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Organoleptic, Chemical, and Physical Characteristics of Sago (*Metroxylon spp.*) Analog Rice Supplemented with Red Bean (*Phaseolus vulgaris*) Flour as a Functional Food

Sri Budi Wahjuningsih[a,1], Y Marsono[b], Danar Praseptiangga[c], Bambang Haryanto[d], Mita Nurul Azkia[a,2]

[a] *Faculty of Agricultural Technology, Semarang University, Semarang, Central Java, Indonesia*
E-mail: [1]sribudiwahjuningsih@yahoo.co.id; [2]mitanurulazkia@gmail.com

[b] *Faculty of Agricultural Technology, Gadjah Mada University, Yogyakarta, 55281, Indonesia*
E-mail : yustimar49@yahoo.co.id

[c] *Faculty of Agriculture, Sebelas Maret University, Surakarta, 57126, Central Java, Indonesia*
E-mail: praseptiangga_de@yahoo.com

[d] *Agency for the Assessment and Application of Technology, Jakarta, Indonesia*
E-mail: bambanghar54@yahoo.com

***Abstract*— Sago analog rice is rice made from sago starch with or without supplementation of other food materials, and its shape resembles that of rice. Red bean flour is added to analog rice to increase its protein content to levels comparable to those of rice. The objective of this research is to investigate the organoleptic preference of panelists, and the chemical and physical characteristics of sago analog rice supplemented with red bean flour. We used a completely randomized design with one factor: the supplementation of red bean flour at 0%, 5%, 10%, 15%, 20%, and 25%. Our organoleptic test applied for the hedonic scale and examined the aroma, taste, and texture of cooked sago analog rice; the observed chemical characteristics were water, ash, fat, protein, and starch content. Physical characteristics were cooking time, water content, the weight of water loss, water absorbability, and granule characteristics. Data were analyzed using the analysis of variance. When results were significantly variable, the analysis was followed by the Duncan multiple range tests (DMRT) at the significance level of α < 5%. Our results show that supplementation of red bean flour up to 10% resulted in hedonic values ranging from "like" to "quite like" for taste and aroma, and "like" for texture; BS100 analog rice had the highest hedonic value. The water content of sago rice and the weight of water loss of cooked sago rice did not show a significant difference. In addition, ash content, protein content, fat content, starch content, cooking time, and water content of cooked sago rice displayed significant differences. A higher supplementation of red bean flour to sago rice influences granule structure, which appears damaged with rough surfaces and high porosity. Moreover, the size of the granules is smaller.**

***Keywords*— sago; Metroxylon spp; analog rice; red bean; extrusion.**

I. INTRODUCTION

Although staple food diversification programs have long been applied, the dependence on rice is still [1]. Potential local sources of carbohydrates are extremely diverse, such as sago, sorghum, corn, cassava, and other kinds of tubers, but they have not been optimally utilized. This indicates that diversification programs applied have not been able to reduce the need for rice consumption due to various reasons. Therefore, another type of approach is needed to provide products that resemble rice, i.e. analog rice. Analog rice is a food product with a shape like rice, and it is processed from materials different from rice, such as sago, corn, cassava, and other kinds of tubers [2],[3]. One of the potential local materials to produce analog rice is sago. In this paper, we refer to rice produced from sago as sago analog rice.

Sago analog rice is made from sago starch as the main material with or without the addition of other materials during the extrusion process; it bears shape and characteristics like rice. Sago is one of the potential sources of carbohydrates in Riau, Sulawesi, Maluku, and Papua. Around 50% of 2.5 million hectares of sago fields in the world are found in Indonesia [4]. According to Ref. [5], sago starch can be produced up to 25 tons of dry starch/ha/year. The weakness of sago as an alternative staple food is its low protein content, which is only 0.18% [6]; to increase its nutritional properties, it needs additional protein sources, such as red bean flour. According to Ref. [7], the protein content of red bean flour is 23.2%. Data obtained by the Central Bureau of Statistics show that the production of red bean flour in Indonesia in 2012 and 2013 reached 93.416 tons/year and 100.961 tons/year, respectively.

Extrusion is the plasticization process of food materials containing starch or proteins on a pipe combining the processes of mixing, heating, mechanical cutting, and shaping to produce particular shapes [8]. The extrusion process can cause gelatinization of starch, protein denaturation, the formation of amylose lipid complexes, and degradation of components that are sensitive to heat [9]. The gelatinization process allows starch retrogradation, which confers resistant characteristics, decreasing the level of digestibility of starch. Several researchers have used the technology of extrusion to produce analog rice by using rice with incomplete shape [10],[11], by using corn with heat extrusion [12], by using mocaf and flour nuts [7], and by using mocaf, arrowroot flour and red bean flour with cold extrusion [13]. Sago starch as the main material for noodles contains resistant starch at 9.45% [14], and has a glycemic index of 28, therefore it can potentially be developed as a functional food [14]-[16]. However, no studies have been published yet on the production of analog rice by using sago starch and red bean flour as raw materials. The aim of this research is to study the organoleptic, chemical, and physical characteristics of analogue rice based sago and red bean flour.

II. Materials and Methods

A. Materials

The main materials used in this research are sago starch (*Metroxylon* spp.) of Meranti variety and red beans (Phaseolus vulgaris) of local variety. Sago starch was obtained from Selat Panjang, Riau. Prior to use for formulation, sago was washed to remove dirt, and its starch was subsequently precipitated and dried.

Red beans were obtained from farmers in the Parakan Sub-district, Temanggung Regency. Red bean flour was prepared as done by [7]. Reagents to analyze chemical and nutritional properties were obtained from Sigma or Merck.

B. Sample Preparation

Six different formulas of sago rice were made from sago and red bean flour: one formula containing sago exclusively (BS100), and five formulas were characterized by sago supplemented with red bean flour at 5% (BSKM5), 10% (BSKM10), 15% (BSKM15), 20% (BSKM20), and 25% (BSKM25), as presented in Table 1.

An emulsion was made before the preparation of sago rice. It consisted of GMS, distilled water, coconut oil, and carrageenan. The emulsion was subsequently mixed with composite flour, homogenized for 5 minutes, and steamed for 15 minutes. Steamed materials were directly inserted into an extruder. Homogenization was performed for 2 minutes, thus completing the shaping of sago starch. The shaped granule were dried in the cabinet dryer at 50°C for 12 hours [13].

TABLE I
FORMULAE OF SAGO RICE SUPPLEMENTED WITH RED BEAN FLOUR

Formula	Sago starch (%)	Red bean flour (%)
BS100	100	0
BSKM5	95	5
BSKM10	90	10
BSKM15	85	15
BSKM20	80	20
BSKM25	75	25

C. Characterization

Sago rice was analyzed according to its sensorial and physicochemical properties. Analysis was conducted by using hedonic scales for aroma, taste, and texture parameters of cooked sago rice [17]. Physical analysis included cooking time, water content, rate of water loss [18], water absorbability [19], and microstructure of analog rice by using the Scanning Electron Microscope SEM [20] FEI type Inspect S50 EDAX AMETEK. Moreover, the chemical analysis tested the levels of proximate and starch [21].

D. Statistical Analysis

The experimental research method used were completely randomized design with a single factor, i.e. supplementation with red bean flour at 6 different levels, namely: BS100: 0%; BSKM5: 5%; BSKM10: 10%; BSKM15: 15%; BSKM20: 20%; and BSKM25: 25%. Data obtained with 4 replicates and tabulated with Microsoft Excel 2013. Statistical analysis using the SAS Software version 9.2 to perform General linier Models (GLM) procedure; when a significant difference among levels was identified, the Duncan Multiple Range Test (DMRT) was carried out at the level of 5%.

III. Results and Discussion

Prior to the production and analysis of sago rice, sago starch and red bean flour were analyzed. Data obtained according to [22] are presented in Table 2. The data in Table 2 indicate that sago is a source of starch rich in amylose (43.69%) and resistant starch, but it has low protein content. On the other hand, red bean flour has high protein content (24.98%) and high dietary fiber, especially insoluble fiber (8.82%).

TABLE II
CHEMICAL COMPOSITION OF SAGO STARCH AND RED BEAN FLOUR (% DB)

Components	Sago starch	Bean flour
Water (%)	12.47	12.34
Ash (%)	1.34	3.79
Protein (%)	1.01	28.06
Fat (%)	0.80	3.76
Carbohydrates (%)	96.85	64.17
Amylose (% of starch)	43.69	27.35
Amylopectin (% of starch)	56.31	72.65
Starch (%)	95.23	49.72
Insoluble fiber (%)	0.93	8.82
Soluble fiber (%)	1.61	5.50
Total dietary fiber (%)	2.54	14.32
Resistant starch (%)	18.31	10.51

A. Organoleptic Test of Sago Analog Rice: Hedonic Test

The sensorial assessment of sago rice was performed with a hedonic test on aroma, taste, and texture parameters, in order to determine the specific product formula preferred by the panelists. The organoleptic test was carried out on 20 semi-trained panelists. The data in Table 3 show that the hedonic value of taste and aroma was between “dislike” (2) and “like” (4), with the one of texture between “quite like” (3) “like” (4). The results of the organoleptic test are presented in Table 3.

TABLE III
RESULTS OF THE HEDONIC TEST CONDUCTED ON SAGO ANALOG RICE

Variable	BS	BSKM5	BSKM 10	BSKM 15	BSKM20	BSKM 25
Taste	3.90^{a}± 0.55	3.55^{a}± 0.76	3.60^{a}± 0.68	2.90^{b}± 0.55	2.60^{b}± 0.59	2.05^{c}± 0.61
Aroma	3.65^{a}± 0.67	3.35^{a}± 0.59	3.65^{a}± 0.67	2.75^{b}± 0.55	2.65^{b}± 0.59	2.10^{c}± 0.64
Texture	4.20^{a}± 0.62	3.90^{ab}± 0.85	3.65^{b}± 0.59	3.20^{c}± 0.70	3.00^{c}± 0.65	2.95^{c}± 0.69

The different notations indicate significant differences with the p-value = 0.05. 1: extremely dislike; 2: dislike; 3: quite like; 4: like; 5: extremely like

The results of the analysis of variance in Table 3 show that the addition of red bean flour to sago rice has a significant effect ($p < 0.05$) on aroma, taste, and texture. Following the DMRT test at the significance level of 5%, aroma, taste, and texture parameters of sago rice (BS100) and the ones of sago rice supplemented with red bean flour up to 10% were liked by the panelists and did not significantly differ, but they were significantly different from the other formulations. Aroma, taste, and texture are important parameters to test the consumer´s acceptance of products.

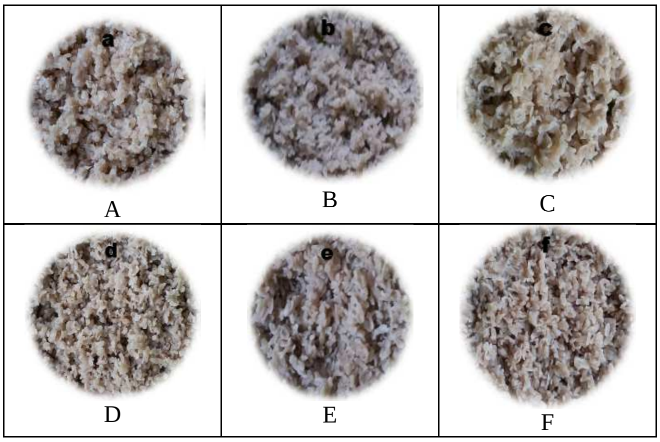

Fig. 1 Sago analog rice and red bean flour. A = BS100; B = BSKM5; C = BSKM10; D = BSKM15; E = BSKM20; F = BSKM25

Results in Table 3 indicate that sago rice with the BS100 formulation had the highest acceptance by panelists for all parameters tested, and the level of fondness decreased for the analog rice with a higher supplementation of red bean flour due to an unpleasant aroma (beany flour). Therefore, considering the aroma, taste, and texture parameters of sago rice, a higher supplementation of red bean flour resulted in the panelists being increasingly disliked. A supplementation of sago rice with red bean flour above 10% was already sufficient for the panelists to dislike aroma, taste, and texture. The emergence of beany flour caused the change of aroma. The lipoxygenase enzyme was already reported to have a role in the formation of an unpleasant aroma beany flour [23]. Similar results were also obtained for soybeans [24] and *faba* beans [25].

B. Physical Characteristics of Sago Rice

The physical characteristics tested of sago analog rice were cooking time, weight of lost water, water content, and water absorption (Table 4), while the rate of water loss of sago rice every 30 minutes is presented in Figure 2.

The physical characteristics tested in this research were cooking time, weight of lost water, water content, water absorption, and rate of 1st falling down of sago rice. The cooking time of the analog rice ranged between 4.1 and 6.5 minutes. The analysis of variance shows that the proportion of sago starch with red bean flour significantly affects its cooking time ($p < 0.05$). A higher supplementation of red bean flour would make the cooking time shorter. Sago starch was assumed to contain higher amylose (43.69%) than red bean flour (27.36%), so that a higher supplementation of red bean flour would shorten the cooking time. The high content of amylose starch strengthened its granules so that they were more resistant to swelling in hot water due to stronger hydrogen bonds. This contributed to make granules more difficult to degrade and to increase the energy and time needed for the gelatinization process to occur [26]. Such conditions make food products slower to digest [27].

TABLE IV
PHYSICAL CHARACTERISTICS OF SAGO ANALOG RICE

Variable	Cooking time (minutes)	Weight of lost water (g)	Water content (%)	Water absorption (%)	Rate of 1st falling ($g\ H_2O/g$ minute)
BS100	6.5^{a} ± 1.59	1.54^{a} ± 0.17	38.68^{d} ± 0.83	207.99^{f} ± 0.87	0.0004^{c} ± 0.00
BSKM5	5.8^{ab} ± 1.16	1.68^{a} ± 0.32	45.40^{c} ± 1.01	213.78^{e} ± 1.31	0.0006^{b} ± 0.00
BSKM10	5.0^{ab} ± 0.99	1.66^{a} ± 0.23	46.73^{c} ± 0.72	217.73^{d} ± 1.14	0.0006^{b} ± 0.00
BSKM15	5.2^{ab} ± 0.72	1.58^{a} ± 0.34	47.96^{c} ± 0.68	223.15^{c} ± 0.78	0.0006^{ab} ± 0.00
BSKM20	4.1^{b} ± 1.29	1.74^{a} ± 0.26	52.45^{b} ± 2.02	231.62^{b} ± 1.33	0.0007^{a} ± 0.00
BSKM25	4.2^{b} ± 1.41	1.83^{a} ± 0.14	55.46^{a} ± 3.10	240.47^{a} ± 1.49	0.0007^{a} ± 0.00

The different notations indicate significant differences with a p-value = 0.05. Rate of 1st falling = rate of water loss in the first 30 minutes.

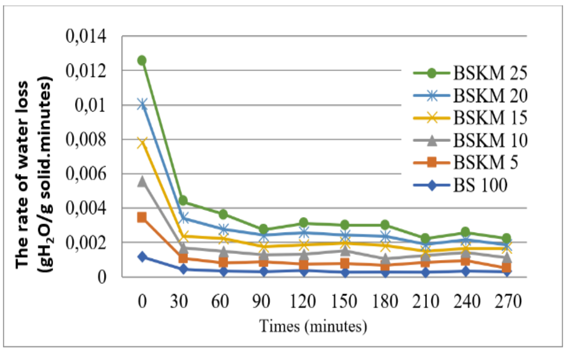

Fig.2 Rate of water loss of sago analog rice supplemented with red bean flour.

Table 4 shows that the weight of lost water of all types of analog rice displayed no significant differences ($p > 0.05$).

The weight of lost water was quantified by measuring the weight of rice (0 minutes) and then subtracting it with the weight of rice after the steaming process and 5 hours of incubation (300 minutes). The higher the amount of water lost, the weaker the rice was in retaining water; in fact, red bean flour contains higher food fiber than sago starch, which increases the ability of binding water molecules. Thus, a larger supplementation of sago rice with red bean flour would provide rice with higher water content and increase the amount of lost water. These findings agree with data obtained by Ref. [18], which proposes that corn analog rice has higher water content, but also a higher amount of lost water.

The rate of 1st falling is a water loss rate describing the first 30 minutes, as well as the biggest decreasing weight rate. This condition is caused by the difference of temperature between the cooking tools and the cooking room, leading to a robust water loss from analog rice within the first 30 minutes. Sago analog rice (BS100) had the lowest rate of 1st falling and was significantly different from other treatments. In accordance with the previous discussion, supplementation with red bean flour caused an increase in water content and water loss rate. Figure 2 shows that the decrease in the water loss rate of sago analog rice (BS100) within the following 30 minutes was flatter than the one of sago analog rice supplemented with red bean flour.

Water absorption is the ability of a material to absorb or bind water. The ability of dried granules of sago analog rice to reabsorb water is dependent on the ingredients of sago analog rice itself. The results of the analysis of variance shown in Table 5 indicate that BSKM25 had the highest water absorption ability.

TABLE V
CHEMICAL CHARACTERISTICS OF SAGO ANALOG RICE (% DB)

Chemical test	**BS 100**	**BSKM5**	**BSKM 10**	**BSKM 15**	**BSKM 20**	**BSKM 25**
Water	11.78^a ± 0.29	11.56^a ± 0.10	12.06^a ± 0.23	11.80^a ± 0.57	12.06^a ± 0.20	12.07^a ± 0.24
Ash	2.54^d ± 0.16	2.77^d ± 0.18	3.06^c ± 0.22	3.33^b ± 0.24	3.55^{ab} ± 0.15	3.70^a ± 0.06
Protein	2.54^f ± 0.09	4.83^e ± 0.08	5.98^d ± 0.14	6.77^c ± 0.082	7.63^b ± 0.24	8.27^a ± 0.14
Fat	0.99^f ± 0.03	1.60^e ± 0.06	1.84^d ± 0.05	1.99^c ± 0.01	2.08^b ± 0.04	2.21^a ± 0.02
Starch	86.58^a ± 0.88	82.30^b ± 0.38	79.32^c ± 0.47	77.25^d ± 0.71	75.46^e ± 1.07	74.50^f ± 0.68

BS100 had the lowest water absorption ability due to the lack of supplementation with red bean flour. Red bean flour contains a high amount of food fiber, and therefore it has a strong ability to bind water. Thus, the higher the supplementation with red bean flour, the greater the ability of sago rice to absorb water was. Based on a research conducted by Ref. [28], the ratio of water-soluble polysaccharides and water-insoluble polysaccharides is higher for extruded products than for other products subjected to different processing, so that their ability to absorb water is increased.

C. Chemical characteristics of sago analog rice

The chemical characteristics of sago rice identified in this research are the results of proximate, water content, ash content, fat content, protein content, and starch content analyses. The chemical ingredients of sago rice were determined according to several parameters: chemical ingredients of analog rice materials (sago starch and red bean flour), effect of extrusion processing using heat and pressure, steaming after extrusion, and other technical factors during processing. The results of the analysis of the chemical characteristics of sago rice are displayed in Table 5. The different notations show significant differences with a p-value.

D. Water content

Water content needs to be analyzed to measure the resilience of food products to damage caused by storage. The water content in sago rice is approximately 11.563% (BSKM5) to 12.070% (BSKM25). All of sago rice formulas have a water content below 14%. It is lower than the safe water content of paddy rice, < 14% (bb). Microbes grow easily in food products having water content between 14% and 15%. The more water added during the preparation of sago rice affects the high-water content of sago rice granules after the drying process. In this research, the water added was 50% of the total starch and flour [29]. The extrusion process caused chemical and nutritional changes in the product. The results of the analysis of variance show that the intercalation of red bean flour in sago rice has no significant effect on the water content of sago rice ($p < 0.05$). Low water content in this analog rice is advantageous because it contributes to reduce the level of damage by bacteria and fungi.

E. Ash content

Ash content in sago rice ranges between 2.54% and 3.69%. Ash content in sago rice intercalated with red bean flour is higher than the one in sago rice without red bean flour (2.54%). Based on the analysis of variance, sago rice intercalated with red bean flour shows a significant variation in its ash content ($p < 0.05$). Red bean flour has a higher ash content (3.38%) than sago starch (1.19%) [22], so that the higher the amount of red bean flour added to sago rice, the higher its content of ash will be. Ash content in food products is dependent on the amount of minerals and organic materials. Higher ash content results in a higher mineral content. The mineral content of sago is lower than the one of red bean. In a study conducted by Ref. [30], it was shown that the ash content of red bean reaches 4.34%; this value is higher than the one of sago 1% [31]. These findings are also in accordance with our results showing that a higher intercalation of red bean in sago rice results in an increased ash content.

F. Protein content

The protein content of sago rice ranged between 2.54% and 8.27%. Based on the Analysis of Variance (ANOVA), the protein content of sago rice intercalated with red bean flour shows a significant variation ($p > 0.05$). The sago rice formulation with the addition of red bean flour led to increased protein content. As a vegetable protein source, red bean flour contains higher protein levels (24.98%) than sago starch 0.9% [22]. Its addition to sago rice, therefore, increased protein content, dependent on the amount of red bean flour added.

G. Fat content

Fat content in sago analog rice ranged between 0.99% and 2.21%. These values are higher than the ones found in a study conducted by Ref. [32], 0.34% − 0.62%. Based on the analysis of variance (ANOVA), sago analog rice with intercalation of red bean flour undergoes significant variations in its fat content ($p < 0.05\%$). The variety of sago rice having the highest fat content is BSKM25, whereas the lowest one was found in BS100. Fat contents of produced sago analog rice are all higher than the ones of other general types of rice. This is caused by the intercalation of red bean flour (fat content: 3.35%) in the sago analog rice formula; the higher the amount of red bean flour added, the higher the content of fat in sago rice is.

According to Ref. [33] the fat content of red bean flour is very high (up to 15%). Food processing methods such as boiling, roasting, etc. can lower the fat content of red bean flour up to 5%, due to dissolution processes. Likewise, extrusion processes, which combine pressure and heating to produce analog rice, can also decrease the fat content in both sago and red bean flour.

H. Total starch content

Sago starch is a source of carbohydrates that can be applied widely in different industries and is highly dependent on physicochemical characteristics and functionalities. The physicochemical characteristics of starch specifically depend on its sources (e.g., starch granule shape and size, color, and composition of its amylose and amylopectin) and processing. Sago starch contains amylose and amylopectin, which affect the solubility and gelatinization properties of sago starch itself. If the amylose content of starch is high, sago starch will be dry and tend to have strong hygroscopic and less sticky characteristics [31].

The results of the analysis of variance (ANOVA) show that the supplementation of sago rice with red bean has a significant effect on its total starch content ($p < 0.05\%$). The total starch content of the produced sago rice ranged from 74.498% to 86.575A%. The more the red bean flour added to sago rice, the lower the level of starch was; such levels were influenced by the supplementation with red bean flour, which has lower starch content than sago starch. Thus, the sago rice with the highest red bean flour supplementation had the lowest starch content.

The results of a research conducted by Ref. [34] on making flakes from corn starch with supplementation of red bean flour show that starch content decreases when higher amounts of red bean flour, which has lower starch content than corn, are added. Before the extrusion process for the preparation of the sago rice analog, pre-gelatinization was performed with high amounts of water (> 40%), so that the cooling process after extrusion would increase the chances of reassociation of amylose molecules to undergo retrogradation. According to Ref. [35], the amount of water added to the starch dough affects the process of expansion of starch and starch granule gelatinization. Supplementation of the starch suspension with scarce amounts of water resulted in a suboptimal amount of amylose discharged from the granules, reducing the chances for retrogradation. The study by [36] also found that applying higher temperatures affected the damage level of granules, causing a decrease in starch content. In this research, the extrusion process was performed with the cold method, whereas the heating process was only carried out in the pre-gelatinization stage. Therefore, when materials were inserted into the extruder, they were immediately cooled, and this caused the starch retrogradation process, which made the starch difficult to be degraded. Sago rice not supplemented with red bean flour had the highest total starch content because sago starch has a more intact and stronger granule structure so that it is more resistant against hydrolytic damage and results in lower starch digestibility.

I. Changes of starch granule structure

Scanning Electron Microscopy (SEM) results show that the extrusion process for the preparation of sago analog rice caused changes in the structure and size of starch granules (Figure 3).

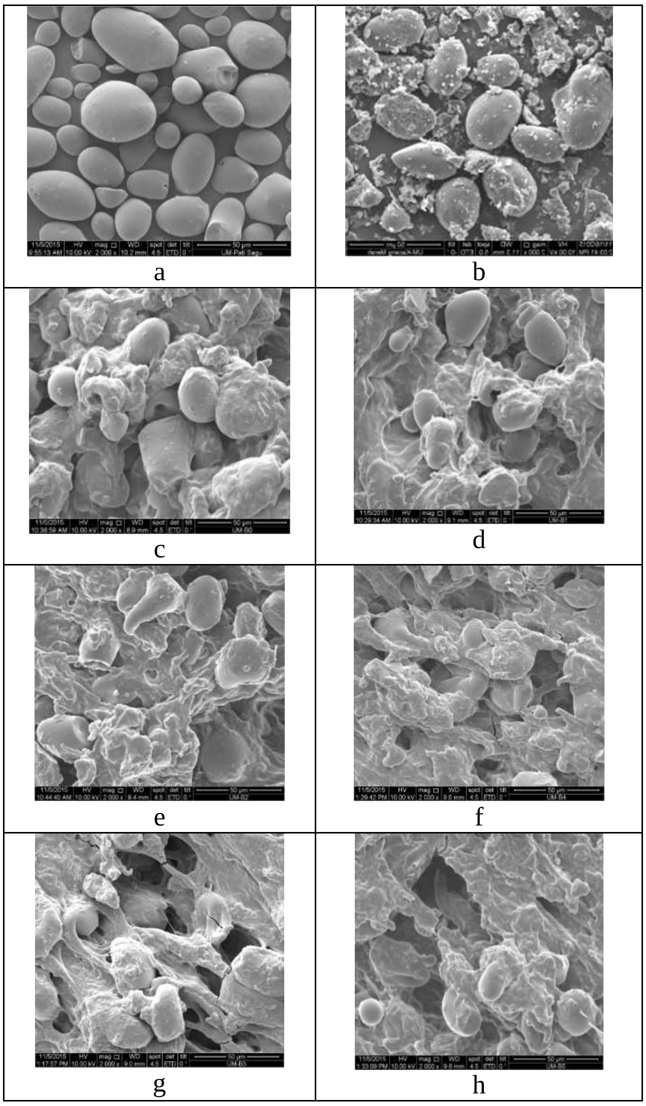

Fig. 3 SEM observation of starch granules. a = Sago starch; b = Red bean flour; c = BS100; d = BSKM5; e = BSKM10; f = BSKM15; g = BSKM20; h = BSKM25

The sizes of starch granules were approximately 28.95-37.33 µm (BS100), 28.63-34.36 µm (BSKM5), 21.49-31.99 µm (BSKM10), 20.35-30.12 µm (BSKM15), 18.11-20.62 µm (BSKM20), and 14.95-24.03 µm (BSKM25). BS100 sago rice displayed more complete starch granules, a more homogeneous surface, and less porosity in comparison with sago analog rice supplemented with red bean flour (BSKM5 to BSKM25). Supplementation with red bean flour made the granule structure appear deteriorated, with rough surfaces and high porosity. Besides, the size of granules of analog rice supplemented with red bean flour. This indicates that sago starch is more resistant to hydrolytic enzyme attack and has lower digestibility.

According to Ref. [37], sago starch has a swelling power of 97%. The swelling power of starch granules is reversible when it does not exceed the temperature of gelatinization, and it is irreversible when it reaches the temperature of gelatinization. The temperature of gelatinization is characteristic for each type of starch, where the temperature was started with the irreversible swells of starch granules in hot water and ended at the time of loss of the crystals [38].

In this study, sago rice was prepared with the extrusion method. According to [39], the process of extrusion induces physical and chemical changes like gelatinization so that starch granules degrade and the molecular structure of starch may rupture. Cutting and mixing at high temperatures and with limited water content cause the conversion of big molecules of starch into dextrin, and produce molecules with shorter chains. The extrusion process can affect particle size by damaging cell wall components. The cooling process of gelatinized starch causes changes in starch structure, and shapes retrograded insoluble starch. The process of gelatinization and retrogradation of starch influences the digestibility of starch by amylase in the small intestine [40].

According to Ref. [41] sago starch granules have a cell diameter of approximately 40-50 µm, whereas according to [42], sago starch has more varied sizes, ranging from 5 to 80 µm. [43] reported that starch granules can be divided into two categories, small size (5-10 µm) and big size (25-40 µm) granules. The size of starch granules is related to the total surface area. The smaller the size of starch granules, the greater the total surface area of granules is. With a greater surface area, enzymes that lyse starch have a larger area available to hydrolyze starch into glucose, and therefore digestion and absorption of starch can occur faster. According to [44], there is a negative correlation between the size of starch granules and the coefficient of digestion. This indicates that starch hydrolysis occurs through a diffusion-controlled or surface-controlled mechanism. In other words, the surface area of starch has a role in controlling the digestion rate. Therefore, if the size of starch is small, starch will be more easily digested, making the value of IG high.

In terms of size, sago starch granules are classified as big size granules [45]. The size of starch granules has a very important role in implementation processes in food industry. Starch is digested in the human body by the amylase enzyme. This enzyme is present in saliva and in the pancreas. Amylase hydrolyzes starch into maltose. The process of digestion of starch by amylase is affected by the size of its particles. The smaller the particle size, the larger the surface area is, so that starch can be more rapidly digested than starch having larger size granules [46]. The amylose and amylopectin contents of starch influence granule size and molecular weight. The amylose fraction of starch granules limits the blooming of starch granules and keeps their integrity. The higher the amylose content of starch is, the stronger its intramolecular bonds are [47]. According to Ref. [48], granules having bigger size have a stronger resistance against heat and water treatment than the ones having smaller size. In addition, [49] propose that there is not any significant correlation between gelatinization and size of starch granules; however, the temperature of gelatinization has a correlation with the compactness of granules and their amylose and amylopectin content.

Several factors have a role in the low level of amylolysis of sago starch granules according to Ref. [50, 51] : (1) α-amylase is not able to enter the sections of granules; (2) the enzyme is restricted by starch granule surface areas, broader crystalline levels, and the existence of minor components which coat the surface of granules. The limited granule surface available for absorption might occur because the size of granules is relatively big or only has several sequence segments suitable because this enzyme can cleave only α-1,4 branches, whereas it is quite far from the last sequence and branch point.

The low digestibility of sago starch also is also related to its crystalline structure and the presence of polyphenol, which coats sago starch granules. Minor components of polyphenol have inhibitory activities on the starch digestive enzyme. Inhibitory compounds also have a role in sago starch durability during degradation processes. Based on the investigation of the organoleptic, chemical, and physical characteristics of sago rice, we conclude that it has a great potential to be developed as a functional alternative staple food.

IV. Conclusions

Sago analog rice supplemented with up to 10% red bean flour (BS100, BSKM5, and BSKM10) was accepted by the panelists of this study. No significant differences were observed in their taste, aroma, and texture, and the values obtained were "quite like" for taste and aroma and "like" for texture. Water content and weight of lost water of sago rice did not display significant differences. Conversely, ash, protein, fat, starch, and water content, cooking time, and water absorption showed significant differences. High supplementation of sago rice with red bean flour made the granule structure appear damaged and with a rough surface, and increased its porosity. Moreover, the size of the granules was also smaller. Sago analog rice with the addition of red bean flour up to 10% has great potential to be developed as a functional alternative staple food.

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REFERENCES

[1] Central Bureau of Statistics. (2017) Study of Consumption of Staples in 2017. [Online]. Available: https://www.bps.go.id/. In Bahasa Indonesia.

[2] Samad, “Pembuatan Beras Tiruan (Artificial Rice) dengan Bahan Baku Ubi Kayu dan Sagu,” Prosiding Seminar Teknologi untuk Negeri (BPPT) Jakarta, pp. 36 – 40, 2003. In Bahasa Indonesia.

[3] [DEPTAN] Ministry of Agriculture of the Republic of Indonesia, “General guidelines for diversifying food consumption in 2011,” Jakarta: Ministry of Agriculture's Food Security Agency, 2011. In Bahasa Indonesia.

[4] [DitjenbunKementan] Directorate General of Plantation, Ministry of Agriculture, “Annual Increase in Production, Productivity and Quality of Sago Plant Technical Guidelines”, Jakarta, 2013. In Bahasa Indonesia.

[5] Sumaryono. “Tanaman sagu sebagai sumber energy alternative,” Warta Penelitian dan Pengembangan Pertanian, 29:4, 2007. In Bahasa Indonesia.

[6] Zi-Ni, T., Rosma, A., Karim, A.A. danLiong, M.T, “Functional Properties of Resistant Starch Type-III from *Metroxylon sagu* as Affected by Processing Conditions,” Jurnal Tropical Agricultural Science, 38 (3), pp. 399-412, 2015.

[7] Wahjuningsih, S.B. and Kurnarto B, “Study on Addition of Prickly to Accelerate Natural Fermentation Time in Making Analog Rice,” Competitive Grant Research Report. Department of Agricultural Product Technology, Faculty of Agriculture Technology, University of Semarang, 11 (2), pp.127-243, 2013. In Bahasa Indonesia.

[8] Riaz, M.N, “Introduction to Extruders and Their Principles. ExrtrudersIn Food Applications,” pp. 1-4. US: CRC Press, Boca Raton, 2000.

[9] Camire, M., Dougherty, M and Briggs, J, “Functionality of fruit powders in extruded corn breakfast cereals,” Food Chem. 101, pp. 765–770, 2007.

[10] Koide, K., Fukushima, T., Tomita, T., Kuwata, T, “Fabricated rice,” U.S patent, Japan, Meiji Milk Products, Co., Ltd. 5.932.271, 1999.

[11] Zhuang , H., An , A., Chen , H., Xie, Z., Zhao, J., Xu , X., Jin, Z, “Effect of Extrusion Parameters on Physicochemical Properties of Hybrid Indica Rice (Type 9718) Extrudates,” Journal of Food Processing and Preservation, 34(6), pp. 1080–1102, 2010.

[12] Budi, F.S., Hariyadi, P., Budijanto, S. and Syah, D, “Effect of dough moisture content and extrusion temperature on degree of gelatinization and crystallinity of rice analogues,” Journal of Development in Suitanable Agriculture, 10, pp. 91-100, 2015.

[13] Wahjuningsih, S.B. and Haslina, “Kajian Pengembangan Beras Analog Berbasis Tepung Mokaf, Tepung Garut dan Tepung Kacang Merah’” Proseding Seminar Nasional dan Pameran Produk Pangan, Perhimpunan Ahli Teknologi Pangan Indonesia (PATPI), pp. 888-901, 2015.

[14] Haliza, W., E.Y. Purwani, and S. Yuliani, “Evaluasi kadar pati tahan cerna dan nilai indeks glikemik mi sagu,” Jurnal Teknologi dan Industri Pangan XVII (2), pp. 149-152, 2006.

[15] Alfons, A. J. B. and Rivaie, A.A, “Sagu mendukung ketahanan pangan dalam menghadapi dampak perubahan iklim,” Journal Perspektif 10(2), pp. 81-91, 2011.

[16] Prabawati, S. and Suismono, “Mendongkrak pemanfaatan sumber pangan dengan sentuhan teknologi,” Warta Penelitian dan Pengembangan Pertanian, 27:6, 2005.

[17] Rahayu, W.P, “Penuntun Praktikum Penilaian Organoleptik,” Jurusan Teknologi Pangan dan Gizi, Fakultas Teknologi Pertanian, Institut Pertanian Bogor, 2001.

[18] Noviasari, S., Feri, K andSlamet, B, “Pengembangan Beras Analog Dengan Memanfaatkan Jagung Putih,” J. Teknol. dan Industri Pangan 24 (2), pp. 194-200, 2013.

[19] Sathe, S. K. and D. K. Salunkhe, “Isolation Partion, Characterization and Modification of The Great Northem Bean (Phaseulus vulgaris) Starch,” Jurnal Food Science, 46 (2), pp. 617-621, 1981.

[20] Goldstein, J. L., Newbury, D. E., Echilin, P., Joy, D. C., Jr. A. D. R., Lyman, C.E., Flori, C andLifshin, E, “Scanning Electron Microscopy and X-Rays Microanali,” 1992.

[21] (AOAC) Association of Official Analytical Chemists, “Official Methods of Analysis of The Association of Official Agriculture Chemist (sixteenth edition),” Virginia, 2006.

[22] Wahjuningsih, S.B., Marsono, Danar, P., Bambang, H, “A Study of Sago Starch and Red Bean Flour-Based Analog Rice Development as Functional Food,” Proceedings on the 3rd International Conference on Agricultural and Food Engineering, 23-25 Agustus 2016, Kuala Lumpur, Malaysia, 2016.

[23] Sessa, D. J. and Rackis, J. J, “Lipid derived flavors of legume protein products,” J. Am. Oil Chem. Soc. 54, pp. 468-473, 1977.

[24] Xiaodi, S., Jingyan, L., Shuming, W., Lei, Z., Lijuan, Q., Tianfu, H., Qianyu, W., Kow-Ching, C.S and Shuntang, G, “Flavor characteristic analysis of soymilk prepared by different soybean cultivars and establishment of evaluation method of soybean cultivars suitable for soymilk processing,” Food Chemistry, 2015.

[25] Jiang, Z., Marjo, P., Yu-jie, W., Anna-Maija, L., Fred, L. S., Hannu, S., Vieno, P and Tuula, S.S, “Faba bean flavor and technological property improvement by thermal pre-treatments,” LWT-Food Science and Technology. 68, pp. 295-305, 2016.

[26] Furia, E. T, “Handbook of Food Additives Volume 1-2,” CRC Press: Boca Raton, 1980.

[27] Behall, K.M. and J. Hallfrisch, “Plasma Glucose and Insulin Reduction After Consumption of Bread Varying in Amilose Content,” European Journal of Clinical Nutrition. 56, pp. 913-920, 2002.

[28] Camire, M. E and Flint, S. I, Thermal processing effects on dietary fibre composition and hydration capacity in corn meal, oat meal and potato peels,” Cereal Chem. 68(6), pp. 645–647, 1991.

[29] Kurachi, H, “Process for Producing Artifical Rice,” U.S. Patent No: 5403606, 1995.

[30] Hayat, A. A., Ahmed, A., Khalil, S. and Gulfras, M, “Exploring the Potential of Red Kidney Beans (Phaseolus Vulgaris L) to Develop Protein Based Product for Food Applications,” The Journal of Animal and Plant Sciences. 24(3), pp. 860-868, 2014.

[31] Uthumporn, U., Wahidah, N. and Karim, A.A, “Physicochemical Properties of Starch from Sago (MetroxylonSagu) Palm Grown In Mineral Soil At Different Growth Stages,” IOP Conf. Series: Materials Science and Engineering 62. 012026, 2014.

[32] Muslikatin, “The Making of Extruction Rice with Adding of Seaweed Extract”, Skripsi, IPB: Bogor, 2011. In Bahasa Indonesia

[33] Audu, S.S. and Aremu, M.O, “Effect of Processing on Chemical Composition of Red Kidney Bean Flour (Phaseolus vulgaris L),” Pakistan Journal of Nutrition. 10(11), pp. 1069-1075, 2011.

[34] Permana, R. A. and Putri W. D. R, “Pengaruh Proporsi Jagung dan Kacang Merah Serta Subtitusi Bekatul Terhadap Karakteristik Fisik Kimia Flakes” Jurnal Pangan Agroindustri 3 (2), pp. 734-742, 2015. In Bahasa Indonesia.

[35] Sajilata, M.G., R.S. Singhal, P.R. Kulkarni, “Resistant Starch – a Review,” Comprehensive Reviews in Food Science and Food Safety, Vol. 5, 2006.

[36] Nazrah, Julianti E., Masniary, L. L, “Pengaruh Modifikasi Fisik Terhadap Karakteristik Pati dan Produksi Pati Resisten dari Empat Varietas Ubi Kayu (Manihot esculent),” Jurnal Rekayasa Pangan dan Pertanian 2 (2), pp. 1-9, 2014. In Bahasa Indonesia.

[37] Hariyadi, P, “Mempelajari kinetika gelatinisasi sagu (Metroxylonsp),” Institut Pertanian Bogor, Fakultas Teknologi Pertanian, Skripsi, 1984. In Bahasa Indonesia.

[38] Anonymous, “Penelitian Pemanfaatan Sagu Sebagai Bahan Pembuatan Makanan,” Laporan Akhir, Kerjasama BPPT dengan Pusat Pengembangan Teknologi Pangan IPB, Bogor, 1987. In Bahasa Indonesia.

[39] Gomes Luciana de Oliveira Froes, Raquel de Andrade Cardoso Santiago, Ana Vania Carvalho, RosangelaNunesCarvalho, Iana Gabriela de Oliveira and Priscila ZaczukBassinello, “Application of extruded broken bean flour for formulation of gluten-free cake blends,” Food Sci. Technol, Campinas. 35(2), pp. 307-313, 2015.

[40] Calixto, F. S. andAbia, R, “Resistant Starch: an indigestible fraction of foods”. 42(3): 239-242, 1991.

[41] Flach, M, “The Sago Palm: Domestication Exploitation and Products,” Food and Agriculture Organization of the United Nations, Rome, 1983.

[42] Wirakartakusumah, M.A., Eriyatno, S., Fardiaz, M., Thenawidjaja, D., Muchtadi, B.S.L., Jenie, and Machfud, “Studi Tentang Ekstraksi, Sifat-SifatFisiko Kimia Pati Sagu dan Pengkajian Enzima,” Dirjen Dikti, Departemen Pendidikan dan Kebudayaan, 1984.

[43] Hoseney, R. C, “Principles of Cereal Science and Technology, 2nd ed,” American Association of Cereal Chemists, Inc. St. Paul, Minnesota, pp. 378, 1998.

[44] Dhital, S., A.K. Shrestha,and M.J. Gidley, “Relationship between granule size and in vitro digestibility of maize and potato starches,” Carbohydrate Polymers 82(2), pp. 480-488, 2010.

[45] Jading, A., Eduard, T., Paulus, P. and G. Sarman, “Karakteristik Fisikokimia Pati Sagu Hasil Pengeringan Secara Fluidisasi Menggunakan Alat Pengering Cross Flow Fluidized Bed Bertenaga

Surya Dan Biomassa," Jurusan Teknologi Pertanian, Universitas Negeri Papua, 2011. In Bahasa Indonesia.
[46] Tharanathan, R. N. and Mahadevamma, S, "Grain legumes: A boon to human nutrition," Trends in Food Science and Technology 14, pp. 507-518, 2003.
[47] Banks, W., Greenwood, C.T. and Muir, D.D, "The Structure of Starch," Molecular Structure and Functions of Food Carbohydrate, London (UK): Applied Sci. Publ. Ltd., 1973.
[48] Suarni, "Produk makanan ringan (flakes) berbasis jagung dan kacang hijau sebagai sumber protein untuk perbaikan gizi anak usia tumbuh," Prosiding Seminar Nasional Serealia, pp. 304, 2009. In Bahasa Indonesia.
[49] Juliano, B.O. and Kongseree, "Physic Chemical Properties of Rice Grain and Starch from line differing in amilosacontentand gelatinization temperature," J. Agric and Food Chem., 20 (3), pp. 714-718, 1968.
[50] Govindasamy, S., Oates, C. G. and Wong, H. A, Characterisation of changes of sago starchcomponents during hydrolysis by a thermostable alpha-amylase," Carbohydr Polym. 18, pp. 89–100, 1992.
[51] Azmi, Azlin & Malek, M & Mohamad Puad, Noor Illi.. A review on acid and enzymatic hydrolyses of sago starch. International Food Research Journal. 24, pp 265-273, 2017.