

Physicochemical and Functional Properties of Vermicelli Made of Modified White Rice, Brown Rice, and Black Rice

Eko Yuliasuti Endah Sulistyawati^a, Akhmad Mustofa^{b,*}, Rina Rismaya^a, Nanik Suhartatik^b

^a Faculty of Science and Technology, Universitas Terbuka, Jalan Cabe Raya, Pamulang, South Tangerang, Indonesia

^b Faculty of Technology and Food Industry, Slamet Riyadi University, Jalan Sumpah Pemuda Street No. 18, Surakarta, Indonesia

Corresponding author: *garadaiva@gmail.com

Abstract—Modification technology of starch has been developed to enhance its utilization in the food industry and for health-related purposes. Starch serves as a carbohydrate source that contributes to energy when digested in the body. The starch modification enables starch to be converted into resistant starch. This study investigated the physicochemical properties of vermicelli made from modified rice flour. The rice flour used in this study originated from three varieties: white rice, brown rice, and black rice. The physicochemical properties of vermicelli evaluated were chemical composition, pasting properties, and starch morphology. Analyses were conducted on both the rice flour and the vermicelli product. The results indicate that the protein content in rice flour ranged from 10.30% to 10.87% (dry weight), whereas the protein content in vermicelli decreased to 9.78% to 10.26% (dry weight). There was also a decrease in other components like lipid content, amylopectin, anthocyanin, and crude fiber. The antioxidant activity of vermicelli tended to be lower than that of the flour form, as did the anthocyanin content. Processing rice flour enhanced the water-holding capacity of starch and reduced its swelling power. Rice flour modification can be employed as an alternative to improve the functional properties of starchy food materials.

Keywords—Rice; modified flour; vermicelli; resistant starch.

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I. INTRODUCTION

Resistant Starch (RS) is a type of starch that cannot be digested by the human digestive system because it is not recognized by the enzymes. Resistant Starch is divided into 5 groups [1]: RS I (resistant starch due to physical barriers preventing water or enzymes from meeting starch, such as seed coats in whole grains), RS II (natural starch that is indigestible due to the presence of type B crystalline structure), RS III (starch that undergoes retrogradation), RS IV (chemically modified starch), and RS V (starch forming complexes with lipids). RS I, RS II, and RS V are abundant in grains (32-36%), whereas they are very low in cereal grains, ranging from 0.1-3.2%. The RS content in starchy materials can be increased through various methods, such as physical methods like HMT, annealing, autoclaving, or chemical and enzymatic methods [2]–[5]. Resistant Starch has lower calories compared to high-amylose starch. Han [6] It was reported that RS's energy content is very low, approximately 10% digestible starch. The low-calorie content of RS is one reason it is widely used in treating diabetes.

Rice is one of the affordable sources of starch. Making rice flour is a potential business opportunity because rice is a staple food for Indonesians. Rice has been widely used to produce Resistant Starch (RS) using various methods. The production of resistant starch from rice can be achieved through heating and cooling, chemical processes, enzymatic processes, or a combination of these methods [7]–[12]. Each method has its strengths and weaknesses. For example, enzymatic methods are widely applied due to their ease of use, minimal heat requirements, and moderate reaction conditions [13]. On the other hand, annealing or repeated heating techniques are preferred as they are simple, straightforward processes that do not require chemical agents. However, using colored rice varieties such as brown or black for resistant starch production remains limited.

The annealing process is categorized as a hydrothermal treatment involving the application of water and heating. The hydrothermal category has two treatment models: annealing and heat moisture treatment (HMT). In the annealing process, a significant amount of water (more than 40%) is applied, followed by heating below the gelatinization temperature.

Conversely, the HMT process involves limited water application and heating above the gelatinization temperature [14], [15]. Faridah [16] emphasized that for optimal RS production through annealing, a water content of 80%, incubation for 24 hours, and heating temperature between 50-54°C are recommended. Hydrothermal treatments can alter the gelatinization characteristics of starch, such as increasing the gelatinization temperature, enhancing the viscosity of starch paste, and improving the starch's retrogradation potential [17].

The annealing process leads to the reorganization of amylose chains, resulting in a solid crystalline structure that is physically impenetrable. This structure prevents digestive enzymes from hydrolyzing glycosidic bonds, producing resistant starch. This method has been applied to various agricultural products such as rice, potatoes, sweet potatoes, sorghum, and others [16]. Faridah [16] reported that materials with amylose content ranging from 20 – 40% yield the highest resistant starch, up to 6.3%, through the annealing method. Conversely, materials with 85% amylose produce the lowest resistant starch. In addition to altering the pasting properties of the resulting starch, the annealing process can also lower the glycemic index of the produced starch [18].

It has been reported that Resistant Starch (RS) can control blood sugar levels in the body [19], [20] and lower cholesterol. Chuathong [21] reported that consuming type 4 resistant starch can lower blood cholesterol for individuals showing symptoms of metabolic syndrome. A person is categorized as having metabolic syndrome if they have 3 out of 5 of the following symptoms: high triglycerides (TG), low HDL cholesterol, blood glucose levels of 100-125 mg/dL, increased waist circumference, and hypertension. [22], [23]. Consuming resistant starch can be used as therapy for several diseases, such as diabetes, obesity, and cardiovascular diseases.

Vermicelli is a processed product made from rice flour or corn flour. This food product is widely consumed by Indonesians as a main meal and as a snack. Vermicelli is typically made from white rice, while vermicelli made from colored rice is uncommon in society. Colored rice has advantages over white rice due to its lower glycemic index [24], [25]. The production of vermicelli from modified rice with a higher level of resistant starch can enhance the health benefits of vermicelli. Information regarding the physicochemical properties of vermicelli made from modified rice flour, especially colored and non-colored (white) rice, is relatively scarce. This research aims to determine the physical and chemical characteristics of vermicelli made from white, brown, and black rice flour modified through annealing. The findings of this study are expected to contribute to the development of functional food based on rice and modified flour.

II. MATERIALS AND METHOD

A. Materials

The main materials used in this research were three types of rice: white, brown, and black, obtained from the local market in Surakarta, Central Java, Indonesia. The chemicals used were of analytical grade.

B. Modification of Rice Flour using the Annealing Method

The modification of rice flour through annealing followed the method outlined by Marboh and Mahanta [26] with some modifications. 300g of rice flour was mixed with water to achieve 80% moisture content. The mixture was then left to stand for 24 hours at room temperature. Subsequently, the solution was heated at 50°C for 24 hours using a water bath shaker. The sample was centrifuged at 2000g for 15 minutes, and the supernatant was discarded. The resulting sample was dried at 30°C and sieved through an 80-mesh sieve.

C. Production of Rice Vermicelli

The production of vermicelli followed the modified method by [27]. The modified rice flour was moistened to achieve approximately 40% moisture content. The obtained dough was then pressed until the water reduced, forming a cake-like dough. The dough was steamed on low heat for 15 minutes, then molded and rolled to a thickness of approximately ± 2 mm. The thin dough was shaped into vermicelli using a vermicelli maker. The resulting vermicelli was dried using a cabinet dryer at 60°C for 8 hours.

D. Analysis of Vermicelli Characteristics

The vermicelli was analyzed to determine moisture content, fat, protein, ash, and crude fiber (proximate analysis). Moisture content was analyzed using a moisture analyzer, ash content by thermogravimetric method, fat content by the Soxhlet method, and protein content by micro Kjeldahl method [28]. The determination of resistant starch content was done using an acid-base titration method described by Rahayu [29]. The three-dimensional structure of rice flour and vermicelli was determined using a Scanning Electron Micrograph (SEM). Anthocyanin content was determined using a pH differential method as described by [30].

E. Swelling Power

Swelling power was determined using the method described by Wang [31]. 0.5 g of the sample was dissolved in distilled water and heated at 60°C and 95°C for 30 minutes using a water bath. The solution was then cooled and centrifuged at 5000 rpm for 15 minutes. The supernatant was discarded, and the sediment was collected and weighed. Swelling power (SP) was calculated using the formula weight of sediment/weight of the dried sample.

F. Pasting Properties

The viscosity of the paste obtained from rice flour and vermicelli was measured using a Rapid Visco Analyzer (RVA) following the method used by [31]. For the analysis, 2 g of the sample was mixed with 25 ml distilled water. Quality parameters of the paste, such as paste formation temperature, time, peak viscosity, breakdown viscosity, final viscosity, and setback viscosity, were determined.

G. Method of Analysis

The collected data were analyzed using One-way ANOVA to determine inter-group dependencies within the industry, followed by Duncan's multiple range test with a significance level of $P < 0.05$. Data analysis was performed using IBM SPSS version 20.

III. RESULTS AND DISCUSSION

A. Morphology of Rice Flour and Vermicelli

The scanning electron micrographs of rice flour and vermicelli are presented in Figure 1. The morphological analysis indicated distinct structures for white rice flour compared to brown and black rice flour. White rice flour displayed a 3D structure with starch granules ranging from 2-5 μm , with few granules entrapped within the protein structure. The micrograph of the starch granules from white rice flour appeared polygonal. Similar results were reported by Xie [32] although their study did not compare the micrograph structures with vermicelli flour. In contrast to white rice flour micrographs, both brown and black rice flours exhibited a smoother surface, suggesting effective entrapment of starch granules within the macromolecular protein structure [33]. The micrograph structures in this study resemble those of white rice flour produced by Suklaew [34].

Annealing is defined as applying heat to starch below its gelatinization temperature in excess water [35]. Based on their composition (Table 1), brown and black rice flours have similar amylose and amylopectin compositions, while white rice flour contains 67.0% amylopectin and 26.66% amylose. The micrograph structure of vermicelli flour showed a pleasing and porous appearance, consistent with findings reported by Sittipod and Shi [36]. However, Zhang [11] reported a different micrograph structure for vermicelli flour from indica rice flour, resembling a honeycomb-like structure with wide pores. This disparity may be attributed to differences in annealing temperature, time, and rice varieties. Higher annealing temperature and longer time result in more pores or holes [36]. Figure 1 shows that black rice vermicelli flour had more pores than brown and white rice vermicelli flour. According to Kunyaneer [37], amylose was more sensitive to the annealing process than amylopectin.

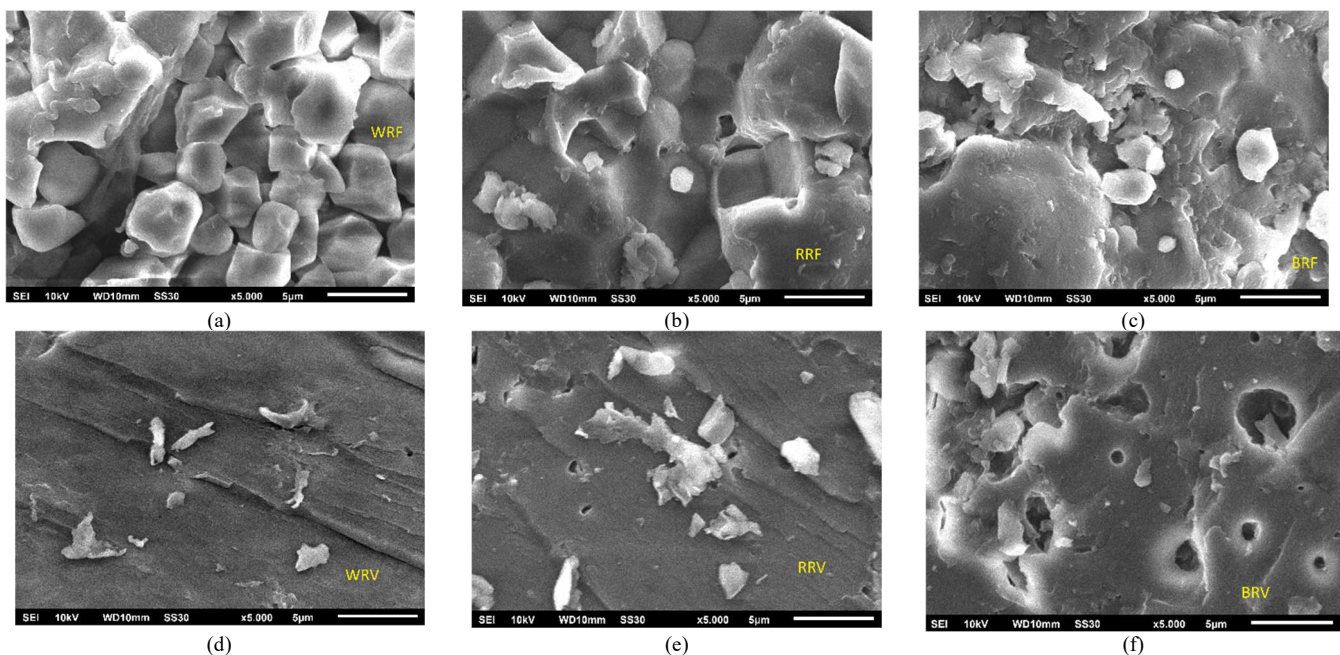


Fig. 1 Microstructure of rice flour and vermicelli flour, A: white rice flour, B: brown rice flour, C: black rice flour, D: white rice vermicelli, E: brown rice vermicelli, F: black rice vermicelli

B. Physicochemical Properties of Rice Flour and Vermicelli Flour after Annealing Process

The moisture content of rice flour ranged from 10.32-13.81%, while for vermicelli, it was relatively lower, ranging from 3.48-4.73%. The annealing process and converting rice flour to vermicelli increased the amylopectin content. Amylopectin is a starch known for its low water-holding capacity. The amylose content of rice flour ranged from 22.83-26.66%. Huang [38] stated that good rice suitable for vermicelli production should have a minimum amylose content of 22%. The ash content of rice flour and vermicelli ranged from 0.726-1.981% (dw). Similar results were reported by Saeri [39] indicating that wet vermicelli made from a mixture of rice and corn flour had ash content ranging from 0.065-0.700% (ww) and fat content ranging from 0.20-0.435% (ww). The processing of rice flour into vermicelli did

not significantly affect the ash content of the vermicelli at a 5% significance level.

Starch in rice flour decreased after being processed into vermicelli and subjected to annealing. As reported by Sapna and Jayadeep [33], processing involving heat and physical pressure caused damage to the starch structure. The reduction in starch content was accompanied by an increase in the amount of resistant starch (Table 1). Similar findings were obtained in a study by Jacobasch [40] revealed that annealing in Novelose 330 products increased the resistant starch content to 67%. Annealing achieves optimal results with appropriate temperature and time.

The antioxidant activity of brown and black rice flour was relatively higher than that of white rice flour. The antioxidant activity of white rice flour was 13.21%, while brown rice flour and black rice flour reached 86.45% and 82.98%, respectively. Rungratanawanich [41] reported that the bioactive components in white rice with antioxidant activity

include γ -oryzanol, vitamin E, γ -aminobutyric acid (GABA), phenolics, flavones, and anthocyanin. Brown and black rice flour exhibited higher antioxidant activity due to anthocyanin pigments in larger quantities. Yamuangmorn and Prom-U-

thai [42] stated that the total anthocyanin content (TAC) in purple rice (often referred to as black rice) ranged from 12-442 mg/100g.

TABLE I
CHEMICAL COMPOSITION, ANTIOXIDANT ACTIVITY, WHC, AND SWELLING POWER OF RICE FLOUR AND VERMICELLI FROM 3 DIFFERENT TYPES OF RICE

Items	WRF	BwRF	BcRF	WRV	BwRV	BcRV
Moisture (%)	13.81±0.02 ^f	10.96±0.06 ^c	10.32±0.08 ^d	4.73±0.07 ^c	3.48±0.14 ^a	4.26±0.06 ^b
Ash (%dw)	0.73±0.16 ^a	1.94±0.11 ^c	1.98±0.12 ^c	1.03±0.11 ^{ab}	1.33±0.12 ^b	1.67±0.12 ^c
Protein (%dw)	10.69±0.04 ^d	10.30±0.07 ^c	10.82±0.03 ^d	10.26±0.11 ^c	9.97±0.02 ^b	9.78±0.19 ^a
Fats (%dw)	0.41±0.01 ^a	2.25±0.04 ^c	2.61±0.14 ^d	0.37±0.03 ^a	0.48±0.04 ^a	0.69±0.04 ^b
Crude Fiber (%dw)	1.66±0.25 ^d	0.73±0.03 ^c	0.77±0.01 ^c	0.00±0.00 ^a	0.33±0.02 ^b	0.67±0.01 ^c
Starch (%dw)	93.66±0.26 ^c	96.38±0.25 ^c	95.03±0.10 ^d	88.65±1.04 ^a	93.35±0.86 ^c	90.40±0.28 ^b
Amylose (%dw)	26.66±0.21 ^d	23.17±0.18 ^c	22.83±0.21 ^b	27.94±0.13 ^c	22.87±0.13 ^b	21.28±0.12 ^a
Amylopectin (%dw)	67.00±0.26 ^b	73.21±0.29 ^c	72.19±0.21 ^c	60.71±1.15 ^a	70.48±0.79 ^d	69.13±0.16 ^c
Resistant starch (%dw)	1.33±0.02 ^a	6.61±0.02 ^c	4.67±0.05 ^c	1.73±0.02 ^b	7.10±0.02 ^f	4.94±0.02 ^d
Antioxidant activity (%dw)	13.21±0.09 ^a	86.45±0.09 ^f	82.98±0.09 ^c	16.86±0.08 ^b	18.63±0.08 ^c	23.31±0.08 ^d
Anthocyanin (mg/100g)	0.00±0.00 ^a	3.39±0.02 ^c	4.81±0.06 ^d	0.00±0.00 ^a	2.59±0.03 ^b	3.43±0.00 ^c
Total phenol (mg GAE/g)	0.00±0.00 ^a	164.53±1.47 ^c	325.08±4.72 ^c	99.01±1.56 ^b	226.95±0.78 ^d	320.17±7.22 ^c
Water holding capacity (%dw)	104.30±0.41 ^a	129.22±0.30 ^c	122.60±0.06 ^b	258.72±1.37 ^f	254.17±0.29 ^e	220.52±0.54 ^d
Swelling power (%dw)	1472.03±1.94 ^f	1250.26±2.86 ^e	1190.29±4.87 ^d	1101.09±1.67 ^c	882.92±5.20 ^b	802.26±3.99 ^a

Note: WRF= white rice flour; BwRF=brown rice flour; BcRF= black rice flour; WRV = white rice vermicelli; BwRV = brown rice vermicelli; BcRV = black rice vermicelli

The processing of rice flour into vermicelli involves several stages, including rice washing, rice milling into flour, mixing, extrusion, heating, and drying [43]. Heating, drying, and high-pressure application during processing generally reduce the anthocyanin content of the product [44]. Similar results were reported by Laokuldilok and Kanha [45] stating that the drying process leads to anthocyanin degradation in black glutinous rice.

The WHC of white rice starch was lower than that of brown and black rice starch. The annealing process and the conversion of starch into vermicelli significantly affected the WHC of the flour. WHC was influenced by various factors, including the amount of starch and other macromolecular components, starch composition (amylose and amylopectin), starch size, starch structure, amylopectin side chains, and processing factors. The presence of protein and fat also affected water-holding ability. The protein content of vermicelli flour was lower than rice flour before annealing and processing it into vermicelli. It is possible that some proteins were lost or damaged during processing. The highest protein content was found in black rice flour, followed by white and brown rice flour. Farooq et al. [46] also reported similar results that the protein content of local varieties (China) of brown rice was lower than that of black and white rice.

White rice flour's swelling power was higher than brown and black rice flour (Table 1). This value decreased after the flour underwent annealing and was processed into vermicelli. The decrease in swelling power ranges from 25.2-32.6%. Similar results were reported by Wang [47] stating that the annealing process increased solubility and reduced swelling power. Furthermore, Wang [47] noted that vermicelli had a

good texture if the production process involved a mixture of native starch and annealed starch.

C. Pasting Properties of Rice Flour and Vermicelli Flour after Annealing Process

Good vermicelli is made from rice with a minimum amylose content of 22% [38]. The rice flour used as the base in this vermicelli-making process meets this requirement. The lowest amylose content was found in black rice flour, reaching 22.8% (Table 1). Good vermicelli can also be obtained from flour with a low pasting temperature and high gel consistency (hardness) [48]. Table 2 shows that the lowest pasting temperature was obtained with white rice flour, followed by black rice flour and brown rice flour. According to Xie [32], vermicelli should have a pasting temperature of less than 70°C, a setback viscosity of 50 RVU (1 RVU = 12cP), and a breakdown viscosity below 60 RVU. Based on these criteria, none of the three types of rice flour meets the requirements. The respective pasting temperatures for each flour were 81.65°C, 87.10°C, and 83.45°C for white, brown, and black rice flour. Amylopectin with high short-side-chain content will result in a lower pasting temperature [49].

Processing rice flour into vermicelli can decrease the peak viscosity (PV) of vermicelli flour. Starch gelatinization causes thermal damage to the starch granules. This damage can result in changes in the characteristics of the produced starch. Looking at the pasting properties, the vermicelli with the best texture is made from white rice flour due to its low pasting temperature. White rice flour has a higher final viscosity (FV) than the other flours. This indicates that the gel texture of white rice flour is more stable than other flour types.

The highest viscosity was achieved by white rice flour, followed by brown rice flour and black rice flour, which have similar values. These differences in pasta formation properties

were caused by varietal differences, differences in planting seasons [32], and the composition of amylose and short-side-chain amylopectin [50]. The peak viscosity was also influenced by the composition (amylose-amylopectin ratio) and the composition of either short-side chain, medium, or long-side chains. Furthermore, Xie [32] mentioned that the best vermicelli was obtained from rice flour of the

"Zhongjiazao17" variety, which has PV values of 200 RVU, TV 132.0 RVU; BDV 68.3 RVU, FV 251.8; STV 51.5 RVU, and pasting properties of 72.1°C. Flour with such pasting properties will result in a hardness of 3.16N and adhesiveness of 2.65 mJ with an unidentified fracture value. Annealing treatment on rice flour increased the hardness and springiness of the resulting vermicelli [11].

TABLE II
PASTING PROPERTIES OF RICE FLOUR AND MODIFIED RICE VERMICELLI FLOUR

Variety	Peak (PV), RVU	Trough (TV), RVU	Break Down (BD), RVU	Final Visc (FV), RVU	Set Back (SB), RVU	Peak Time (Min)	Pasting Temp (°C)
White rice flour	471.75	390.08	81.67	591.42	201.33	11.67	81.65
Brown rice flour	316.83	248.67	68.17	327.58	78.92	11.67	87.10
Black rice flour	290.83	217.75	73.08	351.42	133.67	10.87	83.45
White rice vermicelli	123.58	121.75	1.83	126.08	4.33	13.00	52.30
Brown rice vermicelli	32.50	26.67	5.83	30.17	3.50	13.00	nd
Black rice vermicelli	53.67	50.75	2.92	60.67	9.92	13.00	91.00

nd = not detected

The pasta formation of rice flour and modified vermicelli flour occurred between minutes 6-9 (Figure 2). Additionally, the gel formation of rice flour before annealing occurred faster than flour that has undergone annealing and processing into vermicelli. Annealing could damage the starch structure and reduce the crystallinity of the resulting flour. Processing annealed flour into vermicelli, involving high-temperature and high-pressure processes, could alter the starch structure in

the flour. Another noticeable change was that the peak viscosity of each flour before and after annealing and processing into vermicelli (Table 2) significantly differed. Good vermicelli made from brown or black rice flour took longer to reach the peak viscosity. This broader time range could be advantageous when applied in industrial-scale processing.

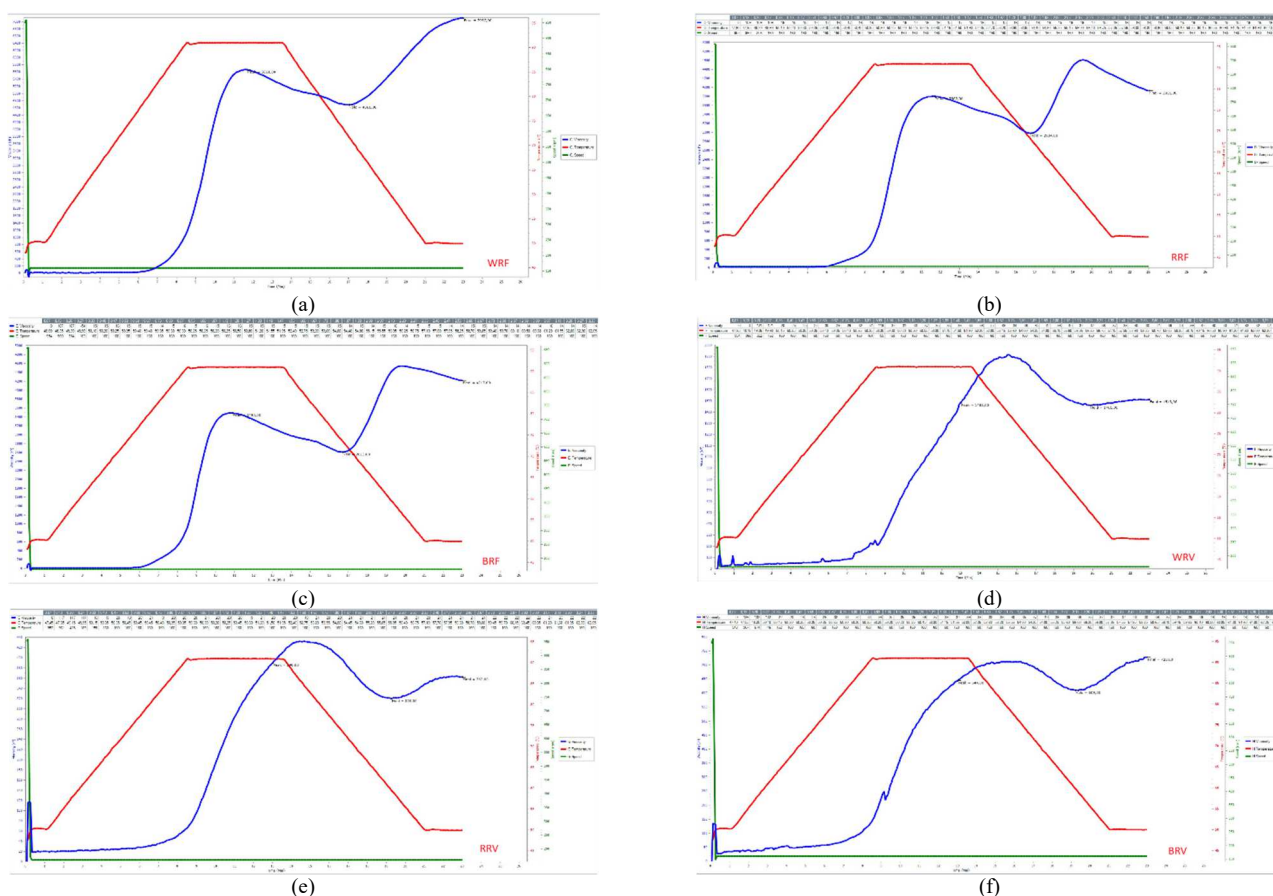


Fig. 2 Pasting properties of rice flour and vermicelli flour, (a): white rice flour, (b): brown rice flour, (c): black rice flour, (d): white rice vermicelli, (e): brown rice vermicelli, (f): black rice vermicelli

IV. CONCLUSION

Modifying rice flour through annealing and processing it into vermicelli generally decreased the percentage of nutritional components in rice flour. However, the resistant starch content of modified rice flour and its water-holding capacity increased. Compared to regular flour, the quality of the modified vermicelli pasta exhibited notable disparities. Modified white rice vermicelli had a low pasting temperature, while vermicelli made from modified colored rice flour exhibited higher resistant starch content and antioxidant activity.

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