680	0.9647	0.9469	0.9808
Adjusted R^2	0.9452	0.9394	0.9090	0.9672
Lack of Fit	0.7053^{ns}	0.3746^{ns}	0.2652^{ns}	0.0521^{ns}
P-value	<0.0001	<0.0001	0.0003	<0.0001

Note: *significant, ^{ns}not significant. Equation: $\beta_0 + \beta x_1 + \beta x_2 + \beta_{12}x_1x_2 + \beta_1 x_1^2 + \beta_2 x_2^2$.

In the study, glucomannan content affected the PYKF's viscosity. The higher the glucomannan content in PYKF the higher viscosity of its. Based on **Faridah (2016)** and **Wardhani et al. (2016)**, viscosity is positively correlated with glucomannan enclosed in yellow konjac flour. **Ryan, Yuan and Crosby (2004)** added that glucomannan had a higher viscosity than other polysaccharides at the same concentration. Besides, the MMYKF mass had not affected the viscosity of PYKF.

Degree of Whiteness (DoW)

The DoW of PYKF was in the range of 59.94 – 62.38. This result was lower than the results reported by **Impaprasert, Borompichaichartkul and Srzednicki (2014)** and higher than data reported by **Witoyo, Widjanarko and Argo (2019)** and **Witoyo et al. (2020)**. The DoW of PYKF was merely affected by the polishing cycle, as illustrated in Figure 3C. The polishing cycle provided a positive quadratic trend to PYKF's DoW. Decreasing impurity (non-glucomannan) components covering yellow konjac flour granules during the polishing process increase PYKF DoW. This result was consistent with the previous study by Nurhasanah and her team who claimed that the polishing process can increase the DoW of sorghum using abrasive polishing machines or modification of polishing machines with three-cylinder levels **(Nurhasanah, Antarlina and Syah, 2017; Nurhasanah et al., 2019)**. **Reddy et al. (2017)**, and **Paiva et al. (2016)** noted that improving color or DoW was closely related to the reduction of certain impurities during the milling process. **Witoyo et al. (2020)** reported that that the content of non-glucomannan compounds, such as proteins, fat, calcium oxalate, and starch had decreased during the polishing process of yellow konjac flour. However, in the present study, the MMYKF mass had a not significant effect on PYKF's DoW.

Glucomannan Content

Glucomannan is the most important parameter to determine the quality of yellow konjac or konjac flour based on international standards. According to the international standard for konjac flour, particularly concerning common konjac flour, glucomannan is divided into three classes, namely top-grade, first-grade, and second-grade with glucomannan content ≥75%, ≥65%, and ≥60% d.b, respectively **(Liu et al., 2002)**. Based on these standards, PYKF is ranking second in the category of first-grade common konjac flour with glucomannan content in the range of 60.72 – 69.92% d.b. This result is lower than KGM content by wet extraction from yellow konjac flour, as reported by **Impaprasert, Borompichaichartkul and Srzednicki (2013); Wardhani et al. (2016)** and similar to **Faridah, Widjanarko and Sutrisno (2011)** study.

In the present study, the polishing cycle affected glucomannan content. The number of polishing cycles exerted a quadratic effect on the glucomannan response, as shown in Figure 3D. The increase of the number of polishing cycles to five enhanced the glucomannan content, then decreased subsequently. The increased number of polishing cycles reduces distinct compounds, such as calcium oxalate, starch, protein, and other impurities surrounding the glucomannan cells in yellow konjac flour, due to friction between rotors of the centrifugal mill and flour as well as between the flour particles. According to **Witoyo et al. (2020)**, the polishing process destroys non-glucomannan compounds on the glucomannan cell surface in yellow konjac flour. Subsequently, the non-glucomannan components were detached and separated from glucomannan granules using a cyclone separator. Moreover, glucomannan content decreased after polishing treatment under the optimum conditions due to attrition of larger glucomannan particles that turned into fine particles and were eliminated in the cyclone separator. This finding was supported by **Faridah, Widjanarko and Sutrisno (2011)** and **Wachyuningsih (2011)** after milling yellow konjac chips using the stamp mill, and polishing yellow konjac flour using an abrasive polisher, respectively. Furthermore, the MMYKF mass had not affected the glucomannan of PYKF.

Optimization and Verification of Prediction

Polishing parameters were optimized to produce PYKF (Figure 1C) with high viscosity, DoW, glucomannan content, and low calcium oxalate content by using the centrifugal mill. The independent variables and response criteria to achieve the desired characteristics of PYKF are compiled in Table 5. The predicted optimum polishing condition was obtained at 10.00 kg and 6.17 polishing cycles (Table 6), with the following characteristics: 0.52 ±0.00% w.b. calcium oxalate, 20362.00 ±16.00 cP viscosity, 62.22 ±0.01 DoW, and 69.43 ±0.02% d.b. glucomannan content with desirability value of 0.927 (Figure 3E). The verification with modified conditions (Table 6) obtained the following characteristics: 0.56 ±0.05 % w.b. calcium oxalate, 20208.00 ±564.00 cP viscosity, 62.16 ±0.29 DoW, and 68.18 ±1.28% d.b. glucomannan content. Consequently, the verification data revealed no significant differences (p-value >0.05) for all responses compared to predicted values. This shows that the quadratic model was accurate and appropriate for optimizing yellow konjac flour polishing using the centrifugal mill **(Mohapatra and Bal, 2010)**. The desirability value of 0.927 expressed the prediction accuracy of the optimum polishing conditions equivalent to 92.70%.

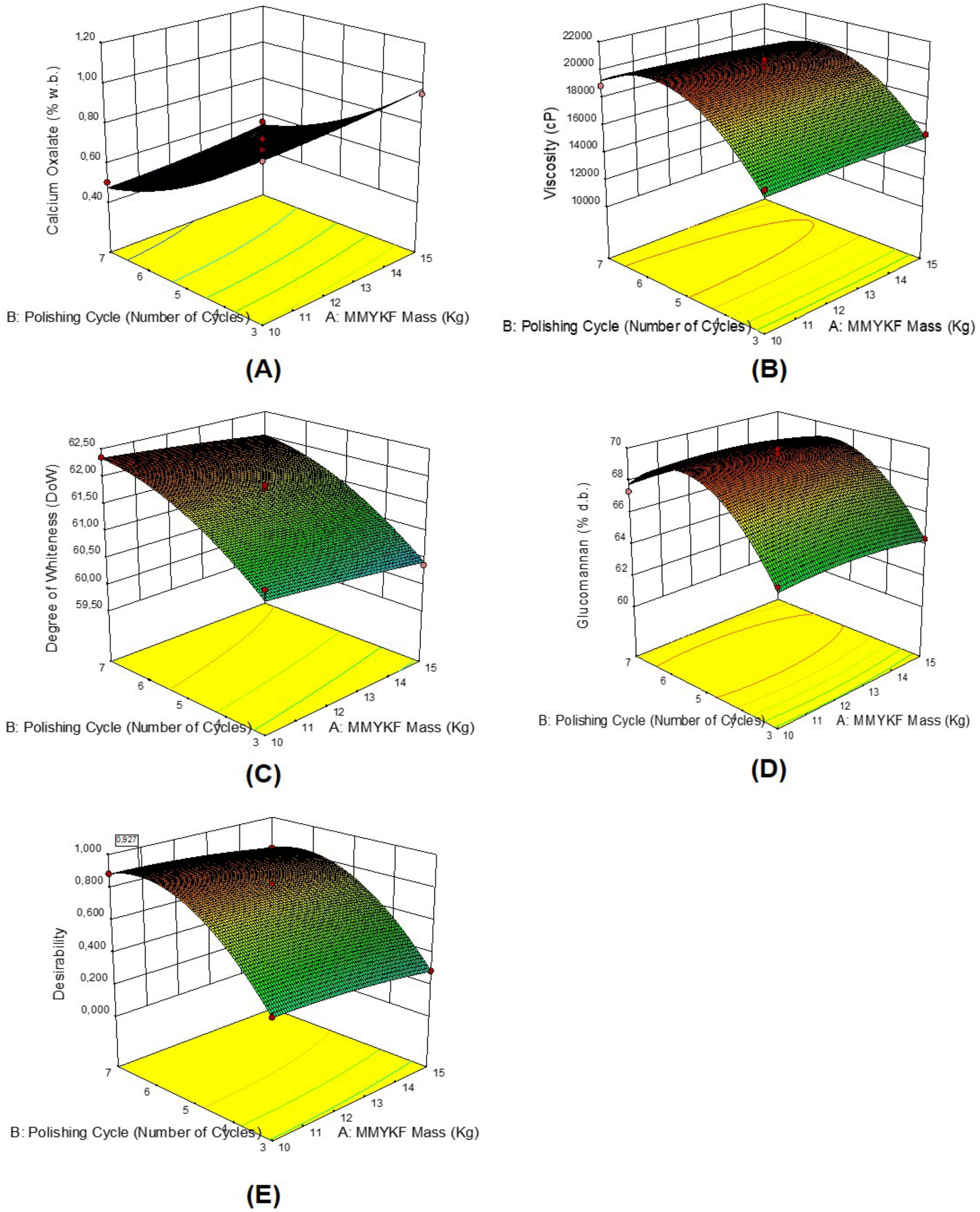

Figure 3 The 3D-surface plot of calcium oxalate (A), viscosity (B), DoW (C), and glucomannan (D), and desirability of the optimum conditions (E) as affected by MMYKF mass and polishing cycle.

Table 5 The independent variables, and responses criteria for polishing optimization.

Constraints	Goal	Lower Limit	Upper Limit	Importance
Independent Variable				
MMYKF Mass	Is within range	10	15	3
Polishing Cycle	Is within range	3	7	3
Response				
Ca-Oxalate	Minimize	0.45	1.12	3
Viscosity	Maximize	11125	20750	3
DoW	Maximize	59.94	62.38	3
Glucomannan	Maximize	60.72	69.91	3

Table 6 The comparison of the software prediction and actual verification for all PYKF responses.

	MMYKF Mass (Kg)	Polishing Cycle (Number of cycles)	Calcium Oxalate (% w.b.)	Viscosity (cP)	DoW	Glucomannan (% d.b)	Desirability
Software Prediction	10.00	6.17	0.52 ±0.00	20362.00 ±16.00	62.22 ±0.01	69.43 ±0.02	0.927
Verification	10.00	6.00	0.56 ±0.05	20208.00 ±564.00	62.16 ±0.29	68.18 ±1.28	-
	P-Value		0.305	0.678	0.791	0.219	-

CONCLUSION

The optimization of yellow konjac flour polishing using a centrifugal mill was successfully investigated. In the present study, all responses of PYKF were only affected by the number of polishing cycles. The quadratic model represented all the responses of PYKF, with R^2 ≥0.94, and *Adjusted*-R^2 ≥0.90. The optimum polishing condition using a centrifugal mill was obtained at MMYKF mass of 10 kg and six polishing cycles, with characteristics as follow: 0.56 ±0.05% w.b. calcium oxalate, 20208 ±564 cP viscosity, 62.16 ±0.429 DoW, and 68.18 ±1.28% d.b. glucomannan content. As a result, polishing using a centrifugal mill appears feasible and promises to be scaled up to industrial scale for yellow konjac flour polishing before the wet extraction process.

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Conflict of Interest:

The authors declare no conflict of interest.

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