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Review Article

The Effects of Chemical Composition of Rice Flour on Physico-Chemical and Functional Properties

Supaluck Kraithong and Saroat Rawdkuen*

Unit of Innovative Food Packaging and Biomaterials, School of Agro-Industry, Mae Fah Luang University, Muang, Chiang Rai 57100, Thailand

Abstract

Rice flour is an extremely versatile material, which is made from grinding rice grain. It is utilized for producing both food and non-food products. The qualities of rice flour including physicochemical and functional properties are important keys for controlling and predicting the products qualities, particularly in foodstuffs. Different properties of rice flour are contributed to the various quality attributes in the final products, which effecting to consumer buying decision. Thus, a reasonable understanding of rice flour properties is necessary for manufacturing or fabricating novel rice-based products. Rice flour properties mainly depend on the chemical composition, influencing from rice varieties, growing conditions, as well as rice flour processing. There have been several pronouncements described the relation between rice flour composition and its properties, however some disagreements, ambiguities, and conflicts in the formation have been seen. Therefore, this work aimed to provide more current information of the effects of chemical composition on rice flour properties, focusing on relationship between chemical composition and its properties.

Keywords: Rice flour, Chemical composition, Pasting, Thermal and functional properties

*Corresponding author: E-mail: saroat@mfu.ac.th

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อิทธิพลขององค์ประกอบทางเคมีต่อสมบัติทางเคมีกายภาพและสมบัติเชิงหน้าที่ของแป้งข้าว

ศุภลักษณ์ ใคร้โท้ง และ สาโรจน์ รอดคืน*

หน่วยวิจัยนวัตกรรมบรรจุภัณฑ์อาหารและวัสดุชีวภาพ สำนักวิชาอุตสาหกรรมเกษตร มหาวิทยาลัยแม่ฟ้าหลวง
อำเภอเมืองเชียงราย จังหวัดเชียงราย 57100

บทคัดย่อ

แป้งข้าวคือผลิตภัณฑ์ที่ผลิตจากการบดเมล็ดข้าว แป้งข้าวจัดเป็นวัตถุดิบเอนกประสงค์ที่สามารถใช้ในอุตสาหกรรมอาหาร สมบัติทางเคมีกายภาพและสมบัติเชิงหน้าที่ของแป้งข้าวเป็นกุญแจสำคัญในการควบคุมคุณภาพหรือคุณลักษณะต่างๆ ของผลิตภัณฑ์อาหาร นอกจากนี้ความแตกต่างของสมบัติของแป้งข้าวยังมีผลต่อลักษณะของผลิตภัณฑ์อาหารและยังส่งผลต่อการยอมรับของผู้บริโภคอีกด้วย ดังนั้นองค์ความรู้และความเข้าใจเกี่ยวกับสมบัติแป้งข้าวจึงเป็นสิ่งจำเป็นต่อการผลิตสินค้าหรือผลิตภัณฑ์ใหม่จากแป้งข้าว สมบัติของแป้งข้าวส่วนใหญ่นั้นจะขึ้นอยู่กับองค์ประกอบทางเคมีและโดยทั่วไปองค์ประกอบทางเคมีนั้นจะมีความแตกต่างกันขึ้นอยู่กับสายพันธุ์ของข้าวและสิ่งแวดล้อมระหว่างการเจริญเติบโตของข้าวรวมทั้งกระบวนการผลิตแป้งข้าว นอกจากนี้ยังมีงานวิจัยจำนวนมากที่ได้ศึกษาและอภิปรายถึงความเกี่ยวเนื่องกันระหว่างองค์ประกอบและสมบัติของแป้งข้าวแต่ยังขาดความชัดเจนในบางประเด็น ดังนั้นบทความนี้จึงมีวัตถุประสงค์เพื่อนำเสนอข้อมูลที่เกี่ยวกับผลขององค์ประกอบทางเคมีต่อสมบัติของแป้งข้าว

คำสำคัญ: แป้งข้าว องค์ประกอบทางเคมี สมบัติด้านความหนืด สมบัติทางความร้อน และ สมบัติเชิงหน้าที่

* ผู้เขียนให้ติดต่อ: E-mail: saroat@mfu.ac.th

Introduction

One of the most substantial cereals in the world is *Oryza sativa*, universally known as rice. The cereal is a member of the tribe Oryzeae (Poaceae), belonging to the grass family. According to USDA (2017), rice has been produced about 487,125 thousand metric tons throughout the globe in 2016-2017, nearby 19,200 thousand metric tons of that has been manufactured from Thailand. At the same period, its consumption has also been raised up from Thailand, nearby 480,959 thousand metric tons (USDA, 2017). As a result, rice is considered as one agricultural product that running the world economy. Rice utilization, it is comprehensively consumed in a grain form. Nonetheless, the powder form (rice flour) is extensively conveyed to food product manufacturing by reason of convenience of using.

Rice flour is a versatile matter that is widely used as raw material and also an ingredient in numerous products such as salad dressing, baby foods, bakery, pasta, noodles, gluten-free products, as well as snacks (Hui, 2006). Regularly, it is prepared from milling rice grain (Setyawati *et al.,* 2016). The differences of rice varieties, growing conditions of rice grain, and also rice flour processing have an effect on the rice flour chemical composition including carbohydrate, protein, and others (Falade and Christopher, 2015). The various chemical compositions contribute to the different properties of rice flour such as pasting, thermal, retrogradation, and functional properties, in which these properties affect the quality attributes of the final products (Putseys *et al.,* 2010). In consequence, a good understanding of the relation between the compositions and properties of rice flour is necessary for fabricating or developing the novel products, since it can predict or control the qualities of the final products (Mir and Bosco, 2014).

Many studies focused only on correlation between carbohydrate content (specifically amylose and amylopectin) and rice flour properties (Varavinit *et al.,* 2003; Wang *et al.,* 2015). Nonetheless, the properties could be also ruled by other components (e.g. lipid, protein) that are contained in the flour (Putseys *et al.,* 2010; Parada and Santos, 2016). These lead several scientists trying to find out about the relationship between the chemical compositions and rice flour properties, however some disagreements, inconsistences, confusions, and also arguments in the information still have been found. An ambiguous perception of rice flour characteristics could lead to inferior quality control in starchy food production.

Hence, this work aims to deliver a better understanding of the effects of chemical composition on rice flour properties. Hopefully, this review will be useful for choosing an appropriate rice flour to manufacture food products and ruling the qualities of foodstuffs or any other that related to rice-based products.

Rice flour processing

Rice flour is manufactured by means of grinding/milling the whole or broken rice grains. Largely, the milling methods are categorized into 3 approaches including dry, semi-dry, and wet millings. These three milling techniques are broadly used to prepare rice flour in both industry and household.

The first milling process is dry grinding, the broken and whole rice grains are ground by the hammer mill or pin mill without adding any water (Asmeda and Noorlaila, 2015). This process is somewhat convenient for conducting. However, the dry grinding method caused some damages to starch granules because of heat generating during processing. This phenomenon is cause of exposing hydrogen groups, in which the groups will be able to interact with water molecules while the flour being used or applied in the food processing with adding of water (Leewatchararongjaroen and Anuntagool, 2016).

In the meantime, the other two grinding methods that are semi-dry and wet milling processes require water during conducting. In the case of semi-dry milling, rice kernels are soaked with water. Then, these are drained and dried before grinding (Arendt and Zannini, 2013). The last method for preparing rice flour is wet grinding. In general, rice grains are soaked with water. After that, they are ground with excess water (Tong *et al.,* 2015a). Rice flour that is obtained after grinding method undergoes to drying process (40-60°C) to decrease its moisture content (<15%), subsequently rice flour from semi-dry and wet milling methods is reground (Hui, 2006).

Conditions of the milling processes such as time and ratios of rice: water for soaking (semi-dry and wet grinding processes), along with temperature and time for decreasing moisture in all grinding techniques could be different in each manufacturing, depending on the facility, practicability, and convenience. The differences in the conditions of rice flour processing are presented in Table 1.

Different grinding techniques and conditions provide the variation in rice flour chemical composition (Table 1). Rice flour prepared by means of semi-dry and wet grinding contains less soluble components such as soluble protein, sugars, and non-starch that bind with lipids, since those components are dissolved during the soaking process (Kale *et al.,* 2015). Chiang and Yeh (2002) also confirmed that wet grinding offers the lower lipid and protein contents to the rice flour. However, rice flour that is prepared by the wet and semi-dry milling processes has finer particle size as compared to dry milling, giving smoothness and consistency to final products textures. In terms of functional properties, the values of water absorption index, flour swelling volume and solubility in rice flour made from dry grinding are higher than that of rice flour prepared from the other two methods, fitting with products that require high specific volume (Asmeda and Noorlaila, 2015).

Rice chemical composition

The most enormous content that is universally found in rice is carbohydrate (over 70%) and the second one is protein (usually found as 7-9%) (Thirumdas *et al.,* 2016). In addition, the small amounts (<5%) of lipid, ash, as well as fiber are also observed (Table 2). Rice flour presents different chemical compositions because of the differences in varieties, growing conditions (e.g., soil and weather), and also rice flour processing (Serna-Saldivar, 2010).

Carbohydrate is consisted of starch, cellulose, hemicellulose, as well as sugar (sucrose) (Mir *et al.,* 2014). According to Oko and Ugwu (2011), starch is the biggest part in rice carbohydrate (generally above 70%). Nonetheless, some rice varieties including Jamila (49.2%), Jeep (47.6%), and Kwandala (46.5%) (Table 2) have the less number of starch content than 70% due to containing higher in other contents. The main components that are found in starch are amylose (AM) and amylopectin (AP). Regarding the difference of AM content, rice flour is divided into 2 types, non-waxy (≈2-37%) and waxy rice flours (≈1-2%). This content is presented in a single-helix form due to hydrogen bonding among glucose molecules (Fig. 1 [g]). However, it is also consisted of light branches, supporting from α-(1, 6) glycosidic link-ages (Tikapunya et al., 2017). AM has an average molecular weight of 2.5×105 (Hamaker, 2007). It can associate with free fatty acids, fatty acid components of glycerides, some alcohols, and iodine, because of its hydrophilic groups (Putseys *et al*., 2010). Besides, the formation between AM and iodine can turn amylose color to blue (Fig. 1 [f]), using as AM determination. On the other hand, AP is known as the highly branched polymers, consisting of 5-6% α-(1, 6)-glycosidic link-ages (Fig. 1 [b]). Nevertheless, its primary structure is still made of α-(1, 4)-glycosidic bonds (Zhu, 2015). AP is composed of approximately 600,000 glucose molecules, which has a molecular weight of 10^8 (Seager and Slabaugh, 2011).

It is generally represented in a double-helix form, in which the integration of that form is contributed to double-helix cluster, as shown in Fig. 1 [d], located in the crystalline areas. In contrast, the branch points of AP are commonly situated in amorphous regions (BeMiller and Whistler, 2009). According to Hamaker (2007), the branched chains of AP are categorized into A, B, as well as C chains (Fig. 1 [e]). A chain is considered as no further branching point, whereas B chain contains one or more branching points. A chain that was possessed reducing end is known as a C chain (Hii *et al.,* 2012).

Protein in rice has been found around 5-12% (Table 2). According to Juliano (1993), the rice varieties that contain protein content higher than 10% have been considered as a high protein rice, such as K/A92VM0611 (12.63%) and Beihan (11.94%) (Table 2). Whereas, the varieties that contain protein content around 7% or lower have been considered as a low protein rice, including TK8 (6.4%), Jamila (7.7%), MR 219 (7.7%) (Table 2). Rice protein is consisted of glutelins (80%), globulins (10%), albumins (5%), and prolamins

(5%), considering as the hypoallergenic and highly digestible proteins (Amagliani *et al.,* 2017).

The amount of protein content in rice flour mostly depends on nitrogen fertilization and water availability during rice grain growth (Serna-Saldivar, 2010). According to Hui (2006) and Parada and Santos (2016), protein contains both hydrophobic and hydrophilic groups, and also its side chains can associate with AM, known as AM-protein complex. For that reason, protein is one component that plays an important role in rice flour properties. Sun *et al.* (2008) studied the effects of protein on rice flour rheology. They found that protein increased heat-resistant capacity and kept hardness and stickiness of rice flour gel when the temperature is changed, whereas it decreased pasting temperature. Pracham and Thaiudom (2016) also studied the effects of Jasmine rice flour protein on the textural and rheological properties of pudding made from that flour. They reported that protein increased adhesiveness, springiness, and cohesiveness of the product.

Lipid is not plentifully presented in rice flour (0.3-3.9%) (Table 2). Rice lipid is composed of several fatty acids such as oleic, linolenic, as well as palmiotic acids (approximately 75-95% of total fatty acids) (Tester *et al.,* 2004). According to Hamaker (2007), the main lipids in rice flour are triglyceride, along with the small amount of phospholipids, glycolipids, as well as waxes. Some lipids in rice flour can interact with AM and also the branches of AP under a high temperature condition, specifically polar lipids such as monoglycerides, lysophospholipids, and fatty acids (BeMiller and Whistler, 2009). The relationships between rice flour properties and lipid have been reported. Tharise *et al.* (2014) described that having higher lipophilic parts in rice flour tended to increase the value of oil absorption index, improving mouth feel. Tong *et al.* (2015b) studied effects of lysophospholipids on rice flour properties. The authors found that the lipids had an effect on rice flour pasting properties including trough and breakdown viscosities due to restricting water absorption and swelling of starch granules. Moreover, gelatinization of rice flour is also influenced by AM-lipid complex (Bhandari *et al.,* 2013). Consequently, rice flour lipid is one component that has an impact on the final product quality attributes.

The crude fiber is the indigestible carbohydrate parts that could not be digested by dilute acid and alkali, such as cellulose, hemicelluloses, pentosans, and lignin (Kaur *et al.,* 2015). Values of crude fiber in rice flour have been found in the range of 0.1-1.5% (Table 2). Dietary fiber or total dietary fiber in rice flour consists of non-starch polysaccharides, inulin, resistant starch, and fructo-oligosaccharides, in which the non-starch polysaccharides could be categorized to soluble (non-cellulose) and insoluble dietary fibers (cellulose and non-cellulose) (Murray, 1997). These carbohydrates could not be digested in human small intestine because they are able to resist digestion by human alimentary enzymes, although the carbohydrates are partially fermented in the large intestine by microbiota (Chawla and Patil, 2010). The values of soluble, insoluble and total dietary fibers in rice flour have been found as 1.1-1.3%, 1.1-1.4%, and 3.2-9.8%, respectively (Table 2).

The fiber contents can help to prevent constipation and increase mucin secretion for lubrication, resulting in a lower incidence of colon and rectum cancers (Strugala *et al.,* 2003). Therefore, the fiber contents are considered as a health benefit provider.

A little amount of ash has been observed in rice flour, in range of 0.3-1.8% (Table 2). Higher value of ash content contributes to higher levels of mineral elements in rice flour (Arendt and Zannini, 2013). According to Kale *et al.* (2015) and Reddy *et al.* (2017), minerals that are usually found in rice (Chak-hao Amubi, Chak-hao Angangba, and PB1121) are potassium (449.2-2,048.4 mg/kg), magnesium (56.8-568.5 mg/kg), phosphorous (456.7-2,248.1 mg/kg), calcium (16.3-136.2 mg/kg), manganese (1.3-377.2 mg/kg), and also zinc (20.2-431.8 mg/kg) (Table 2). There is no reports on the relation between ash content and rice flour properties such as pasting, thermal, and functional properties. However, too high ash content might affect rice flour color, especially decreasing the lightness (Verma and Srivastav, 2017).

Pasting properties

Pasting properties of rice flour are generally determined with a rapid visco analyzer (RVA), in which the machine provides RVA profile (Fig. 2 [a]) and pasting parameters. Values of rice flour pasting properties including peak, trough, breakdown, final, as well as setback viscosities have been found as 427-7,771 cP, 391-4,104 cP, -4 cP to 4,974 cP, 974-7,581 cP, 203-3,980 cP, respectively (Table 3). Pasting properties of rice flour are measured under excess water with heating. Firstly, rice starch granules absorb water and swell (Tester *et al.,* 2004). Then, the overlaps of swollen starch molecules lead to the increase of viscosity.

Next, the over absorptions of energy and water result in breaking down of starch molecules and solid components leaching out, decreasing viscosity. During cooling process, the re-arrangement of starch molecules is occurred by hydrogen bonding among starch molecules, increasing viscosity again (Kaur *et al.,* 2015).

Carbohydrate (particularly starch) is the main content that has a great influence on rice flour pasting properties (Falade and Christopher, 2015). Nevertheless, the two components in starch, namely AM and AP have different effects on these properties. Gani *et al*. (2017) found that higher values of peak (4,420 cP), trough (2,342 cP), and breakdown viscosities (2,883 cP) (Table 3) in rice flour are encouraged by a higher amount of AP. Serna-Saldivar (2010) also reported that high values of those pasting properties could be caused by high number of AP, thanks to the good abilities to attach and hold water molecules by its highly branched chains. These support to more swollen starch granule, increasing viscosity, providing smooth texture to products, indicating low heat, and shear tolerances (Varavinit *et al.,* 2003).

In the meantime, another content in rice starch (AM) brings about to high values of final and setback viscosities in rice flour by reason of a good re-association of starch molecules, encouraging from its linear structure (Seager and Slabaugh, 2011). On the other hand, this structure contributes to a less occupied volume of starch granule hydration, that its cause of dropping values of peak, trough, and breakdown viscosities (Hamaker, 2007). According to Lin *et al.* (2011) and Tikapunya *et al.* (2017), AM tends to decrease peak (610-924 cP), trough (≈400 cP), as well as breakdown viscosities (159-527 cP) in rice, while which contributes to the high value of setback (2,256-3,766 cP) (Table 3). These contribute to the high stability or consistency of rice flour gel, providing hardness and integrity to food product textures (Lin *et al.,* 2011). Nevertheless, high numbers of short chain lengths of AP (degree of polymerization [DP] <13) also result in high values of final and setback viscosities because of a fast re-association of its molecules during cooling (BeMiller and Whistler, 2009).

Both declining and increasing values of pasting properties could be caused by rice protein. The reduction of peak, trough, and breakdown viscosities could be due to a formation of AM-protein complex during food processing, disrupting water holding capacity of starch molecules (Mir and Bosco, 2014). Besides, dropping setback viscosity also could be from interrupting starch molecule re-arrangement during cooling (Lin *et al.,* 2011; Falade and Christopher, 2015). Oppositely, the increases of peak, breakdown, as well as final viscosities could be strengthened by protein, thanks to improving the ability to trap water molecules by means of its hydrophilic groups and stability to rice flour gel by protein network (Lin *et al.,* 2010; Arendt and Zannini, 2013). Higher contents of lipid and fiber in rice tend to drop all values of pasting properties. According to Sigh (2010), the interactions between lipid and linear structure of AM and short branched chains of AP resulted in the reduction of all values of rice flour pasting properties. Moreover, lipophilic parts in lipid also decline water binding ability of rice flour, shrinking the viscosities, improving shear resistance (Parada and Santos, 2016). In the case of fiber, the content has higher ability to absorb water molecules. Thus, it interferes starch granule hydration, reducing values of all pasting properties (Parra *et al.,* 2015; Wang *et al.,* 2015; Siriamornpun *et al.,* 2016). The low values of pasting properties in rice flour indicate poor final product qualities such as lacks of flexibility, consistency, and integrity in product structures (Borad *et al.,* 2017).

Thermal properties

Thermal properties are usually referred to as rice flour gelatinization temperature. That could be detected by using a differential scanning calorimetry (DSC). The machine delivers an endothermic thermogram (Fig. 2 [b]) that demonstrates the gelatinization temperatures including onset (T_o); an initial temperature of gelatinization (°C), peak (T_p); the gelatinization temperature (°C), conclusion temperatures (T_c); the temperature when starch granules are completely gelatinized (°C), and enthalpy of gelatinization (ΔH_g); the energy required for the gelatinization (J/g).

Mostly, the beginning of rice flour gelatinization or T_o is commonly observed around 60°C and the end of that (T_c) is usually detected beyond 80°C (Table 4). The values of gelatinization enthalpy have been found in range of 0.11-29.6 J/g (Table 4). According to Asmeda *et al.* (2016), a low value of T_o (59.42-74.32°C) brings about to the low values of T_p (59.86-75.31°C), T_c (60.32-76.84°C), and ΔH_g (0.11-3.55 J/g) (Table 4). On the other hand, a higher T_o (72.50-75.82C°) contributes to higher T_p (76.52-79.75°C), T_c (82.92-87.81°C), and ΔH_g (7.45-7.90 J/g) (Table 4). Furthermore, Gani *et al.* (2017) also reported that higher values of ΔH_g (14.3-29.6 J/g) could be caused by higher values of T_c in rice flour (97.3-107.6°C) (Table 4).

The lower energy needed and shorter time for gelatinization or lower in gelatinization temperatures could be consequents by a lower number of lipid, protein, and fiber contents in rice flour, because they interrupt water absorption of starch granules (Varavinit *et al.,* 2003; Chinma *et al.,* 2015). Whereas, a higher amount of carbohydrate content, especially AP contributes to a faster gelatinization because it rapidly absorbs water, generating quicker water penetration into crystalline areas, dropping energy required of gelatinization (Ilowefah *et al.,* 2015; Chen *et al.,* 2017).

Oppositely, more energy required and longer time for rice flour gelatinization could be strengthened by larger crystalline regions in starch granules, contributing from long chain lengths of AP (DP>13) (Ye *et al.,* 2016; Gani *et al.,* 2017). Furthermore, retardation of water entering into crystalline areas via higher fiber content and more formations of starch with protein/ lipid also tends to increase values of thermal properties, namely T_o, T_p, T_c, and ΔH_g (Seager and Slabaugh, 2011; Xu *et al.,* 2017).

The high content of AM also retards starch granule hydration and swelling, thus it contributes to high values of thermal properties (Varavinit *et al.,* 2003; Chinma *et al.,* 2015). These could be caused of higher temperature required and longer processing time for starchy product manufacturing (Borad *et al.,* 2017).

Retrogradation

Retrogradation refers to the re-association or aggregation of granule remnants upon cooling after gelatinization (BeMiller and Whistler, 2009), forming the ordered structure or re-crystallization (Fig. 2 [c]). The phenomenon has an effect on the sensory and storage qualities of the numerous starchy foods, since which increases the firmness or rigidity of product textures during storage (Wang et al., 2015). Starch retrogradation is often characterized by DSC via investigating the change of gelatinization enthalpy after storage at 4°C.

The percentage of retrogradation (R%) is estimated by using an equation (Xiao and Zhong, 2017):

$$\text{Retrogradation (\%)} = \frac{\Delta H_r}{\Delta H} \times 100$$

Where ΔH_r is enthalpy of flour after storage at 4°C and ΔH is enthalpy of flour before storage.

In general, an occurrence of retrogradation results in the staling of the starch-rich products particularly in bread, reducing shelf-life and consumer acceptance. Conversely, it is desirable for some products such as breakfast cereals, rice vermicelli, and parboiled rice, because of forming product structures (Wu et al., 2010).

Values of R% in rice flour have been found in range from 1.7% to 100% (Table 5). A rapid initial rate of starch retrogradation or high in R% are positively related to number of carbohydrate content, specifically AM as well as short chains of AP because of a quick re-crystallization (Zhang *et al.,* 2014; Hsu *et al.,* 2015; Xiao and Zhong, 2017), ≈85-100% (Table 5). Thus, rice flour with high AM content is suitable for making food products with rigid texture.

In contrast, the restriction of the phenomenon is contributed by longer chain lengths of AP, due to slowing down the retrogradation rate (Eliasson, 2004). Hence, a higher in AP content contributes to lower value of R% in rice flour (Varavinit *et al.,* 2003; Lee *et al.,* 2015), 1.7-18.2% (Table 5). Additionally, the retardation of starch retrogradation is also contributed from the higher ontents of protein, lipid, as well as fiber because these components disturb starch molecules re-arrangement (Bao and Jin, 2007). Wu *et al.* (2010) reported that the staling or retrogradation of bread could be prevented by the interactions between the swollen starch granules and protein network, destroying hydrogen bond which is disrupting the binding of starch granule remnants. Siriamornpun *et al.* (2016) also confirmed that re-crystallization of starch granules by hydrogen bonding could be retarded by AM-protein/lipid complexe formation, delaying the occurrence of retrogradation. Moreover, increasing the fiber content in rice flour resulted in the reduction of R%. Philpot *et al.* (2006) informed the remove of lipid from rice flour could increase the retrogradation rate.

Functional properties

Determinations of water absorption, water holding, or hydration capacities of flour are regularly measured in terms of water absorption index (WAI) as well as swelling power (SP) (Sharma et al., 2002). The various values of WAI and SP in rice flour are found around 1-14 g/g (Table 5). Undoubtable, the properties are positively related to hydrophilic groups in the starch molecules (Tong *et al.,* 2015a), in which that groups are largely contained in carbohydrate (especially AP), fiber, and protein contents (Tester *et al.,* 2004). Thus, the higher numbers in those contents have the tends to increase values of WAI (10.1-14.8 g/g) and SP (8.6-12.2 g/g) (Table 5) in rice flour due to the higher ability to interact with water molecules (Thirumdas *et al.,* 2016). Higher in WAI and SP also have an impact on other properties, decreasing thermal properties, as well as increasing viscosity of rice flour (Sarangapani *et al.,* 2016). These could shrinkage temperatures and processing times of starch-based product producing (Sigh, 2010). In contrast, higher contents of AM and lipid could be caused of lower in WAI (1.1 g/g) and SP (2.2-4.6 g/g) (Table 5) due to interrupting water absorption by linear structures and lipophilic parts, respectively (Chinma *et al.,* 2015; Ali *et al.,* 2016). Moreover, WAI and SP values could be also dropped by AM-lipid/protein complexes since the occurrence of the complexes reduce hydrophilic parts in rice flour, increasing temperatures and processing times of starchy product making (BeMiller and Whistler, 2009).

Amounts of solid that leach out from starch molecules during heating are indicated by water solubility index (WSI). The values of this property were found in range of 1.8-15.7% (Table 5). The low value of WSI (1.8-3.2%) (Table 5) indicates the stronger bonding among starch molecules, representing high temperatures and shear resistance during food processing (Arendt *et al.,* 2013; Ocloo *et al.,* 2017). These could be maintained by higher content of AM, protein, and lipid in rice flour (Tong *et al.,* 2015a). The linear structure of AM and AM-protein/lipid complexes retards water absorption of starch granules, whereas they maintain the integrity of the granules, owing to having athletic interaction amongst starch molecules (Putseys *et al.,* 2010; Parada and Santos, 2016). Conversely, the higher of this property (7.3-15.7%) (Table 5) could be contributed from higher content of AP. According to Parra *et al.* (2015), the highly branched chains of AP contribute to an appropriate capacity of flour hydration, in which a capacity stimulates more soluble components leaching out from starch granules, booting up WSI value. These indicate low temperatures and shear resistances during food productions (Hamaker, 2007).

Oil absorption index (OAI) of rice flour refers to the ability to maintain oil in its structures, which has been found as 0.8-2.4% (Table 5). The higher numbers of lipophilic parts in rice flour contribute to the higher value of OAI because the parts are able to interact with oil molecules (Chinma *et al.,* 2015; Sarangapani *et al.,* 2016). Thus, lipid is considered as a foremost part that plays an important role in this property thanks to holding a high number of lipophilic groups. Thirumdas *et al*. (2017) also reported that a greater number of lipid content leads to a higher value of OAI (2.4%) (Table 5). Besides, having both hydrophilic and hydrophobic groups of protein molecules also raise the values of OAI up, improving mouth feel and flavor retention in food products (Ilowefah *et al.,* 2015). In contrast, a higher content of carbohydrate in rice flour always drops OAI value (≈1 g/g) (Table 5) due to higher in hydrophilic parts, as well as low ability to interact with oil (BeMiller and Whistler, 2009; Chinama *et al.,* 2015; Ali *et al.,* 2016).

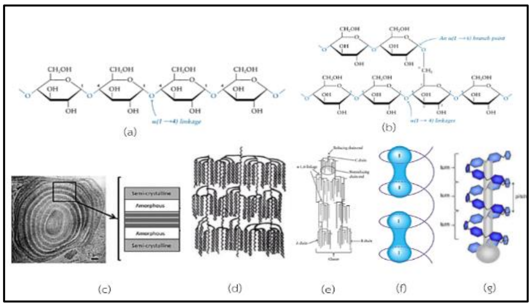

Fig. 1 Schematic representations of starch granule, AM, and AP structures; [a] α-1, 4-D glycosidic linkages in AM molecules; [b] α-1, 6-D glycosidic bonds in branched chains of AP; [c] Semi-crystalline and amorphous regions in starch granule; [d] Cluster of double-helix amylopectin; [e] Side-branching chains of amylopectin molecule; [f] AM-iodine complex; [g] Single amylose helix.

Source: [a & b] Thomas and Atwell (1999); [c & d] Zhu (2015); [e] Hii *et al*. (2012); [f] Seager and Slabaugh (2011); [g] Putseys *et al*. (2010)

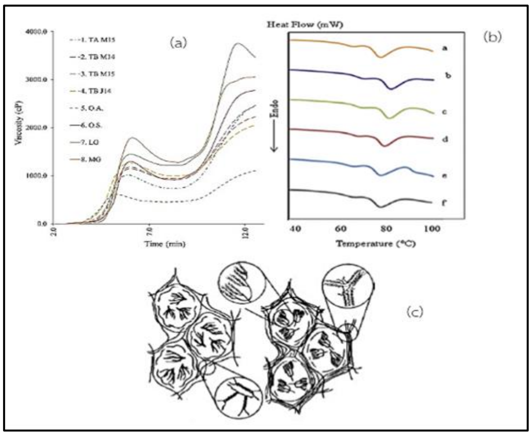

Fig. 2 Schematic representations of RVA profile, endothermic thermogram, and the retrogradation mechanism of rice flour; [a] RVA viscograms of five wild rice samples (TA M15, TB M14, TB M15,TB J14, O.A.), Oryza sativa L cv. Nipponbare (O.S. 5) and two unpolished commercial rice samples (LG, MG); [b] DSC thermograms of high-amylose rice flour gel: a = rice flour (control); b = sucrose; c = sorbitol; d = glycerol; e = citric acid; and f = acetic acid; [c] the re-association of amylose and amylopectin molecules during cooling (retrogradation) of the starch paste.

Source: [a] Tikapunya *et al*. (2017); [b] Ploypetchara *et al*. (2015); [c] Wang *et al*. (2015)

Table 1 Milling conditions and chemical composition of rice flour from different milling methods

Milling method	Milling condition					References
	Ratio of rice and water	Soaking time (h)	Temperature of soaking water (°C)	Drying temperature (°C)	Drying times (h)	
Semi-dry	1:1;1:2;2:1	0.3-16	30	40-60	12	Asmeda and Noorlaila (2015) Joy and Ledogo (2016) Prasad *et al*. (2012)
Wet	1:1;1:2	4---24	25-30	40	12	Joy and Ledogo (2016) Leewatchararongjaroen and Anuntagool (2016) Prasad *et al*. (2012) Tong *et al*. (2015b)

Milling method	Rice flour chemical properties						References
	Rice variety	Protein (%)	Ash (%)	Lipid (%)	Carbohydrate (%)	Fiber (%)	
Dry	MR211; MR220; Suwon No.542; Suwon No.541; Unbong No.30	7.96-12.89	0.08-0.82	0.26-1.49	79.49-89.69	0.42-0.53	Asmeda and Noorlaila (2015) Choi *et al*. (2015) Rosniyana *et al*. (2016)
Semi-dry	MR211; Nigerian and non-Nigerian rice	7.35-11.15	0.03-1.14	0.13	77.68	0.64	Asmeda and Noorlaila (2015) Joy and Ledogo (2016)
Wet	MR211; MR220; Suwon No.542; Suwon No.541; Unbong; Nigerian and non-Nigerian rice	7.20-11.22	0.01-1.05	0.18-0.99	74.23-91.68	0.38-1.37	Asmeda and Noorlaila (2015) Choi *et al*. (2015) Joy and Ledogo (2016) Rosniyana *et al*. (2016)

Table 2 Rice flour/starch chemical composition

Chemical composition	Waxy rice	Non-waxy rice		
		Low amylose	Medium amylose	High amylose
	Rice variety			
	K/A92VM0611, Chak-hao Angangba, TCW70, TKW1, TKW5, & TSW2	Beihan1, Xing2, Kwandala, At 405, Chak-hao Amubi, SKAU-338,SKAU-406, Jhelum, & Hualiangyou	TCS10, TK8, TS2, TNG67, TK16, Jamila, Jeep, & Zhongguangxiang	TCN1, TCN17, Yuxiangyouzhan, CH-1039, CIC, PB1121, & MR 219
Amylose (%)	ND-2.6	6.1-16.7	19.9-20.6	26.9-30.4
Crude ash (%)	0.9	0.3-1.8	1.1	0.8-1.4
Crude lipid (%)	1.4-3.2	0.3-3.9	1-2.8	1.3-2.7
Crude protein (%)	7.4-12.6	5.3-11.9	6.4-10.3	7.8-10.7
Carbohydrate (%)	73.1	74.4-85.6	-	74.5-77.5
Crude fiber (%)	-	0.1-0.3	-	0.1-1.5
Total dietary fiber (%)	3.2-9.8	-	-	-
Soluble fiber (%)	-	1.3	1.1	1.1-1.2
Insoluble fiber (%)	-	1.3	1.3	1.1-1.4
Total starch (%)	82.8-94.1	46.5-94.1	47.6-90.7	49.0-87.8
Mineral				
Potassium (mg/kg)	449.2-1,546.8	566.1-1, 606.6	-	1,303.5-2,048.4
Magnesium (mg/kg)	56.8-379.1	106.6-377.2	-	509.3-568.5
Phosphorus (mg/kg)	456.7-2,248.1	718.5-2,062.1	-	917.4-1 ,729.0
Calcium (mg/kg)	42.5-77.6	53.6-136.2	-	16.3-32.6
Zinc (mg/kg)	20.2-34.9	24.6-53.9	-	386.4 -431.8
Manganese (mg/kg)	56.8-379.1	106.6-377.2	-	1.3-5.5
References	Giuberti *et al*. (2017) Lin *et al*. (2011) Morales-Martínez *et al*. (2014) Kale *et al*. (2015)	Ali *et al*. (2016) Chinma *et al*. (2015) Gani *et al*. (2017) Reddy *et al*. (2017) Somaratne *et al*. (2017) Ye *et al*. (2016)	Lin *et al*. (2011) Chinma *et al*. (2015) Wang *et al*. (2017)	Gani et al. (2017) Kale *et al*. (2015) Lin *et al*. (2011) Somaratne *et al*. (2017) Ye *et al*. (2016)

Table 3 Rice flour/starch pasting properties

Pasting properties					
Peak viscosity (cP)	Trough viscosity (cP)	Breakdown viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)	References
924-7,771	434-4,104	527-4,974	637-7,626	203-3,766	Lin *et al.* (2011)
1,632-3,354	1,475-2,683	143-742	3,236-6,631	1,604-3,267	Mir and Bosco (2014)
2,376-6,080	1,992-4,036	636-3,155	4,086-7,581	2,279-3,980	Falade and Christopher (2015)
1,359-1,637	-	-	2,899-3,381	1,311-1,605	Kaur *et al.* (2015)
526-1,302	-	-14 to -4	1,505-3,995	979-2,693	Kale *et al.* (2015)
315	263	53	-	413	Luo *et al.* (2017)
610-1,791	451-1,276	159-515	1,100-3,464	648-2,256	Tikapunya *et al.* (2017)
427	391	36	974	583	Xu *et al.* (2017)
1,153-1,377	840-1,251	127-313	1,883-2,141	890-1,043	Borad *et al.* (2017)
2,466-4,420	1,188 -2,342	798-2,883	2,330-4,146	1,068-3,332	Gani *et al.* (2017)
998	833	165	1,630	798	Perez-Quirce *et al.* (2017)
4,542	1,360	1,753	4,610	-	Thirumdas *et al.* (2017)
1,679-2,103	942-1,488	615-738	2,623-3,296	944-1,194	Ding *et al.* (2018)
1,010-3,818	684-2,892	325-1,539	1,650-4,960	836-2,389	Leewatchararongjaroen and Anuntagool (2016)

Table 4 Rice flour/starch thermal properties

Thermal properties				
T_o (°C)	T_p (°C)	T_c (°C)	ΔH_g (J/g)	References
69.20-82.90	74.80-89.80	83.50-98.10	2.70-13.90	Chen *et al. (*2017)
61.10-62.04	69.04-70.53	75.33-77.27	8.01-8.67	Setyawati *et al.* (2016)
76.10	79.30	83.30	-	Jongsutjarittam *et al.* (2014)
59.42-74.32	59.86-75.31	60.32-76.84	0.11-3.55	Asmeda *et al. (*2016)
74.77	77.99	81.70	4.56	Ilowefah *et al. (*2015)
63.10-66.25	66.10-68.97	71.60-72.80	5.29-6.82	Chinma *et al. (*2015)
60.20-68.60	67.72-74.57	73.90-79.80	6.14-6.71	Ye *et al. (*2016)
66.40-71.10	64.3-72.8	76.00-85.90	6.50-12.20	Lin *et al. (*2011)
71.50	75.80	80.90	12.40	Xu *et al*. (2017)
74.50	81.40	-	5.40	Sansano *et al.* (2018)
58.30-72.50	82.70-93.30	97.30-107.60	14.30-29.60	Gani *et al.* (2017)
63.10	73.50	79.60	14.90	Thirumdas *et al.* (2017)
63.20	66.20	71.30	7.37	Kumar *et al.* (2017)
72.50-75.82	76.52-79.75	82.92-87.81	7.45-7.90	Sarangapani *et al.* (2016)

Note: Onset temperature (T_o); peak temperature (T_p); conclude gelatinization temperature (T_c); enthalpy (ΔH_g)

Table 5 Rice flour/starch retrogradation and functional properties

Functional properties					R%	References
WAI (g/g)	SP (g/g)	WSI (%)	OAI (g/g)	References		
2.2-14.8	2.2-3.0	3.2-13.1	-	Tong *et al. (*2015b)	18.2-69.4	Varavinit *et al.* (2003)
10.1	10.8	5.3	1.8	Thirumdas *et al. (*2016)		
2.0	5.8	2.7	0.8	Ilowefah *et al. (*2015)	1.7-65.2	Lee *et al.* (2015)
1.10-2.3	4.1-5.8	-	1.0-1.9	Chinma *et al. (*2015)		
1.1 -1.1	9.3	2.0-4.0	1.1	Ali *et al.* (2016)	2.9-85.6	Hsu *et al.* (2015)
1.1-1.6	6.6-8.6	5.4-7.3	1.1-1.4	Ocloo *et al. (*2017)		
2.4	9.6	5.1	2.4	Thirumdas *et al.* (2017)	10.4-100	Zhang *et al.* (2014)
-	12.2	15.7	-	Kumar *et al.* (2017)	≈10-85	Xiao and Zhong (2017)
4.2-4.7	4.6	1.8-2.0	0.9-1.4	Sarangapani *et al. (*2016)	54.1	Bao and Jin (2007)

Note: Water absorption index (WAI); swelling power (SP); water solubility index (WSI); oil absorption index (OAI); percentage of retrogradation (R%).

Conclusion

Chemical compositions of rice flour including carbohydrate, protein, lipid, and fiber have an effect on its properties, nonetheless those contents show that they have different impacts on the flour characteristic properties. Higher values in pasting properties including peak, trough, breakdown, final and setback viscosities of rice flour are caused by higher in carbohydrate content (AM and AP). On the other hand, lipid and fiber tend to decrease all values of the properties because of reducing water binding capacity and starch molecules re-arrangement.

Carbohydrate, namely AP is considered as a main content that tends to provide lower values of thermal properties including T_o, T_p, T_c and ΔH_g to rice flour. In contrast, higher in other components of rice four usually contribute to higher values of those properties due to increasing energy required for cooking process by declining water absorption capacity.

Regularly, AM boosts up the value of R% owing to a good ability to re-arrange starch molecules by hydrogen bonding, while the rest of the other contents in rice flour usually demonstrate to drop the value of R%.

In case of functional properties, the increases of WAI, SP, and WSI values could be reinforced by carbohydrate content (AP), because of increasing starch rehydration capacity and also increasing number of solid leaching out from starch molecules. In the meantime, lipid and protein could increase value of OAI due to their lipophilic components.

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