ENHANCEMENT OF PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF RICE FLOUR NOODLES USING COMBINED HYDROCCOLLOIDS

LUBOWA MUHAMMAD

UNIVERSITI SAINS MALAYSIA

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by

LUBOWA MUHAMMAD

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LIST OF SYMBOLS AND ABBREVIATIONS

^{0}C	Degree Celsius
^{C}	Chilling
Ca-ALG	Sodium alginate cross-linked by calcium
CAR	Carrageenan
CTR	Control sample
FTIR	Fourier Transform Infrared
g	Gram
h	Hour
H-AMS	High amylose maize starch
H-AMS + Ca-ALG	High amylose maize starch combined with sodium alginate cross-linked by calcium chloride.
H-AMS + CAR	High amylose maize starch combined with carrageenan
H-AMS + KGM	High amylose starch combined with konjac glucomannan
Kg	Kilogram
KGM	Konjac glucomannan
KGM-CAR	Konjac glucomannan blended with carrageenan
L	Liter
M	Molar
mL	Mililiter
mM	Milimolar
NR	No retort
NC	No chilling
pGI	Predictive glycemic index
RH	Relative humidity
R	Retort

rpm	Rate per minute
SEM	Scanning electron microscope
µl	Microliter
µm	Micrometer
w/w	Weight/Weight

PENAMBAHBAIKAN SIFAT-SIFAT FIZIKO-KIMIA DAN BERFUNGSI MI TEPUNG BERAS MENGGUNAKAN KOMBINASI HIDROKOLOID

ABSTRAK

Mi adalah produk makanan utama yang diproses daripada tepung beras. Walau bagaimanapun, mi beras segar mempunyai struktur yang lemah, umumnya rapuh, lekit dan mudah pecah dalam struktur keseluruhannya apabila pengendalian tinggi / pemprosesan suhu. Mi menjadi lembut, lembik dan hancur menjadi kepingan yang lebih kecil. Ini adalah kompromi utama dalam perbandingan deria. Objektif kajian ini adalah untuk meneroka penggunaan pelbagai kombinasi tepung-hidrokoloid untuk penyediaan mi tepung beras dengan penambahbaikan ciri-ciri fizikokimia dan fungsional yang dipertingkatkan bagi membolehkan mi menahan tekanan tinggi dan panas tanpa kesan buruk terhadap sifat deria. Julat kepekatan hidrokoloid iaitu; 5%, 10% dan 15% untuk H-AMS, 1%, 5% dan 15% untuk k-carrageenan (CAR) dan campuran k-Carrageenan dengan Konjac glucomannan 1%, 5% dan 15% untuk Konjac glucomannan (KGM), dan 0.6%, 0.8% dan 1% untuk natrium alginat (Ca-ALG) digunakan sepanjang kajian. Pada mulanya, penggunaan kanji amilosa tinggi (H-AMS) pra-gelatinisasi sahaja diterokai untuk perumusan mi tepung beras. H-AMS menunjukkan potensi untuk penambahbaikan tekstur, memasak dan sifat fizikal mi tepung beras, tetapi perlu ditambah dengan rawatan penyejukkan. Walau bagaimanapun, kedua-dua H-AMS dan rawatan penyejukan tidak mencukupi untuk melindungi struktur mi semasa retort. Oleh itu, hidrokolloid tambahan telah dicari untuk meningkatkan lagi sifat mi. Di peringkat awal, kajian menyimpulkan bahawa semua hidrokoloid kecuali KGM menunjukkan potensi untuk dimasukkan ke dalam mi tepung beras. Semasa ujian tekstural, gel tepung beras dibuat dengan semua hidrokoloid kecuali CAR dan KGM menunjukkan kekerasan yang tinggi ($p < 0.05$) dan kelikatan yang berkurangan ($p < 0.05$), mencadangkan potensi ini untuk digunakan dalam mi tepung beras. Pada fasa seterusnya, sapuan frekuensi digunakan untuk mencirikan struktur gel yang dibuat dari tepung beras yang digabungkan dengan H-AMS dan Ca-ALG. Penyerapan frekuensi ditambah dengan penilaian sifat pempesan dan tekstur. Tindak balas reologi G '> G "dalam gel H-AMS + Ca-ALG menunjukkan bahawa gel ini berstruktur dan lebih padat. Tingkah laku seperti pepejal ini disokong oleh peningkatan ketara ($p < 0.05$) suhu dan kekerasan gel dan mengurangkan kelekitan. Oleh itu, disimpulkan bahawa lebih baik untuk menggabungkan tepung beras dengan H-AMS + Ca-ALG untuk penyediaan mi daripada menggabungkan tepung beras dengan H-AMS atau Ca-ALG secara individu. Apabila tepung beras digabungkan dengan H-AMS + Ca-ALG1 untuk penyediaan mi, hasil tekstural menyokong keputusan rheologi (G ') dimana mi yang dihasilkan mempunyai ketara ($p < 0.05$) peningkatan kekerasan, kekuatan tegangan dan H-AMS + Ca -ALG1 positif mengurangkan kesan pelunakan haba sehingga 56.2%. Penambahbaikan struktur dibuktikan dalam mikrograf SEM yang menunjukkan penampilan yang padat dan padat dengan peningkatan kesinambungan matriks dan dengan lompang dan rongga kurang dalam tepung beras H-AMS + Ca-ALG1. Tepung beras-H-AMS + Ca-ALG1 meningkat dengan ketara ($p < 0.05$) hasil memasak dan masa memasak yang optimum dan dengan ketara ($p < 0.05$) mengurangkan kehilangan memasak berbanding dengan mi kawalan. Mi juga mendapat markah di atas purata kebolehterimaan sensori (5.91 ± 1.73) dan indeks glisemik ramalan 64.57% berdasarkan kajian pencernaan kanji *in-vitro*. Keseluruhannya, dikonklusikan bahawa terdapat kemungkinan untuk menyediakan mi tepung beras bebas gluten dengan ciri-ciri fizikokimia dan fungsional

yang ditambah baik dengan menggabungkan tepung beras dengan jagung beramilosa tinggi pra-gelatinisasi dan natrium alginat yang disilang oleh kalsium klorida.

ENHANCEMENT OF PHYSICOCHEMICAL AND FUNCTIONAL PROPERTIES OF RICE FLOUR NOODLES USING COMBINED HYDROCCOLLOIDS

ABSTRACT

Noodles are the main processed food product made from rice flour. However, fresh rice noodles have a weak structure, are generally fragile, sticky and easily collapse in overall structure upon high handling/temperature processing. They become soft, soggy and crumble into smaller pieces. This is a major compromise in sensory appeal. The objective of this study was to explore the use of various rice flour–hydrocolloid combinations for preparation of rice flour noodles with enhanced physicochemical and functional properties, which could enable them to withstand high handling and heat stresses without adverse effects on sensory properties. A range of concentrations of hydrocolloids namely; 5%,10% and 15% for H-AMS, 1%,5% and 15% for k-carrageenan (CAR) and blend of k-Carrageenan with Konjac glucomannan (KGM-CAR), 1%,5%,10% and 15% for Konjac glucomannan (KGM), and 0.6%,0.8% and 1% for sodium alginate (Ca-ALG) were used throughout the study. Initially, the use of pre-gelatinized high amylose starch (H-AMS) alone was explored for formulating rice flour noodles. H-AMS showed potential to enhance texture, cooking and physical properties of rice flour noodles, but it required to be supplemented with a chilling treatment. However, both H-AMS and the chilling treatment were not enough to sufficiently protect noodle structure during retort. Therefore, additional hydrocolloids were sought to further enhance noodle properties. In the preliminary stage, pasting studies indicated that all hydrocolloids except KGM showed potential to

be incorporated in rice flour noodles. During textural analysis, rice flour gels made with all hydrocolloids except CAR and KGM showed high hardness ($p < 0.05$) and a reduced stickiness ($p < 0.05$), suggesting the potential of these to be used in rice flour noodles. In the next phase, a frequency sweep was used to characterize the structure of gels made from rice flour combined with H-AMS and Ca-ALG. The frequency sweep was supplemented with an assessment of the pasting and textural properties. Rheological responses of $G' > G''$ in the H-AMS + Ca-ALG gels indicated that these gels were structured and more solid-like. This solid-like behaviour was supported by the significantly increased ($p < 0.05$) pasting temperatures and gel hardness and reduced stickiness. Thus, it was concluded that it would be more advantageous to combine rice flour with H-AMS + Ca-ALG for preparation of noodles than combining rice flour with H-AMS or Ca-ALG individually. When rice flour was combined with H-AMS + Ca-ALG1 for noodle preparation, textural results supported the rheological results (G') whereby resultant noodles had a significantly ($p < 0.05$) increased hardness, tensile strength and that H-AMS + Ca-ALG1 had positively reduced the impact of heat softening up to 56.2%. Structural enhancement was evidenced in the SEM micrographs, which showed a compact and denser appearance with an increase in the continuity of matrix and with fewer voids and hollows in the rice flour-H-AMS + Ca-ALG1 noodles. The rice flour-H-AMS + Ca-ALG1 noodles had significantly ($p < 0.05$) increased cooking yield and optimum cooking time and a significantly ($p < 0.05$) reduced cooking loss compared to the control noodles. Overall, it was concluded that it was possible to prepare gluten-free rice flour noodles with enhanced physicochemical and functional properties by combining rice flour with pre-gelatinized high amylose maize starch and sodium alginate crosslinked by calcium chloride.

CHAPTER 1

INTRODUCTION

1.1 Background and rational

Rice noodles are a popular food in many cultures, and its simple ingredient list and ease of preparation make it a quick food option for people around the globe, providing benefits for both consumer and manufacturer. This is because, in addition to being served as a snack, it can also serve as a main dish, thus increased market potential. An example is *Laksa*, an iconic rice noodle dish in the Peranakan cuisine with an addictive and ubiquitous taste (Duruz, 2011). Laksa can be found in Malaysia, Singapore, Indonesia and southern Thailand. Compared to other starch-based noodles, the processing technology for rice-based noodles is simpler. Rice noodles are mainly made from rice flour, water, starch and other additives for enhancing the appearance, texture and cooking properties. Rice noodles are made by soaking rice and then milling, cooking and kneading it into dough and extruding it into threads or slicing into strips. They may then be eaten fresh; otherwise they are dried to extend their shelf life (Lu & Collado, 2010).

Rice is one of the most appropriate cereal grains for producing gluten-free products. This owes to the fact that rice seed storage proteins, though structurally similar to the glutenin in wheat, do not contain the toxic epitopes (α-gliadins) responsible for celiac disease in some individuals (Chen et al., 2018; De Re et al., 2017; Kawakatsu & Takaiwa, 2019; Komatsu & Hirano, 1992). Though rice has the least protein content among cereals (which ranges between 5-15%), net utilization of the protein is the highest, because more than 80% of the total protein in rice is concentrated in the milled rice flour, thus utilized in the finished product (Chen et al., 2018; De Re et al., 2017; Kawakatsu & Takaiwa, 2019; Komatsu & Hirano, 1992; Lu & Collado, 2010). The rice proteins also have a well-balanced amino acid profile, thus can be an excellent source with high nutritional and health related properties - such health-related properties as hypocholestrolemic (reducing total plasma cholesterol through enhancing fecal excretion of cholesterol), hypolipidemic (decrease in plasma lipoproteins which could be associated with cardiovascular disease) and high anti-cancer activity (Kim et al., 2014; Xia et al., 2012).

1.2 Problem statement

Fresh rice noodle dishes have a high moisture content, high pH values and rich nutrient profile. Thus, a short shelf life, due to spoilage by microorganisms. This affects/ limits utilization of rice noodle dishes beyond households and restaurants. Therefore, high handling cooking/high-temperature processing such as frying and retorting respectively could increase shelf life and provide more avenues for utilization of rice noodles for example canned noodles in emergency/disaster situations.

However, unlike wheat-based noodles which are made from wheat flour which contains gluten capable of providing a firmer texture, reduced noodle stickiness and solids loss, rice noodles, made from rice flour, lack the unique ability to form a cohesive, elastic and extensible dough. This results into rice noodles which have a weak structure and are generally fragile, presenting problems during cooking and processing and often unable to meet the requirements for high handling cooking and high-temperature processing such as frying and retorting respectively. At elevated temperatures, the overall structure of the rice noodle would collapse, with the consequent loss in texture, which is major compromise in sensory appeal.

1.3 Hypothesis

It was hypothesized that formulating rice flour noodles by partially substituting rice flour with selected hydrocolloids would help to enhance noodle physicochemical and functional properties to overcome problems. The hydrocolloids selected for consideration were high amylose maize starch, Sodium alginate, Konjac glucomannan and kappa carrageenan. Despite the potential use of various hydrocolloids to meet the various demands of food processing, this has not been fully explored.

Amylose has been indicated as the component of starch that enables it to maintain the integrity of starch-based noodles (Bhattacharya, 2011; Wang et al., 2015). High amylose starch is used in processed foods to confer desirable functional properties because it has excellent gelling and film forming properties (Juhász and Salgo, 2008; Vesterinen et al., 2001). Such properties aid in the formation of a more uniform and cohesive viscoelastic dough for production of various pastas such as rice flour noodles with a texture that could withstand high handling processing. In addition, high amylose corn starch is added for lowering the glycemic index of foods, thus helping in dietary management of metabolic disorders (Hu et al., 2004; Loubes et al., 2016).

The use of Sodium alginate has also shown potential to enhance the structure and mechanical properties of rice dough (Nitta et al., 2018). Alginate forms thermo-irreversible, heat stable gels which heat treated without melting. The gel is formed by selective binding of alkaline multivalent cations such as calcium. The calcium ion acts as a cross-linking agent, by physically linking a G-block in one alginate molecule to a G-block in another alginate molecule. This is through chain–Ca2+–chain interactions, commonly referred to as “junction zone”, forming a so-called ‘egg-box junction" where the calcium ions fit into the structural void in the alginate chain, like eggs in an egg box. This interaction leads to formation of strong gels with high tensile strength (Djabourov et al., 2013). The crosslinks also could entrap starch, creating even a more compact structure which could withstand high temperature processing.

Konjac glucomannan was selected because it forms thermally-irreversible stable gels in the presence of alkaline salts. The alkali salts enable konjac to build junction zones through hydrogen bonding, enhancing molecular aggregation and gel formation (Parry, 2010; Williams, 2000). Konjac also promotes amylose gelation, forming temperature stable gels (Parry, 2009), while a blend of Konjac and carrageenan has been reported to be synergistic in producing a gel with high gel strength, good and elastic texture, as well as low syneresis (Nieto, 2009). Carrageenan was considered because according to its mechanism of action, it was hypothesized that upon cooling of heated noodles, K-carrageenan polymers align themselves to form individual helices. The hydroxyl groups of K-carrageenan associate with solubilized starch/Amylose forming a strong network that holds the structure together. The sulfate groups interact with the available proteins to form linkages which helps to increase the strength of the structure (Rosell et al., 2011; Huang et al., 2007; Techawipharat et al., 2008).

A chilling treatment was applied to the noodles because it was thought that this could improve their textural and physical properties. During chilling, a short-term retrogradation of amylose and long-term retrogradation of amylopectin occur, favoring the reassociation of starch molecules to yield tightly packed structures stabilized by hydrogen bonding (Dundar and Gocmen, 2013). It could lead to a stronger cross-linked network that would act as a barrier against water penetration during high temperature processing, favor a reduced water absorption, and improve textural and physical characteristics.

1.4 Research objectives

1.4.1 Main Objective

The main objective of this study was to explore the use of various rice flour–hydrocolloid combinations for preparation of gluten free rice flour noodles with enhanced physicochemical and functional properties which can enable them to withstand high handling and heat stresses without adverse effects on sensory properties.

1.4.2 Specific objectives

1. To investigate the pasting and textural properties of rice flour-hydrocolloid combinations and to determine their suitability for formulating rice noodles.
2. To investigate the influence of pre-gelatinised high amylose maize starch combined with Sodium alginate on the dynamic viscoelastic, pasting and textural properties of rice flour gels and suitability for formulating rice noodles.
3. To assess the physicochemical properties of rice flour noodles formulated with pre-gelatinised high amylose maize starch combined with Sodium alginate.
4. To assess the effect of pre-gelatinised high amylose maize starch combined with Sodium alginate on the sensory acceptability and *in vitro* starch digestibility of fresh rice flour noodles.

1.5 Thesis outline

This thesis consists of 8 main chapters. The first two chapters will provide general information and literature regarding the study. The study proceeded in 5 phases whose detailed methodology, results and discussions have been presented in chapters 3 to 7, while the overall conclusion of this research and recommendations for further studies have been presented in the last chapter.

CHAPTER 1 is general introduction to this study. This includes the background and rational of the study as well as the problem statement and research objectives.

CHAPTER 2 provides general information of rice and rice noodles, their production and quality requirements. This chapter also provides information on the selected hydrocolloids to be used in this study; their structure, properties as well as mechanisms.

CHAPTER 3 was an exploratory study on the use of high amylose maize starch and a chilling treatment to enhance texture, physical properties and retort stability of rice flour noodles.

CHAPTER 4 provides experimental results which were done to determine the suitability of selected hydrocolloids in formulating rice flour noodles. Formulation was done by studying the pasting and textural properties of gels made from rice flour combined with selected individual hydrocolloids. This is because pasting and textural properties can be used to predict/estimate the quality properties of rice products.

CHAPTER 5 In this chapter, hydrocolloids that were selected in chapter 4 as most suitable for enhancing gel properties were combined to evaluated whether combining them would improve the pasting, textural and dynamic viscoelastic properties of the rice flour combined with hydrocolloid gels compared to when the hydrocolloids were individually added to rice flour as in chapter 3.

CHAPTER 6 explores and discusses the use of combined hydrocolloids in preparation of rice noodles and assess their effect on enhancement of the physicochemical, sensory and functional properties of rice flour noodles.

CHAPTER 7 provides selection of final formulation and analysis of *in vitro* starch digestibility and predictive glycaemic index as well as sensory acceptability of resultant noodle.

CHAPTER 8 provides the overall conclusion of the finding of this research as well as recommendations for further studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Rice and rice noodles classification

2.1.1 Rice Varieties and classification

Rice is of special importance for the nutrition of large reaches of the population in Asia, parts of Latin America, the Caribbean and, increasingly so, in Africa, where it supports more than half of the world's population (Luh, 1999). It is one of the most appropriate cereal grains for producing gluten-free products (Kim et al., 2014; Komatsu & Hirano, 1992). World Utilization of milled rice is predicted to reach 509.1 million tonnes in 2018/19 (milled basis), which would be a 1 percent increase compared to 503.9 million tonnes in 2017/201 (FAO, 2018).

There are only two major species of cultivated rice: *Oryza sativa* (O.S), or Asian rice, and *Oryza glaberrima* (O.G), or African rice. *Oryza sativa* varieties display much higher yields than the *Oryza glaberrima*, hence dominate in world cultivation while the O.G species are confined to Africa, where they are fast being replaced by the O.S (FAO, 2006).

Rice varieties belong to two subspecies: Japonica (round grain rice), which is characterized by a strong responsiveness to fertilizer applications and the Indica (long grain rice), which is distinguished by its wide adaptability to different environmental conditions (FAO, 2006). The Asian rice is further classified into four groups/varieties as shown in the Table 2.1.

Table 2.1: Classification and characteristics of Oryza sativa (Asian rice)

Species	*Oryza sativa*			
Subspecies	Japonica	Indica		
Variety (type)	Japonica (Japanese)	Javanica (Javanese)	Indica (Indian)	Scinica (Chinese)
Characteristics				
Shape of seed	Shorth kernel	Large kernel	Long kernel	
Shape of flag leaf	Short, narrow	Long, wide	Long, narrow	
Number of tillers	Many	Few	Many	
Awn	Usually absent	Usually present	Usually absent	
Shedding habit	Difficult	Difficult	Easy	
Panicle length	Short	Long	Medium	

Source: (Lu & Collado, 2010)

2.1.2 Rice Noodles; types and classification

Rice noodles (China: mi fen, Japan: harusame) also called rice vermicelli, with an elastic texture, smooth and slippery surface are currently the main processed food product made from rice flour. Next to cooked grain rice, rice noodles are the most consumed form of rice product in Asia, where they serve as a main ingredient in many iconic dishes (Lu & Collado, 2019). In these dishes, the rice noodles are served either by frying and mixing with meat and vegetables, or they are boiled in soup broth and served as a soup noodle.

Unlike other starch-based noodles, the consumption of rice noodles is believed to confer certain nutritional benefits to the consumer. These benefits include a higher intake of proteins, which stems from the fact that the whole polished rice kernel (which is rich in proteins ranging from 5-15%) is utilized in the finished product (Adedokun & Itiola, 2010; Lu & Collado, 2019).

Unlike wheat-based noodles which are made from gluten containing wheat flour that can form an elastic dough through appropriate mixing and kneading, rice-based noodles are made from rice flour which does not contain gluten. This means that rice noodles differ from wheat noodles in several aspects. Gluten is a type of unique protein with viscoelastic properties, which not only provides firmer texture to the product, but it also helps to reduce the stickiness and solid loss of the noodles (Ahmed et al., 2016; Luh, 1999). Because of the elastic property imparted by gluten, wheat dough can easily sheet and slit into strips or strands to produce noodles (Adedokun & Itiola, 2010). However, due to absence of gluten, rice flour does not have this unique ability to form the cohesive, elastic and extensible dough (Delcour & Hoseney, 2010; Lu & Collado, 2010). Therefore, to compensate for the absence of gluten in rice flour, a binder is often added before the dough can be kneaded and extruded into threads and strings (Lu & Collado, 2010). The binder is usually starch such as tapioca starch, potato starch, corn starch e.tc. which, through steaming or pre-cooking in boiling water, gelatinises (Fu, 2008) and provides the desired binding power during the process of extrusion (Ahmed et al., 2016).

Rice noodles are classified based on shaping (molding) method, moisture content and preparation method, fermentation and place of origin (especially in China) (Li et al., 2015).

1. **Classification based on shaping method**: Rice noodles are commonly prepared by two methods; (i) sheeting of dough to develop flat noodle strips (ii) extrusion of dough to develop threads. Therefore, according to shaping method, rice noodles are classified into two groups;

   (a) **Sheeted rice noodles -** (termed as Qiefen in Chinese): prepared by sheeting method, where the rice dough is made into a large and thin sheet and then sliced into broad strips of noodles that range from 1 to 3 mm thick, 4 to 6 mm wide, and around 200-400mm long (Li et al., 2015; Lu & Collado, 2010).

   (b) **Extruded rice noodles –** (termed as Zhafen in Chinese): These are prepared by extrusion methods, where by the dough is fed into hand-held or industrial extruding device and "extruded" into round shaped threads/vermicelli ranging in diameter from 1 to 3 mm and with a length of 50 to 400mm (Li et al., 2015; Lu & Collado, 2010).

   (c) **Spreading and rolling noodles –** (termed Changfen in Chinese): where rice noodles wrappers containing various fillings are rolled.

2. **Classification based on preparation method and moisture content**: Moisture content and processing method of a product plays a significant part in dictating the shelf life, how a product is to be packaged, distributed, cooked and consumed. Under this classification, we have 4 groups of rice noodles namely;

   (i) **Fresh (wet) rice noodles:** These include flat strips and round threads. The noodles can have a moisture content as high as 70%, with a water activity (a_w, 0.91) and a shelf life of 24 h in summer and up to 48 h during winter (Ahmed et al., 2016; Fu, 2008; Lu & Collado, 2010; Rachtanapun & Tangnonthaphat, 2011). They are usually prepared during the night and distributed before dawn to retail markets, restaurants and households where consumers prefer them because of the freshness which gives the best mouthfeel.

(ii) **Dried rice noodles:** Dried noodles have a moisture content as low as 12-13% (Ahmed et al., 2016; Fu, 2008; Lu & Collado, 2010). This low moisture content is crucial for curtailing the growth of micro-organisms and biochemical reactions, which then contributes to product stability and thus a longer shelf life of the dried rice noodles, which can be more than 1 year. Drying also makes handling easy. Dried rice noodles are of two types namely:

(a) <u>Extrusion-cooked rice noodles;</u> These have a longer shelf life of more than 1 year, thus can be distributed to international markets. They are made by drying the noodles, slicing into straight strips and then wrapping in a paper, like it is done in dried wheat noodles. This process can vary in different countries.

(b) <u>Waved dried rice noodles:</u> Here, the dough is extruded to threads and the threads formed into waves, which are steamed, sliced and then dried and packed.

(iii) **Frozen rice noodles:** These are made from fresh rice noodles which are fast frozen at between -25 ^{o}C to -30 ^{o}C (Ahmed et al., 2016; Lu & Collado, 2010). The advantage of freezing is that starch retrogradation is inhibited at -18 ^{o}C. Freezing also inhibits growth of microorganisms which could otherwise contaminate the product. Fast freezing does not damage the starch gel network, as the noodles properties are recovered after thawing and they retain their best quality for more than a year.

(iv) **Instant rice noodles**: These are noodles intended to provide convenience during consumption such as quick rehydration and preparation. They are often sold with a complete seasoning packet and are ready to serve within 3-5 min of preparation. This kind of convenience is achieved by making noodles very thin in diameter (0.5-0.6 mm) and longer steaming times to enable complete starch gelatinisation (Fu, 2008; Lu & Collado, 2010). Instant rice noodles available on the market are of three types namely (a) Instant rice vermicelli (b) Instant Hefen, and (c) instant fresh rice noodles. These defer in method of production.

(a) **Instant rice vermicelli:** These are made by conditioning the noodles for 30 min at 30 ^{o}C and 70% relative humidity, sweating at 85% RH and 40 ^{o}C for 80 min, drying noodles at 50 ^{o}C and RH 85% for 50 min. The noodles shape is finalised for 40 min at 40 ^{o}C and 75% RH. The noodles are then finished at RH 60%, 30 ^{o}C for 70 min (Lu & Collado, 2010). Instant rice vermicelli is classified into; extrusion-cooked instant rice vermicelli and fermented instant rice vermicelli.

(b) **Instant Hefen:** These are made from rice flour with amylose content of about 19%. The rice flour dough has a moisture content of about 70%, made into thin sheets which are completely cooked to a high degree of gelatinisation. The sheets are then pre-dried to a moisture content of 35-38%, retrograded at 4 ^{o}C for 1.5-2 h after which they are sliced, shaped by molder and dried to a final moisture content of 13% before packaging. The noodles are very thin in diameter ranging from only 0.6-0.8 mm, which makes them easy to rehydrate. They are usually ready to eat after being soaked in boiling water for 2-3 min (Lu & Collado, 2010).

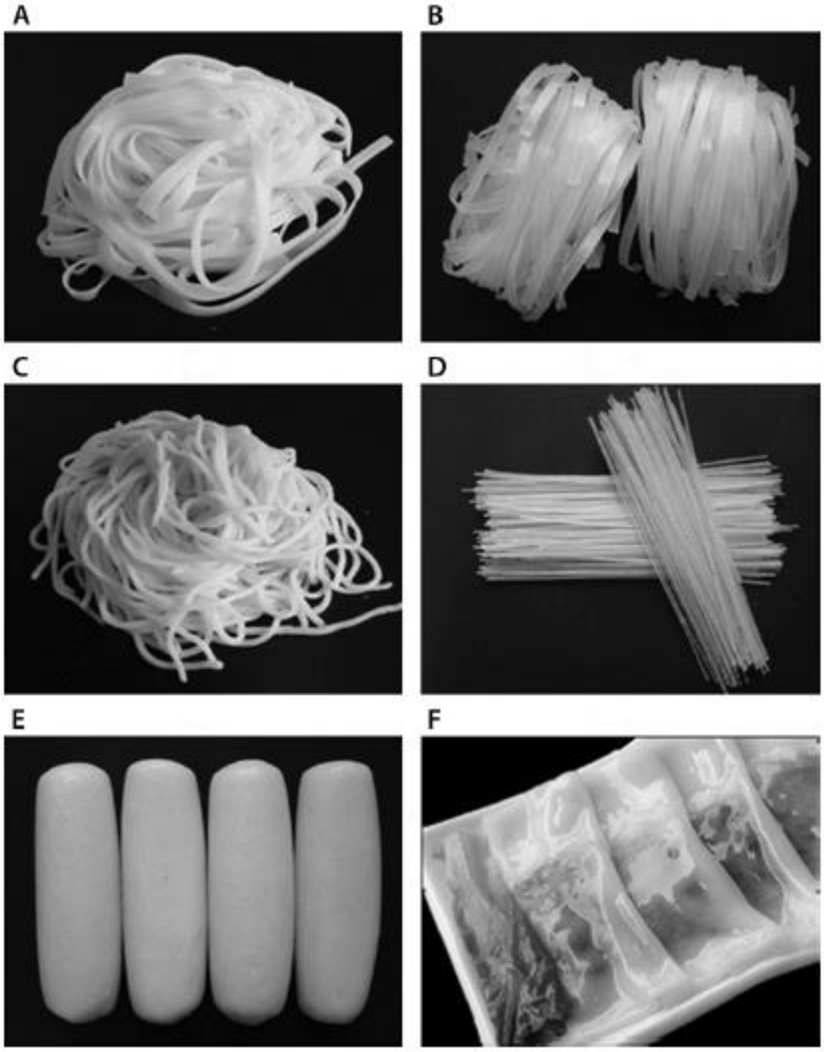

Figure 2.1: Major classifications of rice noodles based on shaping/molding method)
A, fresh sheeted noodles; **B**, dried sheeted noodles; **C**, fresh extruded noodles; **D**, dried extruded noodles; **E**, fenli (extruded); **F**, spreading and rolling noodles
Source: (Li et al., 2015).

2.1.3 Raw materials for making rice noodles

The basic ingredients for making rice noodles are flour and water. These should possess appropriate functional and processing properties needed to develop a quality product. Other additives to the basic ingredients could include modified starches and starches from other sources, sodium chloride, phosphate compounds, glycerine monostearate, and plant oils. These are added or omitted to improve certain quality attributes of the product as desired by the processor. They are judged by determining their physicochemical properties and processing parameters (Ahmed et al., 2016; Fu, 2008; Lu & Collado, 2010).

2.1.3(a) Rice flour

Rice flour is obtained from the fine milling of whole or broken kernels of brown rice or white rice (Kim, 2013). Brown rice is the kernel remaining after the hull is removed from paddy. Following removal of the bran from brown rice, white rice is obtained (Delcour & Hoseney, 2010). Figure 2.2 shows the subsequent steps in the preparation of white rice. The rice grain should first be aged before being milled and processed into noodles. The aging depends on temperature, time and moisture content. Aging should be for at least 9 months. Aging for more than 1 year is considered better (Lu & Collado, 2010). During aging, several physicochemical and physiological changes occur which influence pasting properties, colour, flavour and texture of cooked rice (Park et al., 2012; Park & Baik, 2004; Saikrishna et al., 2018; Zhou et al., 2003). Rice flour from freshly harvested paddy gives very pasty and sticky products compared to products from flour from aged rice, which cook with much less tendency to stick together. Aging also improves product firmness and cooking time tends to become longer with increased storage time (Delcour & Hoseney, 2010). Flour from aged rice grains has a much higher gelling strength compared to that from freshly harvested rice grains (Saikrishna et al., 2018; Zhou et al., 2013). Traditionally long grain rice (*Indica* rice) is commonly used because of its high amylose content, cheap price and high yield (Fu, 2008; Lu & Collado, 2010; Luh, 1999). However, depending on the miller's/

technician's experience, a small amount of *Japonica* rice might be mixed with early *Indica* rice to adjust the texture of the rice noodles (Lu & Collado, 2010).

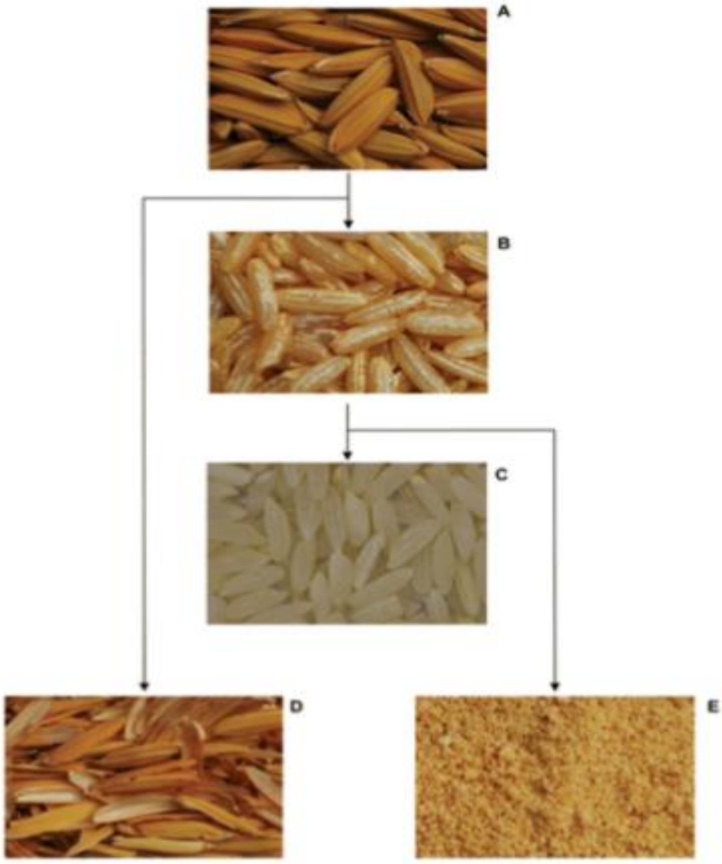

Figure 2. 2: Photographs of the different products obtained in the conversion of paddy rice (A) into white rice (C). First, paddy rice is separated into brown rice (B) and husk (D). The brown rice is then milled to give white rice and rice bran (E). Source: (Delcour & Hoseney, 2010).

There are four available methods for milling rice. However, most rice flour is produced by either dry-milling or wet-milling. In dry milling, rice kernels are milled into dry flour whose moisture is about 10% without any pre-processing (Kim, 2013).

In wet milling, rice is first soaked in water for an extended period before subsequent milling. The soaking is to make its internal structure better conditioned for subsequent milling (Kim, 2013). In order to obtain flour of desirable properties such as bright colour, fine particles, low damaged starches and ash concentration, it is very important to select a proper milling process. Wet milling method is mostly preferred to dry milling because it is believed to yield flour with superior quality, such as a better texture and finer particles of a narrow size distribution with less damaged starch than dry-milled flour (Leewatchararongjaroen & Anuntagool, 2016; Suksomboon & Naivikul, 2006; Wu et al., 2019). Substantial heat is generated during dry milling, which leads to some starch damage (Kim, 2013; Leewatchararongjaroen & Anuntagool, 2016). The downside of wet milling is that it results to large amounts of waste water (Kim, 2013; Leewatchararongjaroen & Anuntagool, 2016). However, studies show that dry-milled rice flour confers better nutritive value to products because it retains components such as proteins, lipids and ash at higher levels than wet-milled flour (Leewatchararongjaroen & Anuntagool, 2016; Suksomboon & Naivikul, 2006).

Flour extraction rate (measure of the percentage of the grain that is made into flour during the milling process) and ash concentration (measure of total mineral content in flour) also affects product quality. A low extraction rate and low ash concentration are preferred for developing high quality noodles which have a bright and clean appearance. On the contrary, a high extraction rate of flour (where by the flour has as more of the bran, germ and outer layers of the endosperm in it) increases noodle darkening due to greater levels of polyphenol oxidases found in the bran layer (Ahmed et al., 2016; Fu, 2008).

Table 2.2: Rice flour milling methods.

Method	Procedure	Reference
Dry	Milling	
Wet	Soaking – Dewatering – Milling – Drying	
Semi-wet	Spraying – Dewatering – Milling – Drying	Lee (2002)
	Soaking – Drying[a)] – Milling	Shin et al. (2007)
Misc.	Water spraying – Tempering – High pressure treatment – Milling	Koh (2013)
Two-step	Washing – Soaking – Dewatering – 1st Roller milling – 2nd Jet Milling-Drying	
Enzyme-treated	Washing – Enzyme treatment – Jet milling – Drying	Yoshii (2011)

[a)] Gentle drying such as ambient air, low-temp. air, or vacuum drying.

Source: (Kim, 2013).

2.1.1(a)(i) Physicochemical properties of rice flour properties indicative of noodle making quality.

Rice flour has a rich nutritional profile which determines its product making and functional quality. Generally, rice flour contains 78% carbohydrates, 5-15% protein, 0.4-0.8% fats, 0.024-0.046% dietary fiber, and substantial amounts of B vitamins; thiamin, niacin and Riboflavin (Ann Bock & Flores, 2011; Ahmed et al., 2016; Lu & Collado, 2010). Below are 4 important physicochemical properties of rice flour which affect its noodle making quality. They are also summarized in table 2.3

1. **Rice flour particle size**

The particle size of cereal flour (which includes rice flour) influences various noodle properties and is regarded as a valuable indicator of their quality and performance. Specifically, particle size is known to play a critical role in developing an optimal and uniform structural network hence influence noodle textural properties (Malahayati et al., 2011; Kruger et al., 1996). Rice flour particle sizes can be classified as Course (>890 μm), Intermediate (120-890 μm) and fine (<120 μm) (Dilip and Surendra, 2013).

According to Malahayati et al., (2011) and Yoenyongbuddhagal & Noomhorm, (2002), fine rice flour (with smaller particle size) yields better quality noodles with a characteristically higher hardness, springiness and chewiness while having reduced stickiness compared to noodles from coarse particle size rice flour. This was attributed to the fact that smaller particle size rice flour provides a large surface area which facilitates water absorption and more amylose release into starch gel, which increases gel hardness. Rice flour particle size also affects pasting properties. Pasting temperature of rice flour decreases significantly with a reduction in particle size (Malahayati et al., 2011).

2. Rice flour starch and its properties (amylose content, granule size)

Starch is the main component of rice flour and is the most important component that determines overall quality of rice noodles (Huang & Lai, 2010). Rice starch has basic characteristics that makes it unique and gives it advantages over other cereal starches. These characteristics include hypo allergenicity, good digestibility, bland flavor, small granules (2-8μm; smallest among other cereal starches, except oats), white color, greater acid resistance, greater freeze-thaw stability of paste, a wide range of amylose and amylopectin ratios and a high variation in gelatinization temperatures (Delcour & Hoseney, 2010; Juliano, 1984; Mitchell, 2009; Waterschoot et al., 2015; Xu et al., 2014).

On the basis of cooking quality, there are two primary types of commercial rice flour available on the market. Glutinous (also called sticky, sweet or waxy) and non-glutinous (also called non-waxy, or normal) rice flour. These are classified based on their relative levels of the polysaccharides, amylopectin, and amylose present. Glutinous rice flour is ground from long-grain or short-grain sweet white rice. It is called glutenous not because it contains gluten (which it does not), but because, when cooked, it gets glue-like and sticky- thus produces chewy and sticky noodles. The carbohydrate in glutenous rice flour does not contain any amylose starch, and if it does, it is only present in very small quantities. On the contrary, non-glutinous rice flour starch may contain up to 35% amylose (Nayar, 2014; Wani et al., 2012). Non-glutinous rice flour produces firm noodles.

Important starch dependent characteristic of rice flour which determines noodle/product quality include: Amylose: Amylopectin ratio, starch granule size, pasting properties (Viscosity), gel strength/consistency and thermal properties (gelatinization and retrogradation) as well as degree of starch damage.

On the basis of amylose content, rice flour can also be classified as waxy (0-2%), very low (2-9%), low (10-20%), intermediate (20-25%) and very high >25% (Juliano et al., 1981; Lu & Collado, 2010; Yu et al., 2012). The differences in amylose content might be related to cultivar differences, growing zone and environment (Juliano et al., 1981; Wani et al., 2012; Yu et al., 2012). The compositions of starches can be different, even when all the samples are from the same rice cultivar. The content of amylose present in the rice flour appears to be the major factor controlling almost all physicochemical properties of rice starch due to its influence on pasting, gelatinization, retrogradation, syneresis, and other functional properties (Wani et al., 2012). Low amylose content flour is not used for noodle making because it results into poorly textured noodles. Intermediate amylose content rice flour produces soft textured noodles with undesirably high cooking loss (Ahmed et al., 2016; Qazi et al., 2014; Wani et al., 2012). High amylose content (> 22%) rice flour is generally preferred for rice noodle making because it contributes to gel network which results into better structured noodles with desirable attributes such as high firmness, high tensile strength, lower density (higher swelling) and also white color (Bhattacharya, 2011; Fari et al., 2011; Lu & Collado, 2010).

The starch granule size also affects the starch noodle processing and quality of starch-based noodles such as rice noodles (Chen et al., 2003; Xu et al., 2014). Starch granule size affects the composition, gelatinization, and pasting properties, enzyme susceptibility, crystallinity, swelling, and solubility (Wani et al., 2012). Generally, noodles from rice flour show a higher water absorption capacity which was attributed to starch granule size and level of damaged starch. The smaller the granule size, the higher the water absorption capacity because small granule size offers greater surface area for water absorption. The higher the level of damaged starch, the higher the water absorption (Ahmed et al., 2016; Malahayati et al., 2011).

3. Rice flour proteins

Protein content is one of the determinants of the nutritional value of rice flour. Protein are made of amino acids at the basic building block. They are generally hydrophilic in nature and also easily dissolve in salt, ethanol, and alkali (Juliano, 1985).

The protein content of rice flour ranges from 5-15% (Ann Bock & Flores, 2011; Ahmed et al., 2016; Lu & Collado, 2010). About 0.25% of the protein in rice flour is associated with the rice starch either at the surface or inside the starch granules where they act either as storage proteins or biosynthetic or degradative enzymes (Baldwin, 2001; Komatsu & Hirano, 1992; Wani et al., 2012). The protein in rice consists of albumin (5%), globulin (12%), prolamin (3%), and glutelin (80%) but lacks gluten (Baldwin, 2001; Juliano, 1985; Komatsu & Hirano, 1992; Wani et al., 2012). Therefore, protein of rice does not develop an interconnected structure upon mixing, which results into a strong and elastic dough as in wheat flour products.

Studies have demonstrated an interaction between rice protein and rice starch (protein–starch interactions) which could influence rice flour product quality characteristics (Lee et al., 2016). Rice flour proteins influence rheological, pasting and thermal properties of starch granules, which in turn affect the textural, sensory and cooking properties of the final product (Bhattacharya et al., 1999; Li et al., 2018; Xie et al.,2008). For example, certain rice proteins with disulfide bonds confer shear strength and gelatinized paste rigidity to rice starch, restricting starch granule swelling during gelatinization and making the swollen granules less susceptible to breakdown by shear (Bhattacharya et al., 1999; Xie et al., 2008). Rice flour containing lower protein concentration is desirable for making fresh noodles, while rice flour containing high protein concentration is required to develop dried noodles. This is because high protein content in dried noodles helps to keep the noodle texture during drying. Likewise, Protein concentration plays vital role in the preparation of instant noodles, because fat uptake decreases as the protein concentration increase during the frying process (Ahmed et al., 2016). A darker color of gluten-free rice pasta was associated to higher contents of rice flour protein (Phongthai et al, 2017), while a lighter and more transparent pasta appearance was associated with a lower protein content of rice flour (Li et al., 2018).

4. Rice flour lipids (Fats)

The amount of fats in rice flour ranges between 0.38-0.8%, which varies with rice variety, rice grain storage time as well as flour milling method (Kaur & Singh, 2000; Saikrishna et al., 2018; Samuel & Juliano, 2004; Zhou et al., 2003). The lipids are classified as non-starch lipids and starch lipids (bound lipids). Starch lipids are further classified into two; (i) Lipids which are inside the starch granules are called endogenous (true-starch) lipids and (ii) lipids from the surrounding proteinaceous matrix of the endosperm are called the surface lipids (Samuel & Juliano, 2004). Non-starch lipids form the majority of lipids present in rice flour, while starch lipids account for 0.3-0.4 in common rice and 0.03% in waxy rice flour (Mitchell, 2009; Samuel & Juliano, 2004). The composition of the starch lipids consists of 32% Free Fatty acids (FFA) and 68% phospholipids (LPLs) including lysophosphatidyl choline (LPC) and lysophosphatidylethanolamine (LPE) (Bao & Bergman, 2018).

The amount of lipids is correlated with the amylose content of the rice flour and it is difficult to distinguish the effects of each on granule swelling and gelatinization (Tester & Morrison, 1990; Waterschoot et al., 2015). The starch lipids, although not as abundant as carbohydrates and proteins, play a very significant role in rice flour functionality such as gelatinization, pasting, and noodle quality (Samuel & Juliano, 2004; Zhou et al., 2003). Lipids complex with amylose forming amylose-lipid complex, which inhibit water uptake and subsequent swelling of starch granules during heating

(Marti et al., 2011). These complexes help reduce leaching of amylose into cooking water (cooking loss) (Biliaderis & Tonogai, 1991; Tester & Morrison, 1990; Waterschoot et al., 2015), quickly settle noodle structure and contribute to noodle firmness (Marti et al., 2010), reduce noodle stickiness and prevent noodle from binding together (Biliaderis & Tonogai, 1991; Lu & Collado, 2019). The presence of lipids in may also contribute to a relatively high freeze–thaw stability. The starch-lipid complexes formed ensure that Starch molecules do not remain close to each other in the granules, which would facilitate their reassociation and in this way it may contribute to a low freeze–thaw stability (Biliaderis & Tonogai, 1991; Waterschoot et al., 2015). This also contributes towards inhibiting long-term retrogradation (Yi et al., 2017). Generally, rice flour made from broken rice that has been stored for 0.5-1 year and with a free fatty acid content of less than 100mg KOH/100 g is known to produce good-quality rice noodles (Lu & Collado, 2010).

Table 2.3: Some chemical composition and physicochemical properties of flour indicative of rice noodle quality

Flour properties	**Indicators of quality**
Chemical composition	
Protein	• ranges from 5% to 15% in milled rice; • indirect indicator of cooking quality; • hydrophobic nature as barrier to inward water diffusion during cooking; • low-protein rice varieties tend to be flavorful, tender, and cohesive in rice noodle making. • use rice protein and strengthen protein cross-linking by transglutaminase to produce laminated rice noodle.
Total starch	• main component and structure provider of rice noodles; • different starch characteristics determine the varied product quality.
Fibre	• good nutrition significance but interrupts the continuous starch gel network, which decreased the tensile strength; • high cooking gain.