The Optimization Of Rice Flour Cross-Linking With Gluten To Improve The Dough Quality Of Rice Flour

Sapta Raharja, Ono Suparno, Faqih Udin, Farah Putri Listyaningrum, Ani Nuraisyah

Abstract: Crosslink between gluten and rice flour is to get rice flour with better dough quality. Thus, the objective of this research was to obtain the optimal treatment combinations in cross-linked rice flour with gluten from two different variable factors which would be gluten concentration (X_1) and heating temperature (X_2) by utilizing Response Surface Methodology (RSM). The response variables that were analyzed to determine the optimal condition were protein content, swelling power, baking expansion, gelatinization point, water absorption, and decanted water protein content. The supporting tests for this research were also done that are FTIR, birefringence and amilograph. The optimum conditions were determined which heating temperature 45.11 °C and gluten concentration at 27.38%. The average characteristics of rice-gluten flour were protein content 18.03%, decanted water protein content 0.26%, water absorption 0.595 ml/g, gelatinization point 74.27 °C, swelling power 5.89 b/b and baking expansion 2.06 ml/g. Birefringence properties of rice flour - gluten is not noticeable compared to rice flour. The FTIR analysis of rice flour - gluten shows a strengthening of the C - N bond spectrum peak at a wavelength of 1155.22 cm^{-1} which from the C bond of rice flour and N of gluten protein. Analysis of amylograph of rice flour - gluten showed peak viscosity value 1060 cP, viscosity damage 2058 cP, and viscosity setback 1083 cP.

Index Terms: baking expansion, crosslinking, gluten concentration, heating temperature, rice flour, RSM

1 INTRODUCTION

The use of rice flour as raw material for the food industry has been widely used, but its use is not as much as wheat flour. The thing that makes rice flour different from wheat flour is gluten protein content. Gluten on wheat has a key role in determining the quality of dough, cohesiveness, and water absorption capacity. Flour dough can be elastic, strong, and easy to expand in the presence of gluten so it has good baking properties [1]. In an effort to increase the quality of rice flour and the reduction of wheat import to Indonesia, the binding of gluten to rice flour is applied. Rice binder crosslinks with phosphorus oxychloride (POCl3) showed changes in physical, chemical, and functional properties of rice flour [2]. Research conducted about the cross-link between sago starch with gluten is also a reference in this study. The study showed that the bond between sago starch and gluten can improve the quality of sago starch dough [3]. This study aims to optimize the gluten crosslinking process in rice flour to improve the functional characteristics of rice flour using Surface Response Method.

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2 RESEARCH METHODOLOGY

This research used rice flour, gluten meal, and $CaCl_2$. Tools used include water bath, a set of agitators, blower dryers, thermometers, and cup glass. The binding of gluten to rice flour is carried out in a reactor consisting of a cup of glass, a stirrer of iron, an agitator, and a waterbath as a heat source. Gluten with a predetermined concentration (10, 15, 20, 25, and 30% of rice flour) was added as much as 1.2 times by weight of rice and gluten meal blends. The mixture was stirred using an agitator at a rate of 50 rpm and with a predetermined temperature (45, 50, 55, 50, 65 °C). $CaCl_2$ concentration of 2% with a volume equivalent to the weight of the rice and gluten meal blends was added to the suspension. Stirring is continued for up to 10 minutes at a predetermined temperature. The suspension is further decanted at room temperature to separate the deposition of gluten-rice flour with water. The gluten-rice flour mixture is then dried in an oven blower for 16-18 hours at 60 °C. The experimental design used was RSM (Response Surface Methodology). The experimental design used was CCD (Central Composite Design) with two factors: gluten concentration (X_1) and heating temperature (X_2). Response variables were sweliing power (Y_1), baking expansion (Y_2), gelatinization temperature (Y_3), protein content (Y_4), water absorption (Y_5), decantation water protein content (Y_6). Further data is processed with Design Expert 7.

3 RESULTS AND DISCUSSIONS

Determination of Temperature and Gluten Concentration as a Central Point Optimum temperature and gluten concentration can be determined from the swelling power and baking expansion results. The correlation between gluten concentration, swelling power and baking expansion are presented on Figure 1a, while the correlation between heating temperature, swelling power and baking expansion are presented on Figure 1b. Based on Figure 1a, the optimum point of gluten concentration in 55 °C was at 25% concentration resulting 5.69 (b/b) of swelling power and 2.56 (b/b) of baking expansion. Furthermore according to Figure 1b, the optimum point of heating temperature with 25% concentration was at 45 °C with 4.47 (b/b) of swelling power and 1.71 (b/b) of baking expansion.

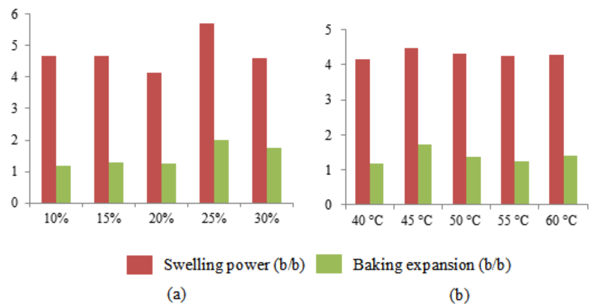

***Fig.1** Correlation between gluten concentration, heat temperature, swelling power result and baking expansion result*

Rice – Gluten Flour Characterization

Protein Content

In analysis of variance (ANOVA), each factor influence on protein content response was known. The most significant factor influencing the protein content was gluten concentration with p-value "Prob> F" smaller than 0.05 (<0.0001). The heating temperature also affected the protein content response because p-value was less than 0.05 (0.0043).

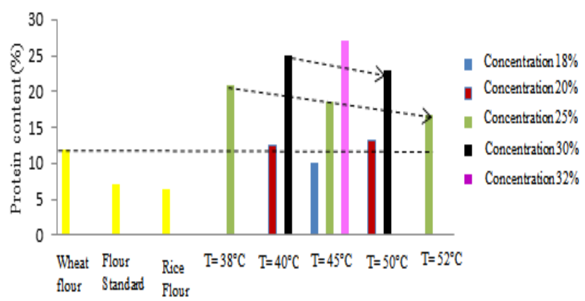

Fig.2 Protein content of wheat flour, rice flour, and rice flour - gluten

Swelling Power

The recommended polynomial model was quadratic. The R^2 value of swelling power response was 0.8864. Equation of polynomial model of power swelling response in its actual form was as followed:

Swelling power (Y) = $-33.48036 + 0.70518X_1 + 1.31566X_2 + 5.60000E\text{-}003X_1X_2 – 0.018225X_1^2 – 0.015725X_2^2$

The result of gluten rice flour swelling power test was from the range of 4.92 - 6.62 (b/b) with the average value of 5.898 (w/w). Swelling power of gluten-rice flour produced was higher than swelling power of rice flour which was equal to 5.12 (b/b) but still slightly lower compared to medium protein flour (12%) i.e. 6.12 (w/w). Swelling power is influenced by the amylose and amylopectin ratio, chain length, and molecular weight distribution. When amylopectin level is lower than amylose, starch will be dry, less adhesive, and tend to absorb much water (hygroscopic) [4]. The greater the swelling power, the more water is absorbed during the cooking process, that is related to the amylose and amylopectin level in the flour. The amylose and fat component can inhibit swelling power and long chains of amylopectin could increase swelling power [5]. In a food product, amylopectin stimulates the process of blooming (puffing) in which starch food products whose high amylopectin content would be mild, porous, crunchy, and crunchy[6].

Water Absorption

The recommended polynomial model was quadratic. The R^2 value of water absorption response was 0.8838. Equation of polynomial model of power swelling response in its actual form was as followed:

Water absorption (Y) = -2.05103 + 4.80330E-003 X1 + 0.11543 X2 + 0.00X1 X2 + 7.00000E-005 X12 – 1.33000E-003 X22

One of the determinants of the bread quality is the volume of water used in the making of the dough. Water plays an important role in the formation of dye viscoelasticity properties, through the formation of disulfide and ionic bonds between protein components [7]. If the water added is few then interaction between components will be inhibited. However, if the water added is excessive, the dough component interactions will be damaged [8]. The addition of water in the right amount can form a dough with optimum viscoelasticity properties. The water absorption capacity of a flour or starch may varies. It influences the volume difference of water required, thus in order to compare the quality of the flour it is necessary to figure the water volume acceptable to the flour, especially when a mixture of two or more different flours is used. The result of gluten-rice flour absorption capacity was 0.51 - 0.68 ml/g and the average of 0.59 ml/g which was higher than the absorption of rice flour water of 0.51 ml/g and higher than the water absorption wheating flour medium protein (12%) of 0.36 ml/g.

Baking Expansion

The recommended polynomial model was quadratic. The R^2 value of baking expansion response was 0.8403. Equation of polynomial model of power swelling response in its actual form was as followed:

Baking expansion (Y) = -0.75151 + 0.040149 X1 + 0.10339X2 + 1E-003 X1 X2 – 1.40500E- 003 X12 – 1.50500E-003 X22

The result of gluten-rice flour baking expansion was from the range of value of 1.89 - 2.17 (ml/g) with an average value of 2.059 (ml/g), higher than the value of baking expansion of rice flour which was 0.98 (ml/g) but still slightly lower than the baking expansion of medium protein wheat flour (12%), i.e. 2.31 (ml/g). Contour graph of baking expansion value is shown in Figure 3c. The increased value of baking expansion in gluten-rice flour compared to rice flour indicated that gluten content plays an important role in determining baking expansion. In a food product, in this case the bread, baking expansion is the ability of bread to increase in size after the steaming process. Good bread is bread that has a volume increase of minimum twice the initial volume and has hollow bread texture. The cavities contained in the bread are the gases formed from the fermentation [9].

Gelatinization temperature

The recommended polynomial model was quadratic. The R^2 value of gelatinization temperature response was 0.8403. Graph of contour of gelatinization temperature value was shown in Figure 3d Equation of polynomial model of power swelling response in its actual form was as followed:

Gelatinization Temperature (Y) = $-81.72462 + 6.05607 X_1 + 3.32607 X_2 - 0.04 X_1 X_2 - 0.083 X_1^2 - 0.023 X_2^2$

The result of gluten-rice flour gelatinization temperature test was range of 70-77 °C value with the average value of 74.27 °C. This value was higher than the rice flour gelatinization temperature i.e. 69 °C. The number of amylose-amylopectin fraction greatly influences the starch gelatinization profile [10]. When starch and water are heated above the gelatinating temperature, the starch granules containing higher amylopectin will swell larger than those with low content. The difference in starch gelatinization temperature is also influenced by the distribution of starch granules weight [11]. The heating process duration during the binding stage causes swelling on starch and pregelatinization process occurs so that the gelatinization temperature of gluten-rice flour is higher than rice flour. The addition of gluten to the rice flour also causes an increase in the gelatinization temperature, it is because heating energy is also needed to gelatinize gluten so that the required energy is greater and the temperature of gelatinization is higher.

Protein Content of Decant Water

The recommended polynomial model was quadratic. The R^2 value of decant water protein content was 0.94. Contour graph of decant water protein content was shown in Figure 3e. Equation of polynomial model of power swelling response in its actual form was as followed:

Decant water protein content (Y) = +14.69545 + 5.69975E-003X1 – 0.65683X2 – 3.00000E-004X1X2 + 3.10000E-004X12 + 7.41000E-003X22

The result of decant water protein content test was the range of values 0.09% - 0.56% with an average value of 0.26%. Decant water protein content level indicates the presence of protein lost during the binding process. Loss of protein in the flour occurs during decant water deposition and drying in the blower oven. The test results showed the value of decant water protein content was higher along with increasing gluten concentration and decreasing heating temperature. This was due to the increased concentration of gluten added to the rice flour which is in line with the increased volume of the base solvent used so that the decant water protein content increases. Heating can damage the protein content contained in the dough so that the protein content decreases.

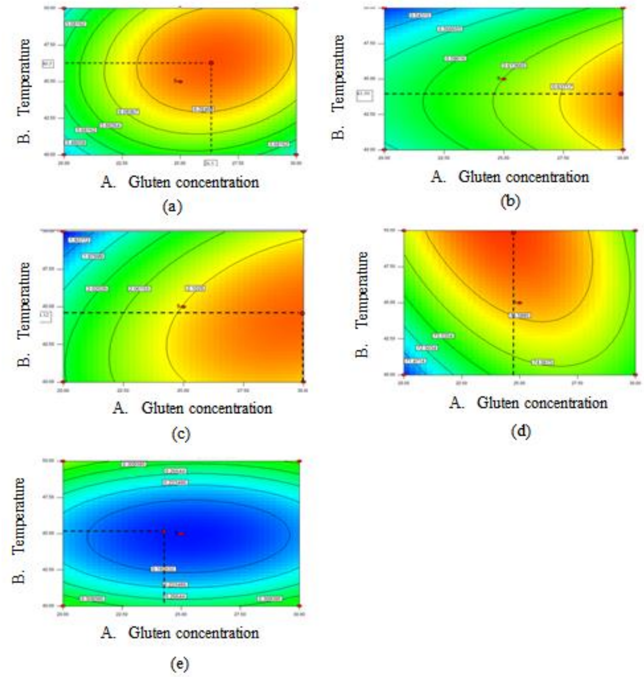

Fig.3 *Graph of gluten-rice gluten-surface contour response to gluten concentration and heating temperature (a) swelling power, (b) water absorption, (c) baking expansion, (d) gelatinization temperature, and (e) protein content of decant water*

Fourier-Transform Infrared Spectroscopy (FTIR) Analysis

Infrared spectrum testing was performed to determine the changes and formation of new functional groups on flour after binding with gluten [12]. This analysis were conducted on rice flour and rice flour-gluten 45 °C and 27% concentration. The infrared spectral absorption frequency table contained in the sample is presented in Table 6.

Table 6. *Intercellation of infrared spectrum peak*

Sample	Wave number (cm^{-1})				
	O-H	C-H	N-H	C=O	C-N
	3200-3600 (cm^{-1})	2840-3000 (cm^{-1})	2360-2380 (cm^{-1})	1630-1695 (cm^{-1})	1020-1250 (cm^{-1})
Rice flour	3385.64	2930.50	2150.71	1650.01	1155.48
Rice flour - gluten	3393.27	2929.29	2154.20	1655.52	1155.22

The results of infrared spectrum analysis of rice flour and gluten rice flour were five spectrum peaks that can represent functional groups in the sample. The spectrum showing the presence of O-H groups in the wavelength range 3385.64-3393.27 cm^{-1}, C-H at 2929.29-2930.50 cm^{-1}, N-H at the range of 2150.71-2154.20 cm^{-1}, C=O in the range of 1650.01-1655.52 cm^{-1}, and C-N at the range 1155.48-1155.22 cm^{-1}. Based on both samples it could be seen that the O-H group of gluten-rice flour has decreased transmittance compared to rice flour. The decrease in transmittance percentage indicates the strengthening of the O-H bond on gluten-rice flour which indicates an increase in water content. The water content of rice flour is 10.17%, while the average water content of gluten rice flour is 11.02%. The C-H bond peak on rice flour is seen at 2930.50 cm^{-1} wave numbers, while in gluten-rice flour is seen at wave numbers 2929.29 cm^{-1}. The C-H bond on the gluten-rice flour exhibits a decrease in transmittance percentage which indicates a hydrogen bond strengthening. The increasing quantity of C-H bonds in gluten-rice flour can be derived from the C-H bond of the amine group present in the protein in gluten. N-H bonds were seen at 2150.71 cm^{-1} wave numbers on rice flour and 2154.20 cm^{-1} on gluten-rice flour. According to the infrared spectral absorption table, the N-H bonds show the presence of an amine functional group as indicative of the protein content. N-H bonds on gluten-rice flour have decreased transmittance compared to rice flour. This proves that the protein content of gluten-rice flour increases. The presence of C = O bonds is seen in the wave number 1650.01 cm-1 in rice flour and 1655.52 cm-1 in the gluten-rice flour. The transmittance percentage of gluten-rice flour decreased compared to rice flour which indicated the strengthening of the C = O bond. According to Patriadi (2015), the increase of the carbonyl group (C = O) plays a role in the starch hydration capacity and the crosslinking process that occurs as a result of the maillard reaction. Presence of carbonyl groups contributes to the starch hydration capacity, as well as carboxyl groups (-COOH) composed of O-H, C-O, and C = O [13]. Maillard's reaction occurs because the carbonyl group reacts with the amino acid [14], while Maillard reaction occurs due to carbonyl or dicarbonyl contained in cross-linked reducing sugar with protein [15]. The visible C = O bond may be due to the protein in the gluten meal added to the rice flour. The C-N bond on rice flour is seen in wave numbers 1155.48 cm^{-1} and 1155.22 cm^{-1} in gluten rice flour. Rice-gluten flour has strengthened the C-N bond caused by the addition of gluten concentration. the C-N bond occurs through the maillard reaction when the carbonyl group (C = O) formed on starch can bind to the protein [15].

4 Conclusion

Optimum conditions of gluten binding on rice flour were gluten concentration of 27.38% and heating temperature of 45.11 °C. Validation of optimum conditions yields 18.33% protein gluten, 6.39 b/b swelling power, 2.14 ml/g baking expansion, 74 °C gelatinization temperature, 0.66 ml/g water absorption, and 0.11% decantation water protein content. Validation results did not vary much with the prediction response so it could be optimization solution suggested by the program was the best value. The nature of birefringence disappears as the temperature and the base solvent were added during the binding process. The FTIR analysis results indicated the strengthening of the C-N bonds derived from the C bonds of rice flour and N from gluten protein. Analysis of amylograph of gluten-rice flour showed an increase in gelatinization temperature and decreases peak viscosity, breakdown viscosity and setback viscosity.

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