

Effect of Dough Moisture Content and Extrusion Temperature on Degree of Gelatinization and Crystallinity of Rice Analogues

Faleh Setia Budi^{1,2,3}, Purwiyatno Hariyadi^{1,2,*}, Slamet Budijanto^{1,2} and Dahrul Syah^{1,2}

¹ Department of Food Science and Technology, Faculty of Agricultural Engineering and Technology

² Southeast Asian Food and Agricultural Science and Technology (SEAFAST) Center

³ Graduate School of Food Science, Bogor Agricultural University,
IPB Darmaga Campus, Bogor, 16680, West Java, Indonesia

Rice is one of the most important staple foods in Asia, including Indonesia. Despite great efforts to increase rice production in Indonesia, imported rice is still needed due to high per capita consumption coupled with high population growth. One approach to overcoming these problems is to prepare extruded rice analogues by using yellow corn flour (maize flour or cornmeal) and corn starch as the base material. The dough moisture content and the extrusion temperature can influence the degree of gelatinization of rice analogues, which in turn affects the hardness of the rice analogue. This research studied the effects of dough moisture contents of 35%, 40%, and 45% and extrusion temperatures of 70°C, 80°C, and 90°C on the degree of gelatinization and the crystallinity of the resulting rice analogue. Raw materials used in this study were yellow corn flour, corn starch, glycerol monostearate and water. A twin screw extruder was utilized, operating at a screw speed of 75 rpm and a feed rate of 42.2 kg of dough per hour. The degree of gelatinization of the produced rice analogue was analyzed by differential scanning calorimetry (DSC) and polarized light microscopy, and the crystallinity was analyzed by X-ray diffraction (XRD). Our results showed that the dough moisture contents and extrusion temperatures examined in this study caused the starch granules gelatinized completely (degree of gelatinization 100%). The A-type crystals of corn flour and corn starch changed into V-type crystals after being extruded into rice analogues, which may be due to the formation of lipid-amylose complex compounds.

Key words: rice analogue, extrusion, gelatinization degree, crystallinity

Introduction

In the last decade, rice production in Indonesia has increased significantly, from 54.09 million tonnes in 2004 to 71.29 million tonnes in 2013 (BPS, 2014). However, at the same time, the consumption of rice in Indonesia also increased to about 130 kg/person/year (BPS, 2012). Consequently, the amount of rice produced was not able to meet the needs of society, necessitating the government to import rice in high amounts (about 1 million tonnes). In addition to rice, Indonesia also produces other staple foods such as

maize, cassava, and sago. Production of maize and cassava reached 17.64 and 24 million tonnes, respectively, in 2011 (BPS, 2012). However, the report of Indonesian National Socioeconomic Surveys in 2009 and in 2013 showed that the rate of rice consumption was higher than that of other staple foodstuffs such as maize, cassava, and sago, while the consumption of non-rice sources such as cassava and sweet potatoes decreased from 5.53 kg/person/year and 2.24 kg/person/year in 2009 (BPS, 2009) to 3.49 kg/person/year in 2013 (BPS, 2013).

These results indicate that the Indonesian people are

Received: September 15, 2014, Accepted: May 25, 2015

* Corresponding author: Department of Food Science and Technology, Faculty of Agricultural Engineering and Technology, IPB Darmaga Campus, Bogor, 16680, West Java, Indonesia.

Tel/Fax: + 62-251-8626725, E-mail: phariyadi@ipb.ac.id

very dependent on rice and are not making sufficient use of other staple food source. This dependence is alarming and can pose the considerable risks to food security in Indonesia. Therefore, it is necessary to conduct a food diversification program to decrease the rate of rice consumption and to increase the consumption rate of other foods; however, attempts to implement food diversification programs in previous years have failed. These failures have shown that non-rice food sources need to be processed into products that have the desirable properties of rice, such as being easy to cook and being able to be prepared in various ways suitable for usage in Indonesian dishes, and which do not require any change of consuming habits (Muaris and Budijanto, 2013). Products that have properties like those of rice and are made of non-rice materials are known as rice analogues (Machmur *et al.*, 2011).

Rice analogues can be made by granulation (Katsuya *et al.*, 1971; Kurachi, 1995; Samad, 2003; Herawati and Widowati, 2009) and by extrusion (Koide *et al.*, 1999; Zhuang *et al.*, 2010). In 2011, a team of researchers at F-Technopark at Bogor Agricultural University successfully produced a rice analogue from yellow corn flour by using of hot extrusion. This opened opportunities to reduce the rice consumption and to increase the consumption of corn.

In general there are two groups of variables that greatly affect the extrusion processing (included the preparation of rice analogues from yellow corn flour). The first group comprises properties of the ingredients, including composition, moisture content, particle size, and additives. The second group comprises operating conditions, which consist of temperature, screw speed, feed rate, and cutter speed (Campanella *et al.*, 2002). Budijanto (2011) reported that different material compositions had influenced on the physical characteristics (color, density, weight of 1000 grains, and percentages of water, ash, crude fat, crude protein and total carbohydrate) and on the sensory aspects (color, odor, taste, and texture) of various rice analogues. In our previous work, different dough moisture content resulted in rice analogue with different physical characteristic such as the degree of gelatinization and hardness (unpublished result). We hypothesized that the dough moisture content and extrusion temperature would influence the degree of gelatinization of the rice analogue. We surmised that the gelatinized starch would function as a binder so that the resulting rice analogue would be not easily broken during packaging and distribution, and

that a higher degree of gelatinization would produce a stronger rice analogue. In this study, we aimed to characterize the raw materials and to assess the effects of dough moisture content and extrusion temperature on the degree of gelatinization and the crystallinity of rice analogues derived from yellow corn flour.

Method

Materials and equipment

The raw materials used for making the rice analogue in this study included yellow corn flour, corn starch, glycerol monostearate, and water. Yellow corn flour with the particle size 40 mesh (opening size 425 μm) was purchased from PT Matahari Corn Mill, Kediri, East Java, Indonesia, and corn starch with the particle size 80 mesh (opening size 180 μm) was purchased from Pd. Anugerah, Tangerang, Banten, Indonesia. The equipment used consisted of a flour mixer, a twin screw extruder (BEX-DS-2256; PT Bertindomas Ciptasatya/Berto, Tangerang, Banten, Indonesia), and a tray dryer.

Rice analogue production process

The corn flour and corn starch were mixed in a 90:10 ratio (by weight) in the flour mixer, then 2% glycerol monostearate was added and water was gradually added to get a final dough moisture content of 35%, 40%, or 45%. Mixing was continued until the mixture was homogeneous (approx. 10 min), and the dough was rested for 2 hours before putting it into the extruder hopper feeder. The die head and cutter blade were mounted and the extruder machine was turned on with an operating temperature set to 70°C, 80°C, or 90°C and the screw speed set to 75 rpm. After the extruder had reached the set temperature, the auger screw of hopper -feeder was set to 30 rpm to deliver the dough with moisture content of 40% from hopper to barrel at a feed rate of 42.2 kg of dough per hour. The arrangement of main component of extruder was illustrated in Fig. 1. Outcoming extrudate from the die was cut by a cutter blade rotating at a certain speed. After reaching a steady operating state and producing good extrudate (uniform), the product was taken to be dried. Samples of dried extrudate were collected and analyzed by using polarized light microscopy and differential scanning calorimetry (DSC) to determine the degree of starch gelatinization (Baks *et al.*, 2007) and by using X-ray diffraction (XRD) to determine the crystallinity (Vermeylen *et al.*, 2006). The flow of the rice analogue production process is shown in Figure 2.

Characterization of raw materials

The corn flour and corn starch were characterized by analyzing the moisture content (AOAC 2009, 925.10), crude ash content (AOAC 2009, 923.03), crude fat content (AOAC 2009, 920.39), and crude protein content (AOAC 2009, 960.52). The total carbohydrate content of the corn flour and corn starch was calculated by difference according to the following formula: Total carbohydrate = 100 – water content % – crude ash content % – crude protein % – crude fat %

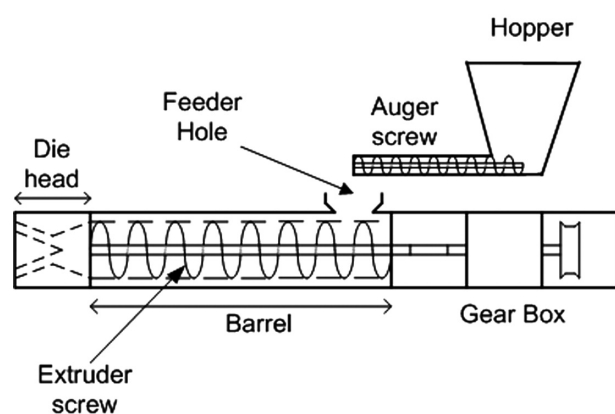


Fig. 1. The schematic of main component of extruder (BEX-DS-2256).

(FAO, 2003). The total starch content of the corn flour and corn starch was determined by the anthrone-sulfuric acid colorimetric microassay after the corn flour and corn starch were extracted and hydrolyzed into glucose (Laurentin and Edwards, 2003), amylose content was determined by the method of Williams *et al.* (1970) and the fiber content in the corn flour and corn starch was determined by using the method of AOAC 985.29 (AOAC, 2009). All chemical analyses of material were performed in duplicate and results are presented as mean values.

Differential scanning calorimetry

The thermal characteristics of the rice analogues were studied by using a Shimadzu DSC instrument (TA-60WS; Shimadzu, Tokyo, Japan). The rice analogues were ground into flour and about 3 mg was weighed into an aluminum DSC pan cell (201-53090; Shimadzu). Distilled water (10 μ L) was added by using a micropipette, and the pan cell was then sealed. The pan cell containing the sample and water was rested for 2 hours at ambient temperature to reach equilibrium before the pan cell was heated from 40°C to 120°C at 5°C /min (Gelders *et al.*, 2004). Enthalpy data obtained from the thermogram were used to calculate the degree of gelatinization (DG) with the following equation:

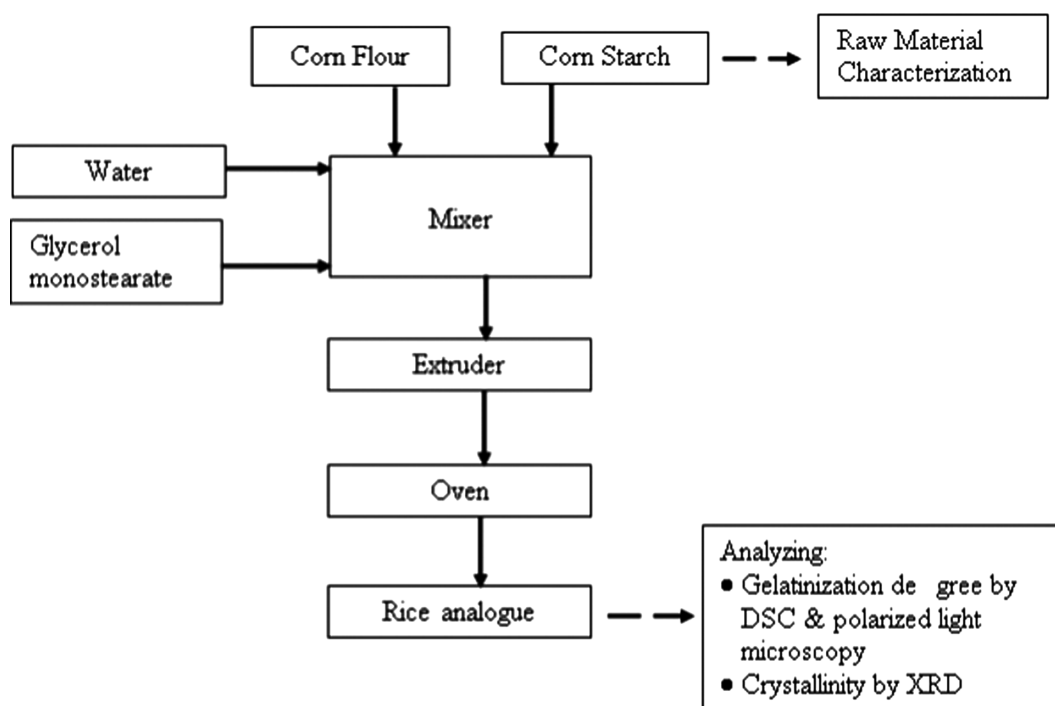


Fig. 2. Block diagram of the rice analogue production process

$$DG = [1 - (\Delta H_r / \Delta H_{\text{native}})] \times 100\% \text{ (Baks } et al., 2007)$$

Where ΔH_{native} is the gelatinization enthalpy value of untreated or unheated material and ΔH_r is the gelatinization enthalpy value of treated material.

Polarized light microscopy

The first step was to make a standard curve of degree of gelatinization versus granule concentration. A 1% starch suspension and a completely gelatinized starch suspension were prepared and mixed to obtain standard starch suspensions with gelatinization degrees of 20%, 40%, 60%, and 80%. These standard suspensions were then dropped onto a glass hemocytometer with a micropipette and were observed under polarized light (200× magnification) with an Olympus microscope equipped with a CCD camera. The number of perfect starch granules was counted to calculate the concentration of perfect granules (Zarguili *et al.*, 2006).

The second step was to analyze granule concentrations in the rice analogue samples. The ground rice analogue sample was diluted in water to a concentration of 1% and was viewed under polarized light (200× magnification) with an Olympus microscope equipped with a CCD camera. The concentration of granules that were still perfect was calculated and plotted on the standard curve to obtain the degree of gelatinization (Baks *et al.*, 2007).

Wide angle X-ray diffraction

The rice analogue sample was ground into powder (approx. 40–60 mesh) and allowed to reach a state of equilibrium in a saturated sodium chloride solution at 23°C. Then it was placed in an aluminum sample holder and exposed to monochromatic X-ray beams (Cu-K α radiation; $\lambda = 1.54 \times 10^{-4} \mu\text{m}$) produced by

XRD Emma (GBC Scientific Equipment, Melbourne, Australia). The scanning region of the 2θ diffraction angle (Bragg angle) was 4° to 30° with step 0.02° which covers all the noteworthy diffraction peaks of starch crystallite (Vermeulen *et al.*, 2006).

Results and Discussion

Characteristics of raw materials

Chemical and physical properties of the materials used were characterized. The results of proximate analyses of corn flour and corn starch are shown in Table 1. The corn flour had a lower content of total carbohydrate and higher contents of crude protein, crude fat, and crude ash than that of corn starch. This difference was probably caused by the type of corn and the milling process. Every variety of corn has a specific chemical composition. The chemical composition is also affected by the weather, soil, fertilizer, etc. Corn flour is processed by grinding the dried corn endosperm (grits) so that all the components contained in the endosperm are included in the flour (Peplinski *et al.* 1984). Corn starch is extracted by using water from the steeped and milled corn and then corn starch is dried so that starch component is very dominant in corn starch product (Eckhoff and Watson, 2009).

The starch, amylose, and fiber contents of the raw materials are listed in Table 2. The corn starch had an amylose content of 38.29% which was higher than that of the corn flour with an amylose content of 14.62%. The corn used as the raw material to make corn starch was derived from corn plants that contain a medium amylose content, whereas corn flour was derived from corn plants with a low amylose content (Cheetham and Tao, 1998). The starch content of corn flour was lower than that of corn starch, and conversely, the fiber

Table 1. Proximate analysis of yellow corn flour and corn starch.

Parameter	Corn flour	Corn starch
Moisture (%)	9.5289±0.0431	12.0350±0.0495
Crude Ash (%)	0.6713±0.0095	0.0900±0.0141
Crude Fat (%)	1.1861±0.0809	0.1950±0.0212
Crude Protein (%)	7.9100±0.0707	0.4550±0.0212
Total Carbohydrate (%) [#]	80.7037±0.2042	87.2250±0.0283

The value is mean±standard deviation of two replicates, each analyzed in duplo.

[#] Calculated by 100 – water content % – crude ash content % – crude protein % – crude fat % (FAO, 2003).

content of corn flour was higher than that of corn starch. This distinction might be due to the type of corn and the milling process for reasons similar to those given for the differences in the proximate analyses (the percentages of water, crude ash, crude fat, crude protein and total carbohydrate).

DSC thermograms of corn flour, corn starch, and corn flour/corn starch mixed at a ratio of 9:1 are shown in Fig. 3. The corn flour had a higher peak gelatinization temperature (73.21°C) than that of the corn starch (69.26°C), but the gelatinization enthalpy (ΔH) of corn flour (5.71 J/g) was lower than that of corn starch (10.14 J/g) (Table 3). The higher gelatinization onset temperature and peak gelatinization temperature for corn flour indicated that more energy was required to initiate starch gelatinization (Sandhu and Singh, 2007). The difference in ΔH reflected the melting of amylopectin crystallites and could represent a difference in bonding forces between the double helices that form the amylopectin crystallite, which results in different alignments of hydrogen bonds within starch molecules (McPherson and Jane, 1999).

X-ray diffractograms showed that the corn flour and corn starch had crystals of the same types (A-type crystals), characterized by the presence of peaks at 2θ angles of 15°, 17°, 18°, and 23° (Fig. 4). However,

the X-ray diffractogram peaks of corn starch were sharper than those of corn flour, a difference that was caused by amylose. The amylose content of corn starch was higher than that of corn flour, and the amylose content played a role in reducing crystallinity or at least was not involved in crystallite formation. An increase in the amylose content in the raw material would decrease the degree of crystallinity (Cheetham

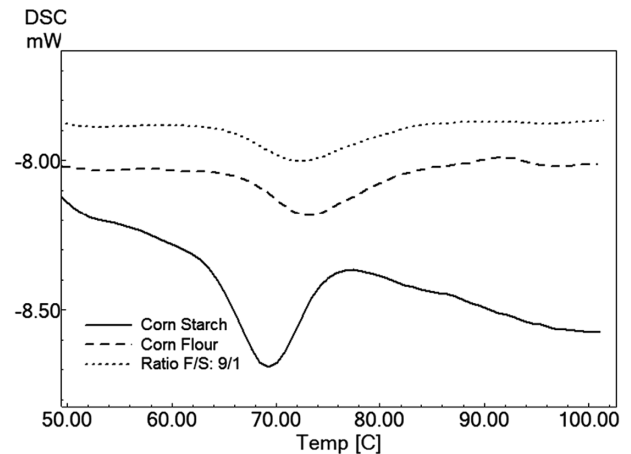


Fig. 3. DSC thermograms of corn flour, corn starch, and corn flour–corn starch mixture in the ratio of 9:1.

Table 2. Starch, amylose, and fiber content in corn flour and corn starch.

Parameter	Corn flour	Corn starch
Starch (%)	74.25±0.118	86.73±2.814
Amylose (%)	14.62±0.134	38.29±0.339
Fiber (%)	5.93±0.057	0.46±0.071

The value is mean±standard deviation of two replicates, each analyzed in duplo

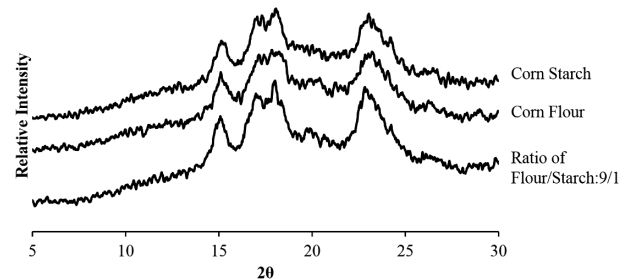


Fig. 4. X-ray diffractograms of corn flour, corn starch, and corn flour–corn starch mixture in the ratio of 9:1.

Table 3. Gelatinization temperatures onset, peak and conclusion and gelatinization enthalpy of corn flour, corn starch, and 9:1 mixture of corn flour–corn starch.

Sample	To (°C)	Tp (°C)	Tc (°C)	ΔH (J/g)
Corn starch	62.28	69.26	84.79	10.14
Corn flour	65.42	73.21	81.84	5.71
Corn flour : corn starch (ratio 9:1)	62.87	72.68	81.9	5.88

To: temperature of gelatinization onset

Tp: temperature of gelatinization peak

Tc: temperature of gelatinization conclusion

and Tao, 1998).

Effects of moisture content of dough and extrusion temperature on the degree of gelatinization of rice analogue

DSC and polarized light microscopy were used to analyze the changes of starch granules due to different processing conditions and the results were displayed in Fig. 5, Fig. 6, and Table 4. DSC thermograms showed that all of treatment in the experiment caused the loss of gelatinization curve peak (Fig. 5). These results indicated that extrusion process at temperatures of 70°C, 80°C, and 90°C and dough moisture contents of 35%, 40%, and 45% had caused the starch granules gelatinized completely (degree of gelatinization 100%). Nyanzi *et al.* (1995) revealed that a mixture of corn starch and soy protein isolate (75:25) with a moisture content of 20% extruded by a single screw extruder at a temperature of 50°C and a screw speed of 120 rpm resulted in degree of gelatinization 91.6%. The shear stress on dough produced by the rotational movement of the extruder screw and high pressure in the cooking zone could destroy the starch granules so that gelatinization could be achieved at low moisture content because of allowing faster transfer of water into the interior molecules (Nyanzi *et al.*, 1995; Liu *et al.*, 2009).

Images of the polarized light microscope illustrated that all of treatment in the experiment caused the damage of the starch granules (Fig. 6b-j). In Fig. 6a the starch granules of native corn starch were still perfect and the birefringence of starch granule were still clearly seen. However, after the treatment the starch granules were broken (loss of birefringence, cracking into many parts, and agglomeration of some fractured granules). These results proved that extrusion process at temperatures of 70°C, 80°C, and 90°C and dough moisture contents of 35%, 40%, and 45% had caused the starch granules gelatinized completely (degree of gelatinization 100%). Polarized light microscope can be also utilized to measure the degree of gelatinization, based on the starch granules that still show birefringence. The degree of gelatinization measured by polarized light microscopy was similar with that of measured by DSC (Table 4). During extrusion the loss of crystallinity was not caused by water penetration, but by the mechanical and thermal disruption of molecular bonds due to the intense shear field and heat within extruder. Shear stress could result in fragmentation of starch granules

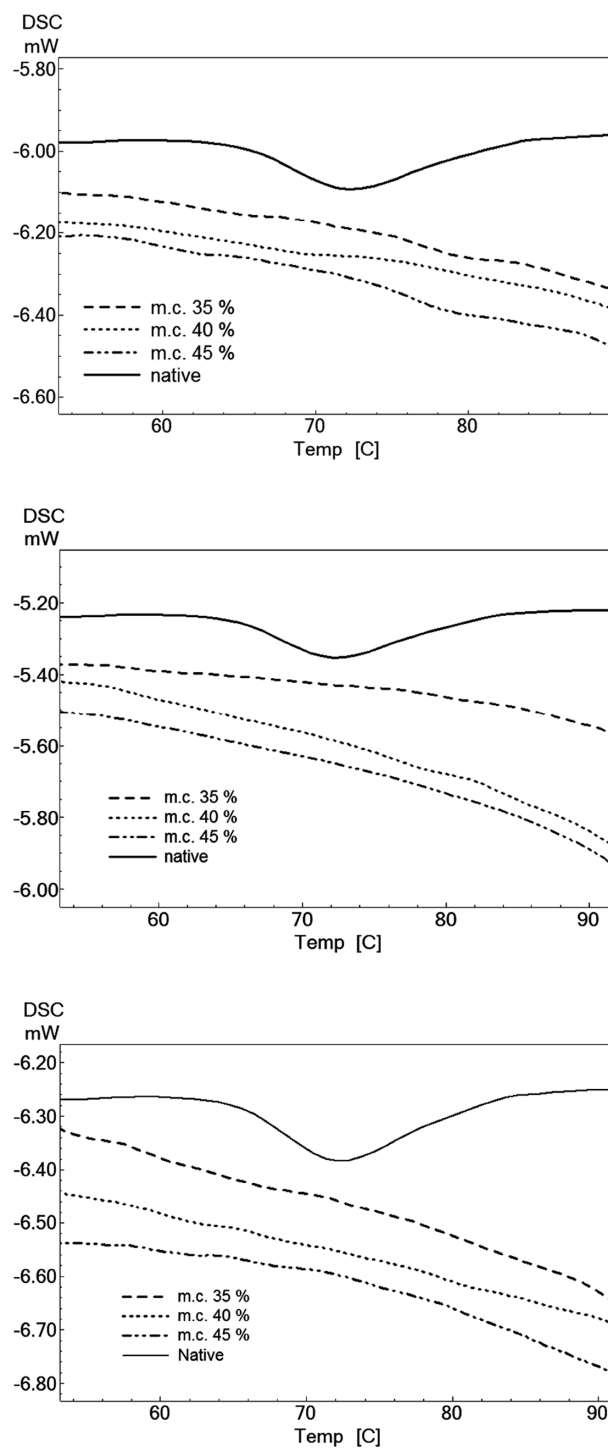


Fig. 5. DSC thermograms of corn flour-corn starch mixture in the ratio of 9:1 (native) and rice analogues produced at the extrusion temperatures of 70°C (a), 80°C (b), and 90°C (c) at moisture contents (m.c.) of 35%, 40%, and 45%.

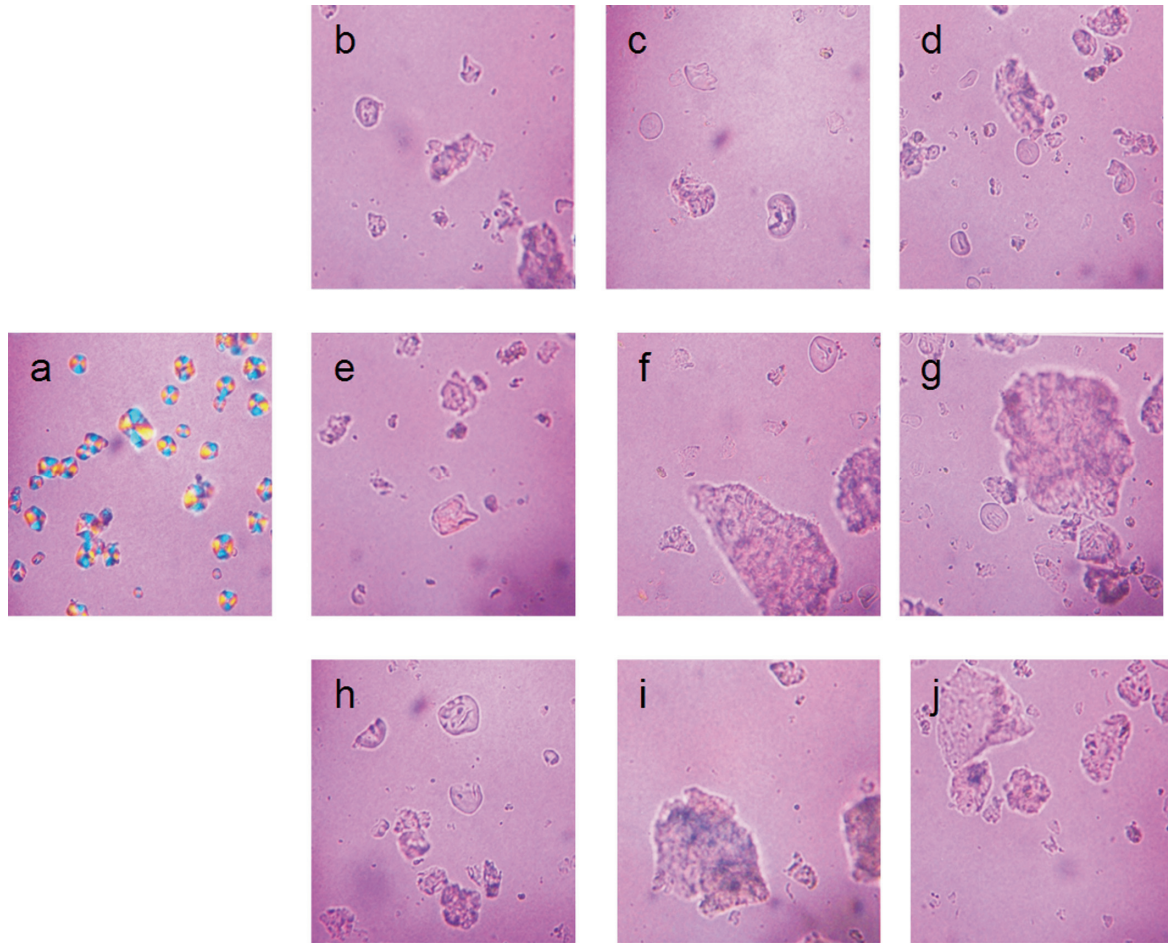


Fig. 6. Polarized light microscope images of native corn flour (**a**), rice analogues produced under processing conditions of 70°C extrusion temperature–35% dough moisture, 70°C–40%, 70°C–45% (**b, c, d**), under processing conditions of 80°C–35%, 80°C–40%, 80°C–45% (**e, f, g**), and under processing conditions of 90°C–35%, 90°C–40%, 90°C–45% (**h, i, j**).

during extrusion. Both the mechanical and thermal energy transferred to starch dough during extrusion would affect the breakdown of the main and secondary valence bonds, and the hydrogen bond between neighboring starch molecules in a starch structure (Barron *et al.*, 2001; Liu *et al.*, 2009).

Koide *et al.* (1999) and Zhuang *et al.* (2010) which also produced rice analogues by using of hot extrusion had the different result. Koide *et al.* (1999) revealed that at dough moisture content of 30% to 40% and an extrusion temperature of 80°C, the degree of gelatinization of the produced rice analogue was about 50% to 60% and at 120°C it was 90% or more. While Zhuang *et al.* (2010) also reported that extrusion process of rice analog at dough moisture content of 28% to 36% and extrusion temperature of 68°C to 90°C

would produce the degree of gelatinization 40.2% to 84.5%. Higher extrusion temperatures and dough moisture content would lead to higher degrees of starch gelatinization. These different result might be caused by the method spent to measure the degree of gelatinization. Both Koide *et al.* (1999) and Zhuang *et al.* (2010) utilized spectrophotometry method after sample was gelatinized and reacted with iodine solution. According to Bhatnagar and Hanna (1994), the lipid could react with amylose released by starch granules to form the amylose-lipid complex compound when they was extruded with heating so that would reduce the amylose measured to determine the degree of gelatinization. The existence of amylose-lipid complex compound in the sample would also decrease the iodine binding capacity. Therefore the measuring of

Table 4. Degree of gelatinization (DG) of rice analogues determined by DSC and by polarized light microscopy (PLM).

Sample (Extrusion temp. – moisture content)	DG (%)	
	DSC	PLM
70°C–35%	100	99.66
70°C–40%	100	100
70°C–45%	100	99.9
80°C–35%	100	99.83
80°C–40%	100	100
80°C–45%	100	100
90°C–35%	100	99.83
90°C–40%	100	100
90°C–45%	100	100

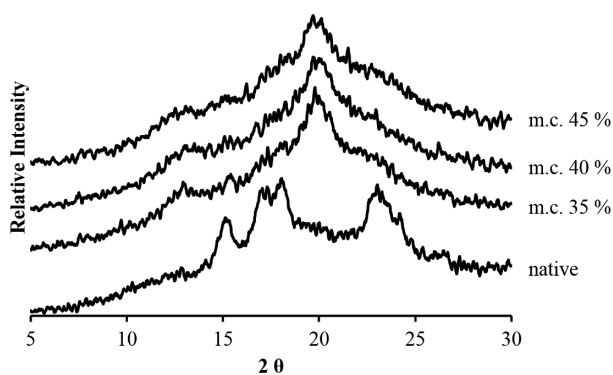


Fig. 7. X-ray diffractograms of corn flour–corn starch mixture in the ratio of 9:1 (native) and rice analogues produced at an extrusion temperature of 70°C and moisture contents (m.c.) of 35%, 40% and 45%.

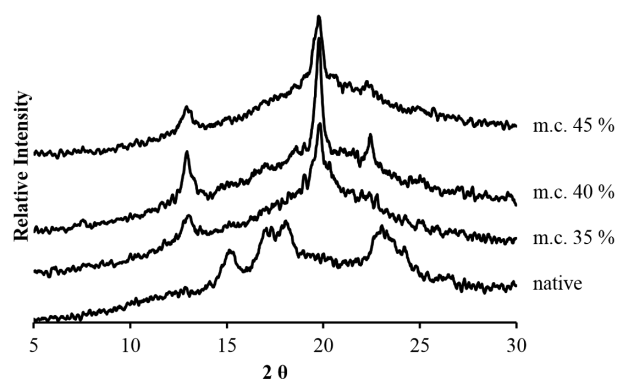


Fig. 9. X-ray diffractograms of corn flour–corn starch mixture in the ratio of 9:1 (native) and rice analogues produced at a temperature of 90°C and moisture contents (m.c.) of 35%, 40%, and 45%.

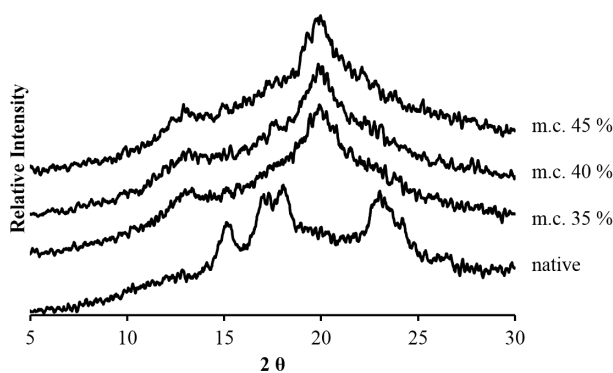


Fig. 8. X-ray diffractograms of corn flour–corn starch mixture in the ratio of 9:1 (native) and rice analogues produced at a temperature of 80°C and moisture contents (m.c.) of 35%, 40%, and 45%.

degree of gelatinization of extruded starch sample by using of spectrophotometry method was not precise.

The effect of moisture content of dough and extrusion temperature on the crystallinity of rice analogues

X-ray diffractograms of the rice analogues showed that all of treatment in the experiment led to the changes of crystalline form, from A-type crystals to V-type crystals (Figs. 7, 8, and 9). V-type crystals of the rice analogues were characterized by peaks at the Bragg angles (2θ) 7°, 13°, and 20°. The changes of A-type crystals in the raw material to V-type crystals in the rice analogue were caused by the formation of amylose–lipid complex compounds (Le Bail *et al.*, 1999). In the hot extrusion process the starch granules would be gelatinized and released the amylose reacted

with the lipid (Glycerol monostearate) to form the amylose-lipid complex compound. The formation of amylose-lipid complex compounds was also reported by Mercier *et al.* (1979) after they extruded maize starch at a dough moisture content of 22% and extrusion temperatures of 70°C to 135°C.

The X-ray diffractograms peaks of rice analogues produced at extrusion temperature of 90°C (Fig. 9) looked sharper than that of the rice analogues produced at extrusion temperature of 70°C and 80°C (Figs. 7 and 8). The X-ray diffractograms of rice analogue produced at extrusion temperature 90°C also owned a peak at angle 2θ of 22°. According to Gelders *et al.* (2004), the X-ray chromatogram with peaks which seem sharp at angles 2θ of 7°, 13°, 20°, and 22° was chromatogram of the amylose-lipid complex compound composed of the long chain amylose with Degree of Polymerization (DP) 400 and 950 and the X-ray chromatogram with main reflection at Bragg angles 7°, 13°, and 20° was chromatogram of the amylose-lipid complex compound structured of the short chain amylose with DP 20 and 60. Consequently the rice analogue generated at temperature of 90°C contained the amylose-lipid complex compound comprised of the long chain amylose with DP greater than 400 and rice analogue manufactured at temperature 70°C and 80°C owned the amylose-lipid complex compound arranged of the short chain amylose with DP less than 60.

Conclusions

At extrusion temperatures of 70°C, 80°C, and 90°C and at dough moisture contents of 35%, 40%, and 45%, the extrusion process led to the starch granules in rice analogues gelatinized completely (degree of gelatinization 100%). Such treatment also resulted in the change of crystalline pattern from A-type crystals to V-type crystals due to the formation of amylose-lipid complex compounds. The increasing of extrusion temperature from 80°C to 90°C caused the change of amylose chain which form the amylose-lipid complex compound from short chain amylose to long chain amylose.

Acknowledgement

We thank to the General Directorate of High Education, Ministry of Education and Culture of Indonesia for funding this research.

References

- AOAC (Association of Official Analytical Chemists International), 2009. Official Methods of Analysis of AOAC International. 18th edition. AOAC International, Gaithersburg.
- Baks, T., Ngene, I.S., van Soest, J.J.G., Janssen, A.E.M., Boom, R.M., 2007. Comparison of methods to determine the degree of gelatinisation for both high and low starch concentrations. *Carbohydrate Polymers*, 67, 481–490. doi: 10.1016/j.carbpol.2006.06.016.
- Bhatnagar, S., Hanna, M. A., 1994. Extrusion processing conditions for amylose-lipid complexing. *Cereal Chemistry*, 71, 587–593.
- Barron, C., Bouchet, B., Della Valle, G., Gallant, D.J., Planchot, V., 2001. Microscopical study of the destructuring of waxy maize and smooth pea starches by shear and heat at low hydration. *J. Cereal Sci.*, 33, 289–300. doi:10.1006/jcrs.2000.0368.
- BPS (Badan Pusat Statistik), 2009. Survei Sosial Ekonomi Nasional, Jakarta. (Central Agency of Statistic, 2009. National Socioeconomic Survey, Jakarta).
- BPS (Badan Pusat Statistik), 2012. Survei Sosial Ekonomi Nasional, Jakarta. (Central Agency of Statistic, 2012. National Socioeconomic Survey, Jakarta).
- BPS (Badan Pusat Statistik), 2013. Survei Sosial Ekonomi Nasional, Jakarta. (Central Agency of Statistic, 2013. National Socioeconomic Survey, Jakarta).
- BPS (Badan Pusat Statistik), 2014. Berita Resmi Statistik, No. 22/03/ Th. XVII. (Central Agency of Statistic, 2014. Official News of Statistic. No. 22/03/ Th. XVII).
- Budijanto, S., 2011. Pengembang Rantai Nilai Serealia Lokal (Indigenous Cereal) untuk Memperkokoh Ketahanan Pangan Nasional. Laporan Program Riset Strategis Kemenristek, Serpong. (Budijanto, S., 2011. The Chain Development of Indigenous Cereal Value to Strengthen the National Food Security. Report of Strategic Research Program, Ministry of Research and Technology, Serpong, Indonesia)
- Campanella, O.H., Li, P.X., Ross, K.A., Okos, M.R., 2002. The Role of Rheology in Extrusion. In: Chen J.W., Barbosa V. G., Aguilera J.M., Engineering and Food for the 21st Century. CRC Press, New York, pp. 405–425.
- Cheetham, N.W.H., Tao, L., 1998. Variation in crystalline type with amylose content in maize starch granules: an X-ray powder diffraction study. *Carbohydrate Polymers*, 36, 277–284.
- Eckhoff S.R., Watson S.A., 2009. Corn and Sorghum Starches: Production. In: BeMiller, J., Whistler, R. (Eds.), *Starch: Chemistry and Technology*, 3rd edition. Academic Press, USA, pp. 373–440.
- Gelders, G.G., Vanderstukken, T.C., Goesaert, H., Delcour, J. A., 2004. Amylose-lipid complexation: a new fractionation method. *Carbohydrate Polymers*, 56, 447–458. doi: 10.1016/j.carbpol.2004.03.012.
- FAO (Food Agricultural Organization), 2003. Food energy – methods of analysis and conversion factors. Rome: Food and Agriculture Organization of the United Nations. pp. 12–13.

- Herawati, H., Widowati, S., 2009. Karakteristik beras mutiara dari ubi jalar. *Bull Teknol Pascapanen Pertan.* 5, 37-44 (Herawati, H., Widowati, S., 2009. Characteristic of rice pearl from sweet potatoes. *Bulletin of Technology, Postharvest of agriculture*, 5, 37-44.)
- Katsuya, N., Sagara, T., Takashashi, R., Yoshida, T., Ojima, T., 1971. Process for producing enriched artificial rice. US patent no 3,628,966.
- Koide, K., Fukushima, T., Tomita, T., Kuwata, T., 1999. Fabricated rice. US patent no. 5,932,271.
- Kurachi, H., 1995. Process of Making Enriched Artificial Rice. US patent no 5,403,606.
- Laurentin, A., Edward, C.A., 2003. A microtiter modification of the anthrone-sulfuric acid colorimetric assay for glucose-based carbohydrates. *Analytical Biochemistry*, 315, 143-145.
- Le Bail, P., Bizot, H., Ollivon, M., Keller, G., Bourgaux, C., Buléon, A., 1999. Monitoring the crystallization of amylose-lipid complexes during maize starch melting by synchrotron X-ray diffraction. *Biopolymers*, 50, 99-110.
- Liu, H., Xie, F., Yu, L., Chen, L., Li, L., 2009. Thermal processing of starch-based polymers. *Progress in Polymer Science*, 34, 1348-1368.
- McPherson, A. E., Jane, J., 1999. Comparison of waxy potato with other root and tuber starches. *Carbohydrate Polymers*, 40, 57-70.
- Machmur, M., Dahrulsyah, Sawit, M. H., Subagyo, A., Rachman, B., 2011. Diversifikasi pangan Solusi Tepat Membangun Ketahanan Pangan Nasional. Badan Ketahanan Pangan. Jakarta (ID). pp. 31-39. (Machmur, M., Dahrulsyah, Sawit, M.H., Subagyo, A., Rachman, B., 2011. Food Diversification is exact solution to build the national food security. Food Security Agency, Jakarta (ID). pp. 31-39.)
- Mercier, C., Charbonniere, R., Gallant, D., Guilbot, A., 1979. Structural Modification of Various Starches by Extrusion Cooking with a Twin-Screw French Extruder. In: Blanshard, J. M. V. and Mitchell, J. R. (Eds.), *Polysaccharides in Food*. Butterworths, London, pp. 153-170.
- Muaris, H., Budijanto, S., 2013. Beras Analog, Gramedia, Jakarta. (Muaris, H., Budijanto, S., 2013. Rice- Analogue. Gramedia, Jakarta).
- Nyanzi, F.A., Maga, J.A., Evans, C., 1995. Changes in microstructure and thermal properties of thermally processed cornstarch/soy protein isolate model food systems. *Developments in Food Science*, 37, 1155-1164. DOI:10.1016/S0167-4501(06)80226-8.
- Peplinski, A.J., Anderson, R.A., Alaksiewicz, F.B., 1984. Corn dry milling studies: Shortened mill flow and reduce temper time and moisture. *Cereal Chem.*, 61, 60-62.
- Sandhu, K.S., Singh, N., 2007. Some properties of corn starches II: Physicochemical, gelatinization, retrogradation, pasting and gel textural properties. *Food Chemistry*, 101, 1499-1507. doi:10.1016/j.foodchem.2006.01.060.
- Samad, M.Y., 2003. Pembuatan Beras Tiruan (Artificial Rice) dari Bahan Baku Ubikayu dan Sagu. In: Prosiding Seminar Teknologi untuk negeri. 2, 36-40. (Samad, M.Y., 2003. Making of Artificial Rice from Cassava and Sago. In: Proceeding of Seminar of Technology for Our Country, 2, 36-40.)
- Vermeulen, R., Goderis, B., Delcour, J.A., 2006. An X-ray study of hydrothermally treated potato starch. *Carbohydrate Polymers* 64, 364-375. doi: 10.1016/j.carbpol.2005.12.024.
- William, P.C., Kuzina, F.D., Hylinka, I., 1970. A rapid colorimetric procedure for estimating the amylose content of starches and flours. *Cereal Chem.*, 47, 411-420.
- Zhuang, H., An, H., Chen, H., Xie, Z., Zhao, J., Xu, X., Jin, Z., 2010. Effect of extrusion parameters on physicochemical properties of hybrid Indica rice (type 9718) extrudates. *J. Food Process and Preserv.*, 34, 1080-1102. doi:10.1111/j.1745-4549.2009.00439.x.
- Zarguili, I., Maache-Rezzoug, Z., Loisel, C., Doublier, J.L., 2006. Influence of DIC hydrothermal process conditions on the gelatinization properties of standard maize starch. *J. Food Eng.*, 77, 454-461. doi: 10.1016/j.jfoodeng.2005.07.014.