PROPERTIES OF WAXY RICE STARCH AND RICE GRAIN:

PROCESS DEVELOPMENT FOR AN INSTANT WAXY RICE PRODUCT

by

ASWIN AMORNSIN

Under the direction of Romeo T. Toledo

ABSTRACT

Soaking the waxy rice grain before cooking to raise the moisture content to 56% (db) before cooking in steam ensures that the applied heat is adequate to gelatinize the starch at the center of the grain. The moisture content of the rice grains increased a maximum of 10% (db) after steaming. The computer simulated moisture diffusivity of raw rice soaked at 1, 24, 40 and 60°C were 1.85, 3.88, 6.36, and 6.90×10^{-9} m^2/min, respectively. Rice soaked above 60°C gelatinized at the surface therefore grain integrity was altered, and a moisture- impervious layer of gelatinized starch was formed on the surface. Moisture absorption poorly fitted the diffusion model when the soaking temperature was higher than the gelatinization temperature. The desirable soaking condition was either overnight (12 hrs) at room temperature or 45 min at 60°C. Differential scanning calorimetry of whole rice grain showed an onset temperature of starch gelatinization from 58 to 67 °C , while the peak temperature was 69 to 72°C. The energy absorbed by the gelatinized transition was lowest on samples soaked the longest time and increased with decreasing sample moisture. Gelatinization transition was still exhibited by samples cooked 3 hr. Instant waxy rice was produced by a process called the "soak-steam-chill-separate-dry" method. To make instant rice, soaked rice was gelatinized in steam for 20 min followed by drying at 1 to 4°C for 48-72 hrs. The slow drying resulted in dense-transparent grains having moisture content 28-32% (db). The clump of gelatinized rice was separated into individual grains then further dried at low temperature until its water activity (a_w) was 0.6- 0.7. Scanning electron micrographs of samples showed that an improperly dried product exhibited large hollow cavities in the grain and densely packed material near the grain surface. Texture profile attributes of reconstituted instant waxy rice was not significantly different from those of conventionally prepared waxy rice. A coconut flavored reconstituted instant rice was not significantly different in sensory attributes from a similar product prepared conventionally from regular waxy rice.

INDEX WORDS: Instant, Quick, Waxy rice, Gelatinization, Fissure

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DEDICATION

This work is dedicated to Thai farmers, the back bone of Thailand.

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CHAPTER 1

INTRODUCTION

Rice is the most widely used staple food in the world. The type of starch in the rice grain determines preference by different populations. Intermediate-amylose rice is the most popular, followed by low and high amylose and lastly waxy rice. Waxy rice is the staple food in Laos and north and northeast Thailand (Juliano,1993). Generally, the higher the amylopectin content, the more sticky the cooked rice. When the rice was cooked, amylose and amylopectin form starch granules leach out, which affects viscosity and consistency of the rice. The content of amylose and the structure of amylopectin significantly affect the final texture of cooked rice. (Ong and Blanshard,1995)

Waxy rice, otherwise known as glutinous rice or sweet rice, is not very well and has limited production in the US (Juliano, 1985). Waxy rice products are considered delicacies in oriental countries and are consumed on special occasions. The problem with preparing waxy rice products is the long time required for preparation. It is used for commercial product such as sauce, gravies, salad dressing, dessert, pizza shells and batter dips for fry products (Juliano,1985).Traditionally, in Thailand, waxy rice is soaked in water overnight and the water saturated rice grains are cooked by steaming. Waxy rice can not be cooked in the same manner as non-waxy rice, because heating in an excess of water results in a product with a slimy and pasty texture. Direct steaming of dry waxy rice grains may result in a pasty, slimy texture while the middle of the grain may not be fully cooked.

Waxy rice starch is primarily amylopectin. This type of starch in the waxy rice grain and the tight packing of the starch granules hinder moisture absorption making it difficult to achieve a desirable texture after cooking. The cooked rice must be tender with no hint of mealiness when chewed. The mealy texture results when the starch is not fully gelatinized. Soaking the grain in water prior to the application of heat, raises the moisture level in the starch granules making it possible to achieve the desirable cooked texture by steaming. Instant or quick cooking long grain rice has been in the market, but to date there is no instant-waxy rice marketed. The reason for not having commercially produced instant-waxy rice might be due to the difficulty in processing the instant product. Orientals are increasing in numbers in the US and a convenient form of waxy rice may have a market among oriental US residents and the increasingly affluent residents of Pacific Rim countries. The challenge is to find a method of making instant waxy rice. The instant waxy rice product defined in this context is one that is shelf stable and will require minimal soaking and cooking time. When cooked, it will have characteristics similar to the conventionally prepared waxy rice. To achieve this objective, the starch in the rice grains must be pregelatinized and the grains dried. In order to facilitate rehydration and regelatinization of starch, the product must be in individual grains.

The hypotheses are:

1. Soaking the grain prior to cooking is accelerated by increasing the soaking temperature. What will be the required soaking time at different temperatures to result in a moisture content that will permit adequate starch gelatinization when the grains are cooked in steam? A method for evaluating rate of moisture

absorption and testing of adequacy of moisture absorption to achieve adequate starch gelatinization on cooking must be developed.

2. A suitable steaming process can be developed to gelatinize the starch in the waxy rice grain such that all grains in a clump will be cooked uniformly.
3. Cooking the waxy rice grains will inevitably result in the grains forming clumps of cooked grains. A drying method can be developed such that all grains in a clump will dry adequately and the dried clump can be separated into individual grains. Since the process objective is for the product to closely resemble the traditionally cooked waxy rice, it is important that the drying process will result in minimal breaking of the grains and the dried product will have a translucent appearance to make it attractive. Product microstructure will be used to evaluate process result.
4. The extent of starch gelatinization during cooking can be used to determine adequacy of cooking needed for the optimum process. Starch gelatinization can be observed by Differential Scanning Calorimetry.
5. The cooked product of the optimized process will resemble the traditionally cooked waxy rice starch in mechanical properties related to texture and sensory properties. Instrumental texture profile analysis (TPA) and sensory evaluations can be used to make the comparison between the traditionally cooked and cooked instant waxy rice product.

CHARPTER 2

RICE PRODUCTION

World rice productions

Rice is considered as a semi-aquatic annual grass plant (*Oryza sativa L.*). It is capable of growing on every continent except Antarctica, in latitudes ranging from 50° N to 40 °S, and up to 3000 m. altitude. It is the most important staple crop in the world. Half the world's people get 80 percent of their diet from rice (Juliano,1993). About 92% of rice produced in the world come from in Asia. FAO's estimate of global paddy rice production in 2002 was at 582 million metric tons (mT) (equivalent to 389 mT, milled). The major producing countries are shown in Table 1. In 2002/2003, China was the largest rice producer (32%), followed by India (21%), Indonesia (8.5), Bangladesh (6.8%), Vietnam (5.3%), Thailand (4.3 %) and the United States (1.7%). The total value of Thai exported rice was US$ 1,553.93 million in 2002 (Department of Foreign Trade, Thailand). Figure 2.1 lists countries that import and export rice in 2001-2002/2003. In year 2000, the international rice trade was approximately 24.1 million metric tons. The major rice exporters by continent were Asia (77%), followed by North America (11%), South America (6%), and Africa (3%). The major rice exporters by country were Thailand (31%), Viet Nam (14.5%), United States (10.4%), Pakistan (9.5%), China (8.3%), and India (7.8%). The major rice importers were Nigeria (6.6%), Indonesia (6.2%), Côte d'Ivoire (4.6%), Philippines (4.2%), Saudi Arabia/Iran (3.3%), Europe (6.6%) and North & Central America (9.5%). Rice cultivars may be categorized by race into 3 groups : Japonica(Sinica), Indica (tropical), and Javanica (Indonesia-Bulu). Rice may also be categorized by trade, e.g. Long/medium grain rice, Aromatics rice (eg. Thai jasmine), and Basmati (Pakistan). However, consumers generally recognize rice types as: long grain rice, Basmati rice, Jasmine rice, waxy rice (Japanese/ Sushi rice) etc. Depending on the subspecies, rice can grow either in dry upland regions or in water as deep as 5 m.

Rice production in Thailand

In 2001, Thailand exported 7.5 million mT of rice with a value of 70.4 billion Baht (Approx. 40 Baht/US$). In the USA, 100% of rice production is in irrigated land while in Thailand (2001) 74% of the rice is grown on low land dependent on natural rainfall for water. Twenty per cent of production in Thailand is on irrigated land while upland and deep water production is 4% each. The growing season depends on the region and the landscape. Normally, in the North, the Northeast and Central regions of Thailand, the growing season is May to July; and the harvesting season is November to December. In the south and other regions, the growing season is between November and December and the harvesting season begins in March and ends in May. The rainfall dependent low land production in 1999 by regions were 70.9% in the North, 91% in the North-East, 71.4% in the South, and 34.3 % in the Central region of Thailand (Rice Research Institute, Thailand 1999). The major rice varieties include Jasmine-Dokmalee 105 (26%), Jasmine-IR15 (2.78%), waxy-IR6 (27.7%) and High Yield Variety (10.9%). The typical rice culture in Thailand include the following steps: land preparation, plowing, seed preparation, resting, drainage, harvesting, and milling. Figure 2.2 shows the steps in rice production followed in Thailand. Land is prepared so soil conditions are favorable for the rice to grow and to level the land surface. Soil should be tilled deeply enough to support the root system and prevent growth of weeds. The land is then flooded with water 1-2 cm deep for 2-3 days before plowing. Plowing could be done either using a draft animal such as a water buffalo or by machine. The flooding process is necessary to eliminate weeds and soften the soil for seeding. The seeding could be by direct seeding or by spreading pre-germinated seedlings. The latter is prepared by soaking rice kernels in water 24-48 hr. The germinated seedlings are 1-3 cm long at the time of planting. The time for seeding depends on varieties, e.g. 40-80 days before transplanting. The seedlings are pulled out of the seedbed and transplanted. Individual plants are set into the soft mud spaced approximately 20-30 cm apart. Transplanting could be done by either hand or machine. After transplantation, the rice plant grows 3 to 4 months before the rice heads mature. During the growing period, the land remains flooded with water 1-2 cm deep. When mature, the paddy rice turns light brown in color. The water in the paddies needs to be drained before harvesting. Drainage is necessary to minimize harvesting losses and facilitate harvesting. The harvesting could be done either by hand or by machine. The threshing step removes grains from the stems and separates the chaff, The paddy rice may be dried and stored or dried and milled. The rice exported by Thailand include; Thai jasmine rice (Indica), brown rice (Indica), short grain rice (Japonica, Korean rice), parboiled rice and glutinous rice (Waxy rice). The cultivar of exported Thai jasmine rice is KDML105 while the waxy rice is RD6 Both are *Oryza sativa L.* The major trading firms for rice products are located in Hong Kong, Singapore, USA, Malaysia, Japan, Netherlands, and France.

Figure 2.1: List of countries that import and export rice in 2001-2002/2003

Source: FAO Rice Market Monitor (FEBRUARY 2003,Volume VI - Issue No. 1)

WORLD IMPORTS OF RICE

	2001	2002 (estimated)	2003 3/ (forecast)
		million tonnes, milled	
WORLD	**24.1**	**27.4**	**26.8**
Developing countries	20.2	23.3	22.7
Developed countries	3.8	4.1	4.1
ASIA	**11.4**	**13.8**	**13.4**
Bangladesh	0.4	0.3	0.3
China 1/	0.3	0.3	0.4
Indonesia	1.5	3.5	3.2
Iran, Islamic Rep. of	0.8	0.8	0.8
Japan	0.6	0.7	0.7
Malaysia	0.6	0.6	0.7
Philippines	1.0	1.2	1.0
Saudi Arabia	0.8	0.9	1.0
Sri Lanka	0.1	0.1	0.1
AFRICA	**7.3**	**7.8**	**7.5**
Côte d'Ivoire	1.1	1.0	0.9
Nigeria	1.6	1.8	1.7
Senegal	0.6	0.7	0.7
South Africa	0.6	0.7	0.7
SOUTH AMERICA	**1.1**	**1.0**	**1.0**
Brazil	0.7	0.7	0.7
Peru	0.1	0.1	0.1
NORTH & C. AMERICA	**2.3**	**2.7**	**2.7**
Mexico	0.5	0.6	0.6
EUROPE	**1.6**	**1.7**	**1.7**
EC 2/	0.7	0.7	0.7
OCEANIA	**0.4**	**0.4**	**0.4**

WORLD EXPORTS OF RICE

	2001	2002 (estimated)	2003 3/ (forecast)
		million tonnes, milled	
WORLD	**24.1**	**27.4**	**26.8**
Developing countries	20.1	23.0	22.5
Developed countries	4.0	4.4	4.3
ASIA	**18.5**	**21.9**	**21.0**
China 1/	2.0	1.9	2.1
India	1.9	6.5	4.5
Myanmar	0.7	0.7	0.7
Pakistan	2.3	1.5	1.5
Thailand	7.5	7.3	7.5
Viet Nam	3.5	3.2	3.9
AFRICA	**0.7**	**0.4**	**0.6**
Egypt	0.7	0.4	0.6
SOUTH AMERICA	**1.4**	**1.2**	**1.4**
Argentina	0.4	0.3	0.4
Uruguay	0.7	0.6	0.7
NORTH AMERICA	**2.6**	**3.1**	**3.4**
United States	2.5	3.1	3.4
EUROPE	**0.2**	**0.2**	**0.2**
EC 2/	0.2	0.2	0.2
OCEANIA	**0.6**	**0.5**	**0.2**
Australia	0.6	0.5	0.2

Table 2.1: World rice production in 1999/2000 - 2002/2003 (milled basis)

Country	1999/2000	2000/01	2001/02	2002/03
China	138,936	131,536	124,320	123,200
India	89,700	84,871	91,600	80,000
Indonesia	33,445	32,548	32,422	32,500
Bangladesh	23,066	25,086	25,500	26,000
Vietnam	20,926	20,473	20,670	20,500
Thailand	16,500	16,901	16,500	16,500
Burma	9,860	10,771	10,440	10,440
Philippines	7,772	8,135	8,450	8,300
Japan	8,350	8,636	8,242	8,200
Brazil	7,768	7,062	7,480	7,600
United States	6,502	5,941	6,764	6,457
Korea, South	5,263	5,291	5,515	5,300
Egypt	3,787	3,965	3,575	3,800
Pakistan	5,156	4,700	3,740	3,500
EU	1,751	1,567	1,620	1,792
Taiwan	1,349	1,342	1,245	1,197
Australia	787	1,259	930	965
Others	28,282	27,270	27,575	28,156
TOTAL	409,200	397,354	396,588	384,407

Unit: thousand metric tons

Source: USDA, Foreign Agricultural Services (FAS), Aug 2002.

Figure 2.2: Typical rice production in Thailand. (A) Dry land leveled, (B) Flood land, (C) Plowing, (D) Transplanting, (E) Resting, (F) Harvesting, (G) Threshing, (H) Paddy for milling.

Source: Images by PechSiam Technotrade Ltd, Thailand, (66)(2)-752-2774 – 5.


A)
B)
C)
D)
E)
F)
G)
H)

CHAPTER 3

RICE CHEMISTRY AND TECHNOLOGY

Rice grain structure and composition

The International Rice Research Institute (IRRI) classifies rice grains by size according to the following scale: extra long, >7.50 mm; long, 6.61 to 7.50 mm; medium, 5.51 to 6.60 mm; and short, <5.50 mm. Rice grains may also be categorized by shape based on length-to-width ratio: slender, >3.0; medium, 2.1 to 3.0; bold 1.1 to 2.0; and round, < 1.0. Table 3.1 shows the size of some rice grown in Japan. The information on the US standard for rice is in Appendix C. Rough paddy rice grain (unmilled rice) consists of 3 main components; hull (husk), endosperm and embryo (Figure 3.1). The hull is the brown, outermost part, which needs to be removed by milling. It is approximately 20 % of the rough grain weight (Juliano, 1985) and is indigestible by both humans and most animals. The next inner layers are the pericarp through aleurone layers. These layers contain valuable nutrients. They impart a higher nutritive value to brown rice compared to white rice when retained on the kernel during the processing of brown rice, These layers and the embryo are normally removed (as mill fraction and bran) during the dehusking (milling) process for white rice. The inner starchy endosperm cells are thin walled cells packed with starch granules. The starch granules are polyhedral in shape, having the size 3-9 µm (unimodal distribution). The cells contain spherical protein bodies 0.5 – 4 µm throughout the endosperm. Milling (abrasive or friction milling) removes pericarp, seed coat, testa, aleurone layer and embryo, which results in a loss of fat protein, crude and neutral detergent fiber, ash, vitamins (thiamin, riboflavin, niacin and α-tocopherol). Compared to brown rice, white rice (polished rice) is mainly starch. Juliano (1993) calculated that 65 % of the thiamin in the rice grain is in brown rice while only 13% is in the polished rice. When processing white rice, twenty two per cent of the thiamin in the grain ends up in the mill fraction while 65% is in the bran. Riboflavin is 39% in bran, 8% in the polished rice and 53% in the mill fraction. Niacin is 54% in the bran, 13% in the polished rice and 33% in the mill fraction. Table 3.2 shows the typical rice composition in the various milling fractions. Table 3.3 shows the composition of rice varieties grown in Thailand. The populations of many rice-consuming countries are malnourished. Eating rice alone (especially white-polished rice) may cause protein-energy malnutrition, vitamin A deficiency, iron deficiency (anemia), iodine deficiency disorder, thiamin and riboflavin deficiency. The protein content of brown rice is about 7% compared to 11% in wheat, 10% in corn and 2% in potato, on a dry basis (Juliano, 1993). However, rice protein has the highest nutritive value compared to other cereals because of its high lysine content. Brown rice is a good source of amino acids (per 16 g N) ; lysine(3.8), threonine(3.6), methionine +cysteine (3.9), tryptophane (1.1). By comparison, wheat contains: lysine(2.3), threonine(2.8), methionine +cysteine (3.6), and tryptophan (1.0). Rice has the highest net protein utilization (73%) among the cereals. By comparison the values are: 53% for wheat, 58% for corn, 62% for barley, 50% for sorghum and 59% for rye and oat (Juliano, 1985). Digestibility of milled rice is 93% compared to 90% for whole wheat and oatmeal. The protein content in milled rice is only slightly lower than in brown rice but significant losses in vitamins occur during the milling of white rice. Polished rice is almost 10 fold lower in thiamin, niacin and a –

tocopherol than brown rice. However, the lipid content in brown rice (2.2%) is higher than in polished rice (0.4%); therefore, brown rice is more susceptible to rancidity development during storage. There are attempts to breed rice that is high in dietary nutrients by gene technology (Genetically Modified Organism (GMO)- rice, such as Golden rice®) or a rice mimic such as Ultra Rice®.

The synthesis of starch granule

Synthesis of starch granules involves 3 main enzymes; ADPglucose pyrophosphorylase (AGPase), starch synthase, and starch branching enzyme (Smith et al., 1997). These enzymes are the primary drivers of starch synthesis (Figure3.2-A). ADPase generates ADP glucose, the substrate for synthesis of the starch polymer by the enzyme starch synthase. The branching enzyme is responsible for the synthesis and packing of amylopectin molecules to form the starch granule, and for the synthesis of amylose. The AGPase that synthesizes ADPglucose in all plant organs vary widely within and between the organs and species. The enzyme has different gene patterns in its large and small subunits. All of the large subunit genes are expressed in the tuber of potato and 2 of 3 are expressed in leaves. In barley, there are 2 genes encoding a large AGPase unit expressed only in the endosperm and there is another gene expressed primarily in leaves (Smith et al., 1997). It is believed that AGPase is present in the plastid where starch synthesis occurs. Starch is a glucose polymer that can be either a highly branched amylopectin or an unbranched amylase, or both. Amylopectin is a polymer of a-1,4 linked (by starch synthase) glucose unit backbone and branched (by starch-branching enzyme, SBE) with a -1,6 linked glucose units. The basic structure of a starch granules is an array-packed cluster of amylopectin molecules, in which the chains are radially arranged with the nonreducing end oriented towards the surface. The amylopectin molecules are organized into alternating crystalline and amorphous lamellae with 9 nm periodicities. The cluster arrays are packed chains of double helices. The chain length distribution of amylopectin molecules is polymodal (Figure 3.2-B). Amylose molecules appears in starch granules as single helices spread out in the amorphous regions of amylopectin. The precise location of synthesis (by non-branching granule-bound-starch syntase I, GBSSI) in the starch granule is unclear. However, some believe that amylose synthesis occurs within the amylopectin matrix rather than at the granule surface at the same time amylopectin is synthesized.

Amylopectin is the major starch fraction in waxy rice. A small amount of amylose (0.8-1.3%), is present in the center (hilum) of the granule (Houston, 1972). Amylopectin stains red-brown in iodine solution, while amylose stains purple-blue. Rice starch exhibits an A-type X-ray diffraction pattern similar to those of most cereal starches. X-ray diffraction patterns of waxy and non-waxy show similar degree of crytallinity, but non-waxy starch has stronger peak at *d* spacing of 4.37 °A than waxy starch.

Starch granules have polyhedral shapes, 3-9µm in size. They are packed 20-60 granules in the amyloplast. The final gelatinization temperature of waxy rice starch and non-waxy starch is similar; 58-79 °C for waxy starch and 58-78 °C for non-waxy starch.

Rice products

Japan and Korea have the most number of types of processed rice products marketed. In Japan, convenient ready to eat or easy to prepare rice products produced with automated equipment are common (Juliano, 1993). Rice can be found marketed as instant/quick cooking rice, rice cereal, rice noodle, rice paper (wrapper), rice cake, rice flour/starch, puffed/popped rice, rice pudding, and rice wine. The methods and names of the products depend on the source and region. *Quick cooking rice* is a product that requires a 15 to 20 min cooking time compared to about 30 min for milled rice. Processes for producing this product will be discussed later.

Rice cereal is prepared by cooking rice slurry then drying in a double- drum dryer. The dry sheets are flaked and packed. Infant cereals are carefully prepared to have a high enough consistency so it can be easily introduced by spoon into the mouth of toddlers but should be easily swallowed without making the child choke. Malt and α-amylase might be used to make the product slightly sweet. *Flat rice noodle* and *Rice wrapper* are prepared from wet-milled rice flour, produced by either a metal or a stone mill. The rice flour should have low lipid content and high amylase to produce a gel with a hard consistency. Flat noodle is prepared by thin coating the wet-milled rice batter (42 % by weight) on a taut cotton belt or stainless steel conveyer. In order to produce products with uniform thickness, a rotating-smooth drum, which is dipped and coated with batter, rolls over the conveyor. The sheet is then scraped out of the first conveyor by a stainless steel blade and transferred to another conveyor. The coated sheet is then gelatinized in a steam tunnel for 3 min (62% moisture content). The cooked sheet is momentarily dipped in peanut oil, folded and cut to the desirable size. The noodle can be sold as fresh noodle or dried. Rice wrapper is prepared using a similar principle. The batter is swirled as a thin layer on cheesecloth, which is positioned above steam. After gelatinization, the sheet is passed between rollers to produce a thin layer, then dried. *Extruded rice noodle* is prepared from aged-high-amylose milled rice similar to that used for flat noodle. The rice batter is kneaded. A small part of the dough is made into a ball, and surface-gelatinized by dipping in boiling water. The ball is then returned to the rest of dough and the mixture is kneaded again. The dough is then extruded by hydraulic press through a die. The extruded noodles may be fully cooked by dropping into hot water (will float) cooled and marketed as a ready to serve cooked noodle. It may also be surface-gelatinized by steaming, cooled then dried for ambient storage and distribution. Starch degradation may occur during the extrusion. In Thailand the dough used for making noodles might be fermented for 3 days prior to processing using the same procedure as above. *Rice cake* can be prepared from either non-waxy rice or waxy rice. Japanese rice cake called Mochi is prepared from milled waxy rice having a gelatinization temperature (GT) of 66-69 °C. The grains are washed then steamed at 100 °C for 15 min to reach a 40% moisture content. The mass is then kneaded, ground to a paste, packed in plastic film then pasteurized at 80C for 20 min. *Rice pudding* or *rice desert* such as the rice snacks found in the Philippines or Thailand could be prepared from a mixture of waxy rice, sugar, salt and coconut milk. The Japanese rice pudding is prepared from waxy rice flour, cornstarch, sugar, water and flavoring. The mixture is steamed at 100 °C for 60 min then served with sweet bean curd, coffee or fruits. *Puffed/popped rice* is prepared by heating freshly harvested rough rice (13-17 % moisture content) at 240 °C for 30-35 sec or in oil bath at 215-230 °C. In order to pop properly, the rice should have the hull tight around the kernel and there should be no cracks or fissure in the grain. Milled rice can also be puffed by contact with hot air or hot sand. Gun puffing can also be used. Milled waxy rice expands more than non waxy rice subjected to the gun-puffing method. Moist rice gelatinizes when heated at high pressure inside a pressure vessel, the expands when the pressure is released suddenly. Puffing guns are batch systems while a continuous system that uses semi-open long heating pipe and super heated steam (6 kg/ cm^2 , 200 °C outlet) is also commercially available. Puffing occurs after the rice is heated for 3-10 sec under pressure and passed through a rotary valve to atmospheric pressure.

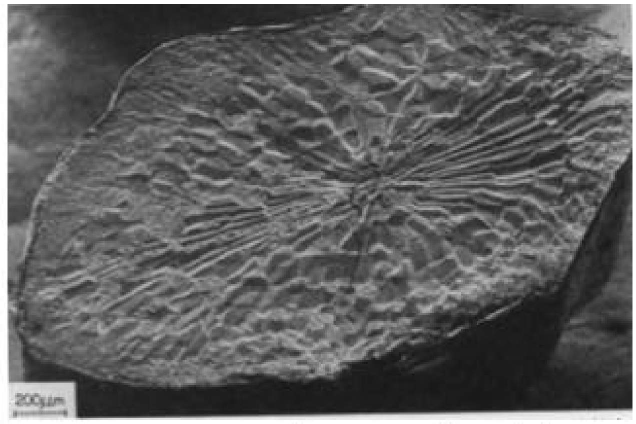
Baked rice might be used in conjunction with wheat to produce baked products for consumers with a celiac problem. Rice flour 10-20 % could be used in the mixture. Non-waxy rice flour with low GT and low amylose is preferable to produce a soft textured crumb. *Canned rice* is widely produced form long grain rice. The mixture might include rice, meat or chicken broth and other seasoning. After steaming for 30 min, the mixture is canned and sterilized at 112°C for 80 min. Canned waxy rice is normally formulated with sugar, beans and others to be suitable as a dessert. *Rice wines* are prepared from waxy rice by fermentation with fungi (mold and yeast). First, starch is converted to sugar by a mold. The sugar is then converted to alcohol in the subsequent yeast fermentation. The milled rice is washed, steeped, steamed, inoculated with *Aspergillus oryzae* and allowed to incubate at 35-38°C for 45 hr to produce the starter. Sake yeast is then added for the alcoholic fermentation under anaerobic conditions. One well known rice wine is Japanese sake, the fermented product of the sake yeast in koji steamed rice. Rice vinegar is produced from completely fermented rice with seed vinegar fermented for 1-3 months.

Quick cooking rice

In the late 1940's, a quick cooking rice called " Minute Rice (I)" was introduced into the US market by General Foods Corporation. The process was a soak-boil-steam-dry method. The product required only 10 to 13 min in boiling water to prepare for serving. Other methods for quick-cooking rice has been attempted and patented. R. Robert described the methods of making quick cooking rice in Houston (1972). The methods are summarized below. *(1) Soak-Boil-Steam-Dry methods*: Soaked rice with 30% moisture is cooked in hot water to 50-60% moisture then steamed to 60-70% moisture and carefully dried to 8-14% moisture. *(2) Expanded dry pre-gelatinized rice methods*: cooked rice is dried at low temperature to produce dense glassy grains then expanded at high temperature to develop a porous structure. *(3) The Bumping treatment*: cooked rice is rolled or bumped to produce flattened grains to promote the rate of rehydration. *(4) Dry heat treatment*: rice is blasted in hot air at 65-315°C to produce dextrinized, fissured and expanded grains. *(5) Freeze-thaw process*: is similar to (1) but cooked rice is frozen and thawed before drying. *(6) Gun-puffing method*: rice encounters high temperature-pressure before puffing in a vacuum chamber. *(7) Freeze-drying*: cooked rice is dried by sublimation. *(8) Chemical treatment*: rice is soaked in sodium chloride to absorb to 25% (w/w) salt then cooked and dried. Another method uses a solution of phosphate or polyphosphate with other compounds such as a sugar (lactose), and surfactant (glyceryl monostearate). *(9) Combinations of methods.*

Figure 3.1: A typical structure of rice grain.

Source: Redrawn from Juliano (1972)



Cross sectional view

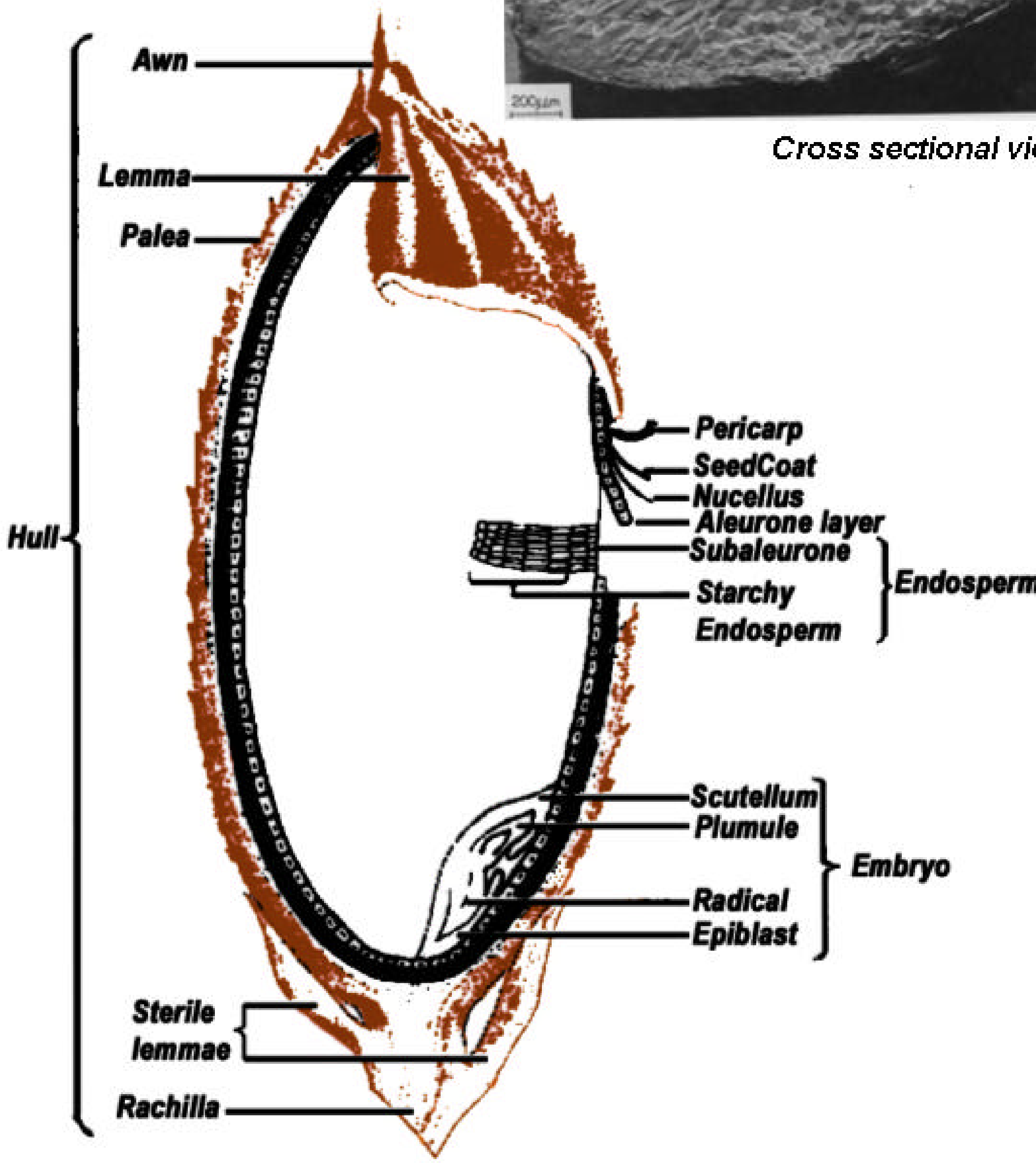


Table 3.1: Physical and chemical characteristics of some rice cultivars

Cultivar	Moisture content (%)	Grain length (mm)	Grain length Type	Grain volume (µl)	Amylose content (%)	Amylose content Type	Gelatinization temperature(°C)
Mochiminori	14.4	4.4 (0.1)c	short	12.9	0.0	waxy	66.4
MilkyQueen	13.7	4.7 (0.2)	short	12.4	10.0	non-waxy, low	73.4
Koshihikari	14.5	4.8 (0.1)	short	12.7	16.1	non-waxy, low	74.3
Kanto 181	14.4	5.3 (0.2)	short	11.6	30.4	non-waxy, High	73.5
Hoshiyutaka	15.3	5.9 (0.2)	medium	10.8	27.3	non-waxy, high	72.1

Source: Horigane et al (2000)

Table 3.2: Proximate composition of rough rice and fractions separated after milling at 14 percent moisture

Fraction	Rough rice	Brown rice	Milled rice	Rice bran	Rice hull
Crude protein (g N x 5. 95)	5.8-7.7	7.1-8.3	6.3-7.1	11.3-14.9	2.0-2.8
Crude fat (g)	1.5-2.3	1.6-2.8	0.3-0.5	15.0-19.7	0.3-0.8
Crude fibre (g)	7.2-10.4	0.6-1.0	0.2-0.5	7.0-11.4	34.5-45.9
Crude ash (g)	2.9-5.2	1.0-1.5	0.3-0.8	6.6-9.9	13.2-21.0
Available carbohydrates (g)	64-73	73-87	77-89	34-62	22-34
Neutral detergent fibre (g)	16.4-19.2	2.9-3.9	0.7-2.3	24-29	66-74
Energy content(kJ)	1580	1520-1610	1460-1560	670-1990	1110-1390
Energy content(hcal)	378	363-385	349-373	399-476	265-332
Density (g/ml)	1.17-1.23	1.31	1.44-1.46	1.16-1.29	0.67-0.74
Bulk density (g/ml)	0.56-0.64	0.68	0.78-0.85	0.20-0.40	0.10-0.16
Vitamins					
Thiamin (mg)	0.26-0.33	0.29-0.61	0.02-0.11	1.20-2.40	0.09-0.21
Riboflavin (mg)	0.06-0.11	0.04-0.14	0.02-0.06	0.18-0.43	0.05-0.07

Table 3.2. Continued.

Fraction	Rough rice	Brown rice	Milled rice	Rice bran	Rice hull
Niacin (mg)	2.9-5.6	3.5-5.3	1.3-2.4	26.7-49.9	1.6-4.2
a - Tocopherol (mg)	0.90-2.00	0.90-2.50	tr-0.30	2.60-13.3	0
Calcium (mg)	29495	18537	37924	30-120	60-130
Phosphorus (g)	0.17-0.39	0.17-0.43	0.08-0.15	1.1-2.5	0.03-0.07
Phytin P (g)	0.18-0.21	0.13-0.27	0.02-0.07	0.9-2.2	0
Iron (mg)	1.4-6.0	0.2-5.2	0.2-2.8	8.6-43.0	3.9-9.5
Zinc (mg)	1.7-3.1	0.6-2.8	0.6-2.3	4.3-25.8	0.9-4.0
Proteins					
Histidine	1.5-2.8	2.3-2.5	2.2-2.6	2.7-3.3	1.6-2.0
Isoleucine	3.0-4.8	3.4-4.4	3.5-4.6	2.7-4.1	3.2-4.0
Leucine	6.9-8.8	7.9-8.5	8.0-8.2	6.9-7.6	8.0-8.2
Lysine + cysteine	3.2-4.7	3.7-4.1	3.2-4.0	4.8-5.4	3.8-5.4
Methionine + tyrosine	4.5-6.2	4.4-4.6	4.3-5.0	4.2-4.8	3.5-3.7

Table 3.2. Continued.

Fraction	Rough rice	Brown rice	Milled rice	Rice bran	Rice hull
Phenylalanine	9.3-10.8	8.6-9.3	9.3-10.4	7.7-8.0	6.6-7.3
Threonine	3.0-4.5	3.7-3.8	3.5-3.7	3.8-4.2	4.2-5.0
Tryptophan	1.2-2.0	1.2-1.4	1.2-1.7	0.6-1.2	0.6
Valine	4.6-7.0	4.8-6.3	4.7-6.5	4.9-6.0	5.5-7.5
Amino acid score[a]	55-81	64-71	55-69	83-93	66-93

[a] Based on 5.8 g lysine per 16 g N as 100% (V/HO, 1985)

Source : Juliano (1993)

Table 3.3: Composition of rice grown in Thailand

Nutrition Facts Serving: 100 g	White Rice	Jasmine	Brown	Glutinous
Calories, kcal	361	355	362	355
Moisture (water), g	10.2	11.9	11.2	11.7
Total Fat, g	0.8	0.7	2.4	0.6
Dietary Fiber, g	0.6	0.8	2.8	0
Calcium, mg	8	5	12	7
Phosphorus, mg	87	65	255	63
Potassium, mg	111	113	326	0
Sodium, mg	31	34	12	0
Vitamin B1, mg	0.07	0.12	0.26	0.08
Vitamin B2, mg	0.02	0.02	0.04	0.03
Niacin, g	1.8	1.5	5.5	1.8
Protein, g	6	6.1	7.4	6.3
Carbohydrates, g	82.0	81.1	77.7	81

Source: Thai Food Composition Table (1999), Institute of Nutrition, Mahidol Univesity

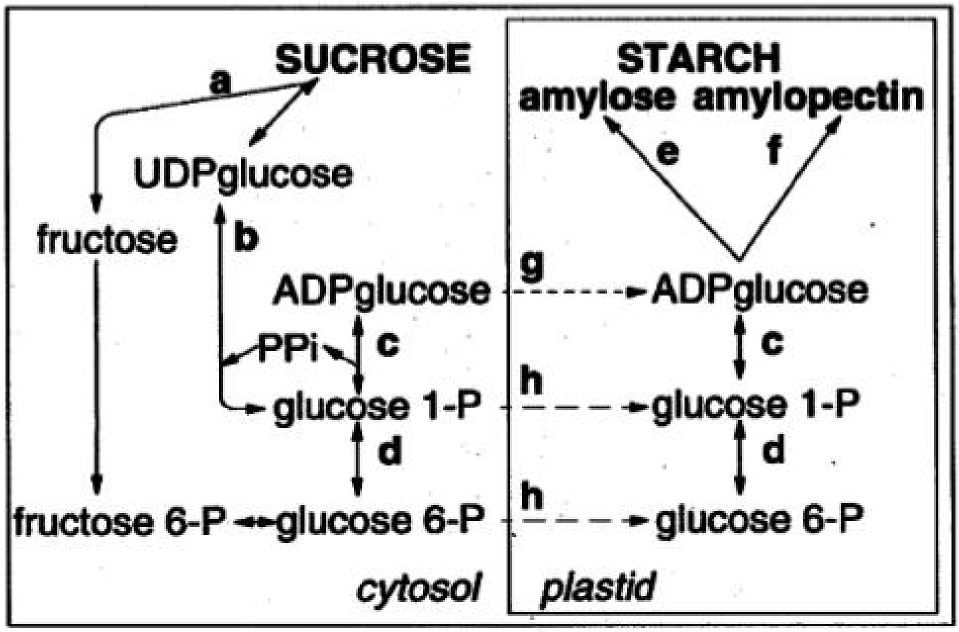
Figure 3.2: Diagrams of starch synthesis and starch molecule organization in the starch granule.

A)The major metabolites and enzymes involved in the conversion of glucose to starch in a storage organ. Enzyme: (a) sucrose synthase; (b) UDP glucose pyrophosphorylase; (c) ADPglucose pyrophosphorylase; (d) phosphoglucomutase; (e) starch synthase (GBSSI);(f) starch synthase and starch-branching enzyme; (g) ADPglucose transporter;h-hexose phosphate transporter, (ppi) inorganic pyrophosphate.

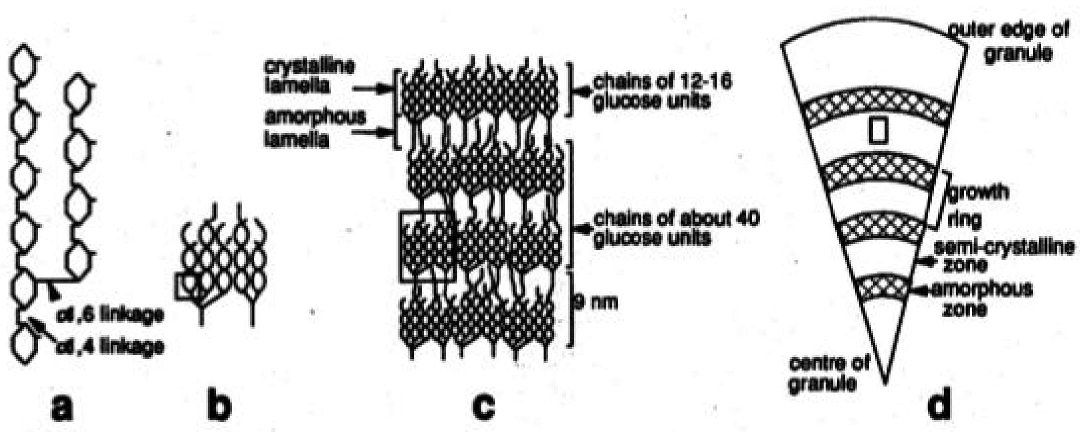
B) The organization of starch molecules in the starch granule. The box within the diagram represents the preceding structure. (a) Structure of two branches of an amylopectin molecule. (b) A single cluster within the amylopectin molecule, forming double helices. (c) Cluster arrangement to form alternating crystalline and amorphous lamellae, the ordered array of packed double helices. (d) slice through a granule, showing the alternating zone of semicrytalline materials, consisting of crystalline and amorphous lamellae, and amorphous material.

Source: Smith et al. (1997)

A)


SUCROSE
a
UDPglucose
fructose
b
ADPglucose
PPi
c
glucose 1-P
d
fructose 6-P
glucose 6-P
cytosol
STARCH
amylose amylopectin
e
f
g
ADPglucose
c
h
glucose 1-P
d
h
glucose 6-P
plastid

B)


α1,6 linkage
α1,4 linkage
a
b
crystalline lamella
amorphous lamella
chains of 12-16 glucose units
chains of about 40 glucose units
9 nm
c
outer edge of granule
growth ring
semi-crystalline zone
amorphous zone
centre of granule
d

CHAPTER 4

THEORIES

Moisture diffusivity simulation

When dry rice grains are soaked in water, liquid will penetrate the kernel raising the moisture content to an equilibrium state. The rate of moisture diffusion is dependent on the soaking temperature. Linear molecule has higher moisture diffusivity than branch amylopectin molecule (Kostaropoulos and Saravascos, 1997). The rate of moisture diffusion into a rice grain may be simulated by a mathematical model, which is based on the hypothesis that the rate of transfer of diffusing substance through a unit area of a section is proportional to the concentration gradient (Crank, 1956). The model is based on Fick's law of diffusion described below.

$$F = -D\frac{\partial C}{\partial X} \qquad (1)$$

where:

F = the rate of transfer per unit area of section

C =the concentration of diffusing substance

X =the space coordinate measured normal to the section

D =the diffusion coefficient

The general form of the Fick's second law can be used to analyze non-steady state diffusion in a symmetric solid as described below.

$$\frac{\partial C}{\partial t} = \frac{1}{r^{v-1}} \frac{\partial}{\partial r}\left(r^{v-1} D \frac{\partial C}{\partial r} \right) \tag{2}$$

where:

t = time

v = geometric factor; infinite slab=1, finite cylinder=2, sphere=3

r = the distance measured from the center of the solid

The analytical solutions given by Newman (1931) and Crank(1975) for defined geometry are below.

Slab:

$$MR = \frac{8}{p^2} \sum_{n=0}^{\infty} \frac{1}{(2n+1)^2} \exp\left(-(2n+1)^2 \left(\frac{p}{2} \right)^2 \frac{D \cdot t}{a^2} \right) \tag{3}$$

Sphere:

$$MR = \frac{6}{p^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp\left(-n^2 p^2 \frac{D \cdot t}{a^2} \right) \tag{4}$$

Infinite length Cylinder:

$$MR = 4 \sum_{n=1}^{\infty} \frac{1}{j_{0,n}^2} \exp\left(-j_{0,n}^2 \frac{D \cdot t}{a^2} \right) \tag{5}$$

Finite length Cylinder:

$$MR = \frac{32}{p^2} \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} \frac{1}{(2m+1)^2} \cdot \frac{1}{j_{0,n}^2} \exp\left(-(2m+1)^2 \left(\frac{p}{2}\right)^2 \frac{D \cdot t}{a^2} - j_{0,n}^2 \cdot \frac{D \cdot t}{L^2} \right) \qquad (6)$$

Where:

MR = moisture ratio, $(C-C_\infty)/(C_0- C_\infty)$; C is average moisture at time t, C_0 is initial moisture content, C_∞ is the equilibrium moisture content.

a = half thickness for slab or radius for the sphere and cylinder (m)

L = finite length of cylinder (m)

D =diffusivity coefficient (m^2/min)

t = time in min (min)

$j_{0,n}$ = Bessel functions $J_0(n)$of the first kind and zero order (MacCluer, 2000)

Steffe and Sing (1980) studied liquid diffusion of rough rice, which they considered the rice kernel as a sphere. Igathinathane and Chattopadhyay (1999) considered the rice endosperm as the prolate spheroid (ellipse) and model the moisture diffusion using the complicated finite element technique.. However, long grain waxy rice can be considered a finite length cylinder (Ece and Cihan,1993). This study uses the finite length cylinder model to simulate the average moisture content in the soaked rice over time. The apparent diffusivity coefficient was determined by an iteration that involves substitution of values of D into equation 6, calculating MR, and selecting a value that gave the minimum least square error (equation 7) between the experimental data and the calculated value.

$$D \Rightarrow \min \sum \left(MR_{\exp} - MR_{sim}\right)^2 \quad (7)$$

where:

MR_{exp}= Moisture ratio from the experiment

MR_{sim}= Moisture ratio from the simulated model

The simulation was performed based on the assumptions from Steffe and Singh(1980) , and Young and Whitaker(1971), which include; (1) the mechanism of moisture movement is liquid diffusion, (2) diffusion coefficients are not a function of moisture concentration, (3) rice was considered to be isothermal during soaking, (4) the component of rice is homogeneous, (5) swelling of rice is neglected.

Diffusivity as a temperature dependent property

The moisture diffusivity coefficient is temperature dependent. The relationship can be expressed as a Arrhenius type equation below;

$$D_T = A \cdot e^{(\frac{-B}{T})}$$

Where:

D_T= Diffusivity

A,B= constants

T= temperature in Kelvin, (°C+273.15)

The equation is based on the assumption that D is affected by temperature only and there is no effect of moisture gradient (Igathinathane and Chattopadhyay,1999).

Starch gelatinization

Naturally occurring starch granules are insoluble in cold water. Heating a starch suspension in water solubilizes the starch as it becomes gelatinized. Gelatinization alters the molecular arrangement of starch in the granules. These changes are manifested by irreversible granule swelling, leaching of amylose and amylopectin , loss of birefringence, and loss of crystallinity (BeMiller and Whistler, 1996). Gelatinization takes place in a range of temperatures. This temperature range depends on the method of measurement, starch water ratio, granule type, granule size, and granule composition. Gelatinization always takes place over a temperature range. The range for a single granule heated in the presence of excess water may be 1 to 2 °C. However, not all granules gelatinize at the same temperature. Gelatinization of a whole population of granules may occur at a temperature range greater than 10 °C (Eliasson and Gudmundsson,1996). Table 4.1 shows the gelatinization properties of various waxy rice starches. The loss of birefringence observed with polarized light under a microscope is one of the methods used to determine gelatinization of starch. Differential scanning calorimetry (DSC) is an effective instrumental method to determine the temperature range of gelatinization as well as the energy involved during this transition. When the starch granule is heated in an excess of water, it swells. With prolonged heating, the starch molecules in the granule (especially amylose) leach out and eventually the starch granules are disrupted. At this stage, the mixture becomes a paste. Cooling of the paste will result in either a viscous solution, or a viscoelastic, firm or rigid gel depending on type of starch and starch-water ratio. During gelatinization, the suspension viscosity increases until it reaches the peak viscosity. Further heating breaks down the starch molecules into shorter molecular length fragments, which results in a drop in viscosity. Water absorption and dissolution start at a lower temperature in starch with low gelatinization temperature (GT). GT of non-waxy starch is lower than that of waxy starch. Non-waxy starch continues to absorb water above its GT, while waxy starch reaches its maximum moisture content close to the GT (Juliano, 1985). The higher the amylose content, the higher the capacity of starches to absorb water and expand. This is because of the presence of more available hydrogen bonds in amylose compared to amylopectin molecules. The peak viscosity of waxy rice flour occurs at a lower temperature than non-waxy rice flour. The former requires twice as much solids concentration in the paste to obtain a similar amylograph pattern as that for non-waxy rice. During cooking of waxy rice, most short chain amylopectin is leaching out leaving the long chain amylopectin, which interacts with other component in the gain. The cooked rice retains complexes, which inhibit softening (Ong and Blanshard,1995). Final waxy rice clump is very cohesive. Cooked waxy rice has higher stickiness than non-waxy rice (Juliano,1985).

Reassociation (recrytallization) of the starch molecules might occur when the paste cools down and allowed to stand for some time. This change is called retrogradation. Retrograded starch becomes less soluble and does not readily re-dissolve upon heating. The rate of retrogradation depends on various factors such as amylase to amylopectin ratio, the molecular structure of the starch polymers, the botanical source and the presence of other components such as protein, lipid and simple sugars. Non-waxy rice starch, which contain higher amylose, has been observed to have a higher rate of retrogradation than waxy rice starch. However, amylopectin that has intermediate and low molecular weight ($2.8\text{-}3.75\times10^7$) show remarkable retrogradation when stored for 4-5°C (Mua and JAcson, 1998, Fredriksson et.al,1998). The rate of retrogradation of a starch gel is maximum when stored in a refrigerator. This rate is lower in frozen storage but the lowest retrogradation rate occurs at room temperature (Kim et al., 1997). Retrogradation cooked rice may reduce the adhesion between the rice grains when stored at low temperature. Retrograded starch is responsible for staling in baked products, an undesirable change which results in increased crumb firmness and loss of aroma. Retrograded amylose is beneficial when in the form of resistant starch type III, an indigestible starch fraction in the human intestine. This starch can be useful as a dietary component of people who desire a limited caloric intake, e.g. the diabetic and the obese. This starch is stable up to 120 °C (Seivert and Pomeranz, 1989) so it can be a component of thermostabilized products. Retrogradation can be studied with Differential Scanning Calorimetry (DSC), X-ray diffraction or a-amylase methods (Kim et al., 1997). As mentioned earlier, the presence of other components in the starch mixture affects gelatinization. In the presence of proteins, e.g. gluten, the gluten-starch interaction will limit gelatinization. Gluten-starch interaction plays a major role in the viscoelastic properties (Champenois et al., 1998) of a gel. Figure 4.4. illustrates the gluten-starch interaction during gelatinization. The gluten molecules interfere with the leaching of amylose from the starch granule thus slowing down the disruption of the granule. Lipid present in cereal starch may form a helical-shaped complex with the amylose molecule.

The complex formation is an exothermic process and will decrease the observed endothermic gelatinization enthalpy (Fredriksson et al.,1998). Rice gelatinization temperature is classified in 3 ranges; low <69°C, intermediate 70-74°C, and high >74°C (Juliano, 1985).

Differential scanning calorimetry (DSC)

The Perkin-Elmer Company has pioneered in modern DSC instrumentation since the early 1960s. DSC has been widely used for thermal analysis of materials. It is capable of studying both the thermodynamic parameters and the kinetic characteristics of process /relaxation transition. DSC measurements reveal the physical properties of substances such as heat capacity and its changes, temperature, enthalpy and entropy of phase transition and energy change. The principle of DSC is the application of a controlled amount of energy to a sample which is heated at a constant rate. The amount of energy applied to give a set temperature rise is the enthalpy. A computer program controls the temperature and measures the compensating heat flux that keeps the temperature of the sample within the predefined rate (Bershtein and Egorov, 1994).

Differential thermal analysis (DTA) may also be used to study thermal transitions in materials. DTA compares transition temperature in the sample to that of a reference sample. The process requires accurate calorimetric measurement and efficient controllers for the heat flux. A schematic diagram of the principle of operation of DSC and DTA is shown in Figure 4.1. Perkin-Elmer DSC7 features advance analysis software, which calculates measurement parameters such as specific heat capacity (Cp), onset or peak of a transition, area under a transition curve, glass transition temperature (Tg), etc., from the measurement data. The types of transition recorded using DSC measurements are shown in Table 4.2. The instrument measures and records heat flux (endothermic or exothermic) on the Y-axis and temperature on the X-axis. The transition that requires the input of heat (enthalpy) into the system, such as melting, will be manifested as a positive increase in output (exothermic), while the transition that releases heat (exothermic) (e.g. crystallization) will show a decreasing output. DSC techniques have been widely used in food analysis such as gelatinization and retrogradation of starch (Aee et al., 1998; Fredriksson et al., 1998), protein denaturation and association (Burova et al., 2003), sucrose dissolution analysis (Bhandari and Roos, 2003**),** glass transition analysis (Borde et al., 2002), crystallization in food emulsions (Kalnin et al., 2002) and adulterations in oil (Marikkara et al., 2002). Figures 4.2 and 4.3 show typical DSC thermograms for gelatinization and retrogradation of various starch-water gels. An endothermic bell-shaped curve occurs in the region of a transition associated with gelatinization. The area under the curve is the enthalpy (ΔH), the energy required to melt the crystalline material. This enthalpy may also be used as an index of recrystallization (retrogradation).

Texture profile analysis (TPA)

Instrumental texture profile analysis (TPA) is used in conjunction with sensory analysis to evaluate the physical properties of foodstuffs. The instrumental analysis of texture is inexpensive, reproducible and reliable if conducted properly. Pon and Fiszman (1996) wrote a good review on the methods and the important rules when conducting the TPA. A compression test employing two bites is usually used. A 75-90 % strain deformation is applied on the sample. TPA parameters are obtained from the force-deformation curve as reviewed by Bourne (1978) and Szczesniak (1975). Figure 4.6 shows a typical TPA curve obtained from the TA-XT2™ texture analyzer (Stable Micro System). Unlike the TPA curve from the Instron Universal Testing Machine® or the GF Texturometer, TA-XT2™ can be programmed to set the time elapsed between the bites. This allows the options of setting test conditions suited for specific products. TPA results are reported as texture profile parameters such as springiness, cohesiveness, gumminess, and chewiness. The earlier TPA-definition proposed by Bourne (1978) was examined on the Instron. The original 7 texture profile descriptors include: (1) *Fracturabilty* , defined as the force at the first significant break of the curve., (2) *Hardness* , defined as the peak force during the first compression cycle or first bite., (3) *Cohesiveness,* defined as the ratio of the positive force area during the second compression portion to that during the first compression (Area2/Area1)., (4) *Adhesiveness,* defined as the negative force area of the first bite., (5) *Gumminess,* defined as the product of $hardness \times cohesiveness$., (6) *Springiness,* defined as the height that the food recovers during the time that elapsed between the end of the first bite and the start of the second bite., (7) *Chewiness,* defined as the product of $gumminess \times springiness$. Other TPA descriptors not included in the original descriptors of Bourne (1978) include: (8) *Stringiness*, defined as the distance that cover the negative area under the curve after the first bite., (9) *Stickiness*, defined as the maximum negative force in the first bite.

Hardness represents the force needed to attain a given deformation (Szczesniak, 1963). This descriptor might also be referred to as firmness or compressive resistance. Under TPA, hardness is a measure of the maximum compression force (peak) that can be applied without causing failure making it possible for the test to be resumed by applying the second cycle. Hardness has the unit of force (Newton or *mass.lenght.time*$^{-2}$). When compressing the sample, its structure might break thus the force reaches a peak and drops. This peak was defined as fracturability or brittleness, a property of a brittle material such as hard candy. In a gel, compression to the point of rupture is not appropriate. Stickiness is the maximum negative force manifested when the probe is pulled away from the sample. It is the attractive force between the surface of food and the test probe. Therefore, the properties of the probe will affect its value. Stickiness is sometimes referred to as *adhesive force*. This property is significant in products such as chewy confectionary, adhesive gum, spread, dough stickiness and other sticky products. Waxy rice starch has almost 10 times higher stickiness values than non-waxy rice high amylose starch (Juliano, 1985). The total area of this negative peak is defined as *adhesiveness* in TPA. It is the work necessary to overcome the adhesive force. It has the unit of work (N.m; *mass.lenght*^{2}.*time*$^{-2}$). TA-TX2 calculates the area giving either units of N.m or N.s (*mass.lenght.time*^{3}). The later unit can be converted to N.m by multiplying with the test speed (*lenght.time*$^{-1}$). However, if the test speed is constant, the values are the same in either units. Stickiness and adhesiveness are the important characteristics of waxy rice (Juliano,1985).

Cohesiveness is the strength of the internal bonds making up the body of the product (Szczesniak, 1963). This is a measure of how the product maintains its integrity when undergoing deformation. This property affects the gumminess and springiness, which involve the energy required to disintegrate the food material. Szczesniak (1963) stated that gumminess should be used to describe semi-solid foods, while chewiness is used on solid foods. Gumminess has the unit of force (N), while the unit for chewiness could be either force or energy depending on the units used for springiness.

Springiness is the rate at which a deformed material goes back to its undeformed status after the deforming force is removed. Springiness might be defined as the height of the food that recovers after the first bite and following a defined delay. The delay time (TA-XT2™) could affect the springiness value. Figure 4.6 contains the definition of springiness as reported in recent papers. There are attempts to standardize the term *Springiness* by expressing it as a *Springiness Ratio*. The latter uses the ratio of the springiness distance to the height of the sample (Lau et al, 2000) or the ratio of the springiness distance to the first peak distance. A problem might occur if a sample fractured or if the peak does not occur at the maximum distance of the down stroke. In this case the ratio will have a value greater than 1.0. One approach is to use the ratio of the time covering the second peak and the first peak. This will give the springiness range of 0-1 (0 - 100%). The later method might result in reduced data variance and is more systematic. The statistic comparison, however, compared within the same experiment might not show significant difference among the methods of calculation. The springiness is further used to calculate chewiness.

The general testing condition for the TPA depends on the sample characteristics. Table 4.3 lists examples of TPA test conditions found in the literature. Normally, the compression probe is larger than the sample size, which allows the TPA to be measured as a uniaxial compression force (Pons and Fiszman, 1996). The samples shape can be either cubes or cylinder. Most of samples have diameter of 1.5 – 3.0 cm and height of 1.5

– 2.0 cm. In the most cases, diameter was larger than its height. The general test speed ranges from 0.5 to 2 mm/s.

Table 4.1: Gelatinization properties of various rice starches

Cultivar	Amylose (%)	Lipid (mg/100mg)	λ_{max} (nm)	DSC T_o (°C)	T_p (°C)	T_r (°C)	ΔH (J/g)	SF_{80}
RD6	0.15	16	522	46	64.3	81	13.4	24.3
IR65	0.94	24	526	45.6	65.7	85.3	13.7	33.3
Khao Khao	0.32	20	522	50.1	65.9	83.3	13.4	24.2
IR29	1.86	Na	534	49.6	66.1	83	14.2	32.4
Malagkit SS	0.39	17	526	49.3	66.8	91.6	14.4	41.9
IR39368-31-1-2	0.79	20	526	52	67.3	52.3	13.9	36.3
Inilang-ilang	9.79	14	526	59.3	75	90.6	15.3	32.9
Pururutong NBA	1.97	24	530	52.3	75.7	92.6	16.2	30.5
Nathasiq	2.32	Nd	534	56.3	76.3	93.6	17.5	39.9
Tapol	2.31	52	530	50.3	77.1	94.6	16.1	35.2
PyaGuyTaung	2.31	21	532	51.3	77.6	94.3	15.7	31.3
RD4	1.94	15	532	62.3	78.8	94.8	15.9	28.7

T_o=onset temperature, T_p=peak temperature, T_r =recovery temperature,ΔH=endothermic enthalpy, SF_{80}=swelling factor at 80 °C.

Source: Tester and Morrison (1990)

Figure 4.1: Schematic diagram of calorimeter chamber. (A) DTA and (B) DSC: 1-sample; 2-reference

Source: redrawn from Bershtein and Egorov (1994).

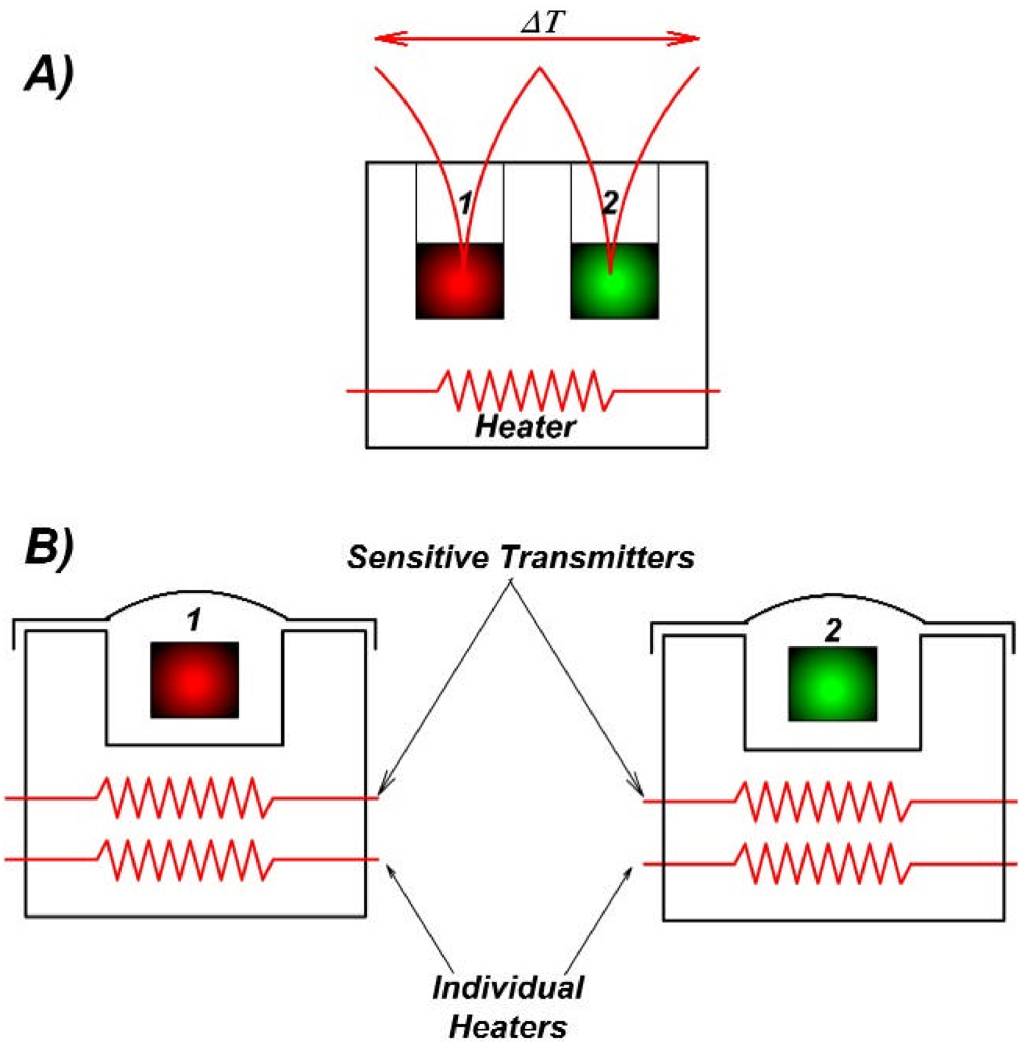

A)
ΔT
1
2
Heater
B)
Sensitive Transmitters
1
2
Individual
Heaters

Table 4.2: Typical DSC curves.

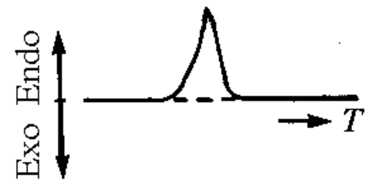
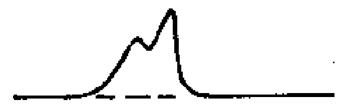
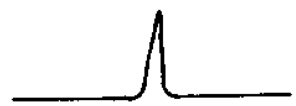
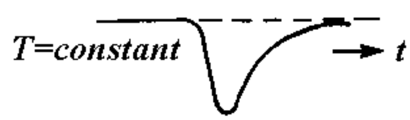
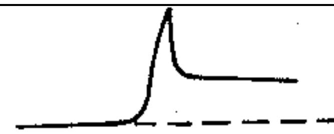
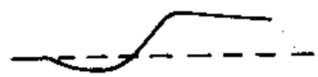
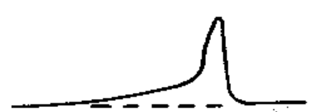
Type of transformation	DSC curve
<u>Melting</u>	
Quasistable crystals	
Melting with crystal reorganization	
Multiple melting (different phases or sizes of crystals of one polymer, mixture of crystalline polymers, liquid-crystalfine polymers, etc.)	
Melting of orientated polymer	
<u>Crystallization</u>	
Isothermal conditions	
Cooling of melt	
Cold crystallization on heating of solid polymer	
<u>Devitrification (α-Transition) and Relaxation T< -Tg</u>	
Quenched state	

Table 4.2. Continued.

Type of transformation	DSC curve
Annealed state	
Quenching with partial (low-temperature) annealing	
Highly plasticized polymer	
Strongly quenched or preliminarily deformed glassy polymer	
<u>Glass Transition</u>	
Cooling from melt or rubbery state	
<u>Other Physiochemical Processes</u>	
Polymerization, curing of resins, decomposition, adsorption, chemisorption	
Desolvation, decomposition, depolymerization	
Evaporation, sublimation	
Evaporation in sealed capsule	

Source: reprinted from Bershtein and Egorov (1994).

Figure 4.2: DSC thermograms of retrograded rice starch from 50% starch gels stored for 3 days.

Source: redrawn from Kim et al. (1997).

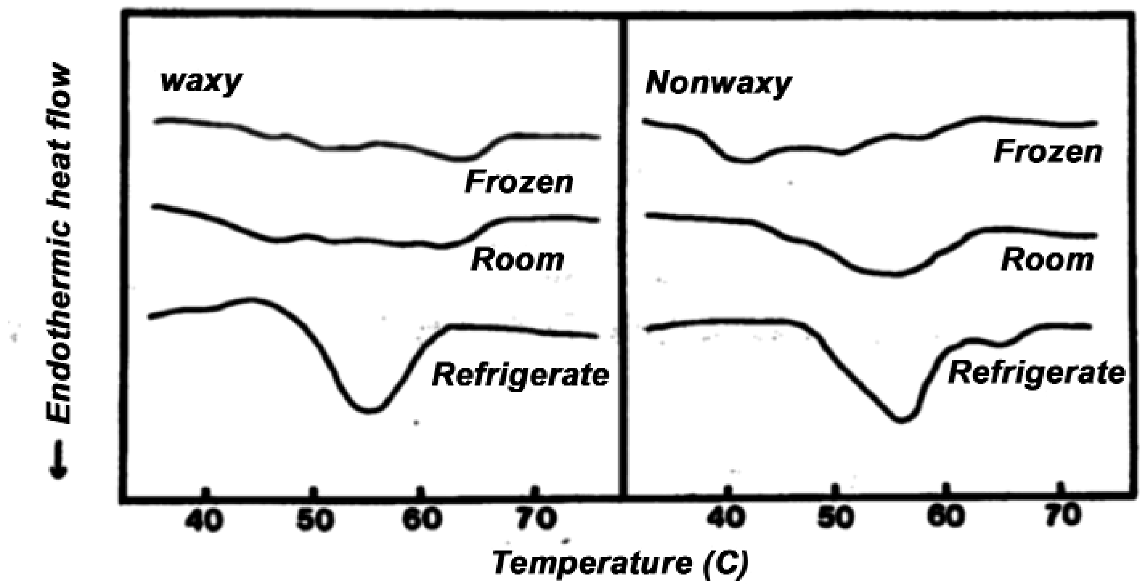

waxy
Nonwaxy
Frozen
Room
Refrigerate
Frozen
Room
Refrigerate
Endothermic heat flow
40
50
60
70
40
50
60
70
Temperature (C)

Figure 4.3: Gelatinization endotherm of starch water mixture (1:1) before gelatinization and after gelatinization and retrogradation by storing at low temperature.

(A) Ungelatinized starch

(B) Gelatinized starch stored 4 days at 6 °C.

Source: redrawn from Fredriksson et al. (1998)

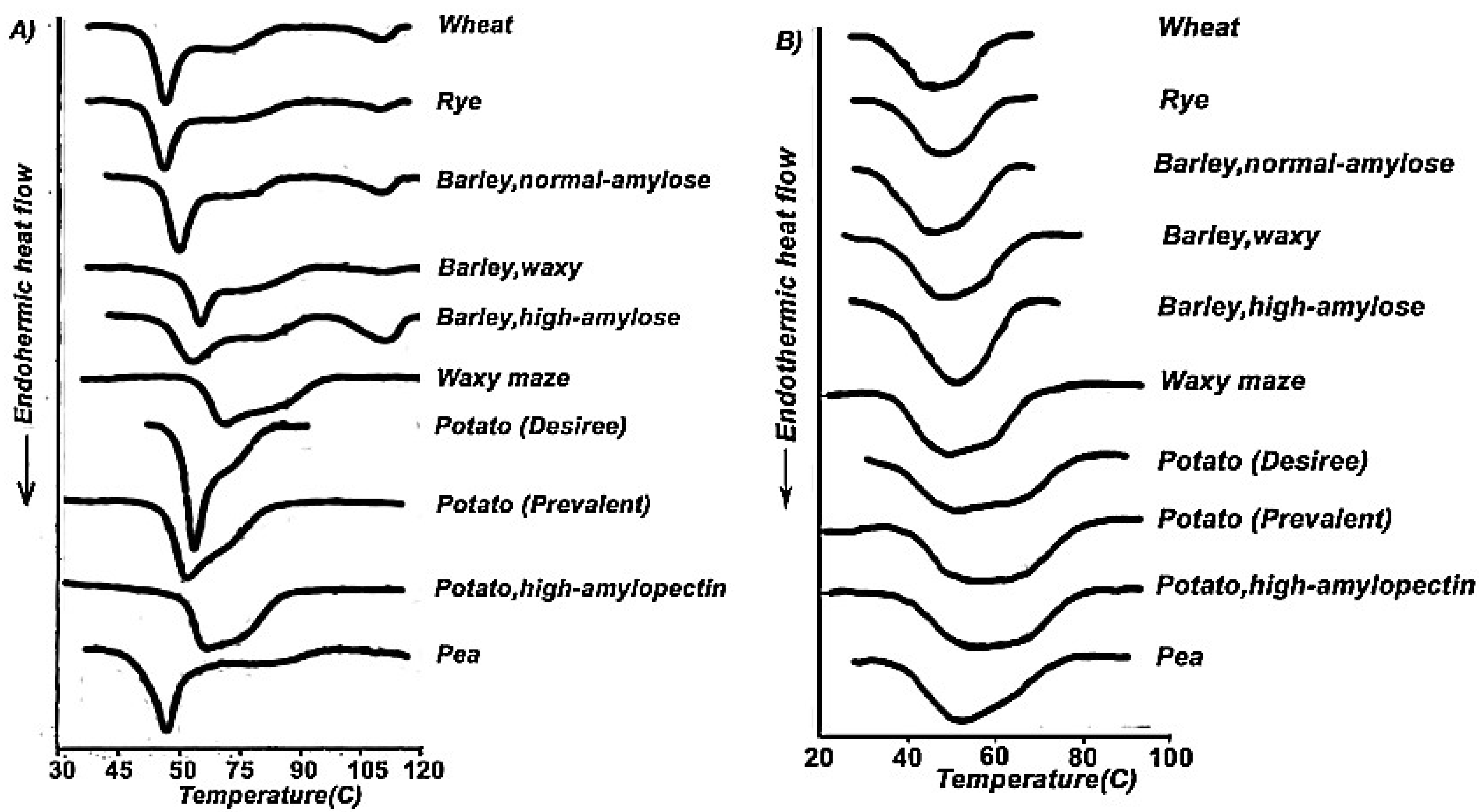

A)
B)
Wheat
Rye
Barley,normal-amylose
Barley,waxy
Barley,high-amylose
Waxy maze
Potato (Desiree)
Potato (Prevalent)
Potato,high-amylopectin
Pea
Endohermic heat flow
Endothermic heat flow
30 45 50 75 90 105 120
20 40 60 80 100
Temperature(C)

Figure 4.4: Gluten-starch interaction in gelatinization of starch

Source: Redrawn from Champenois et al. (1998)

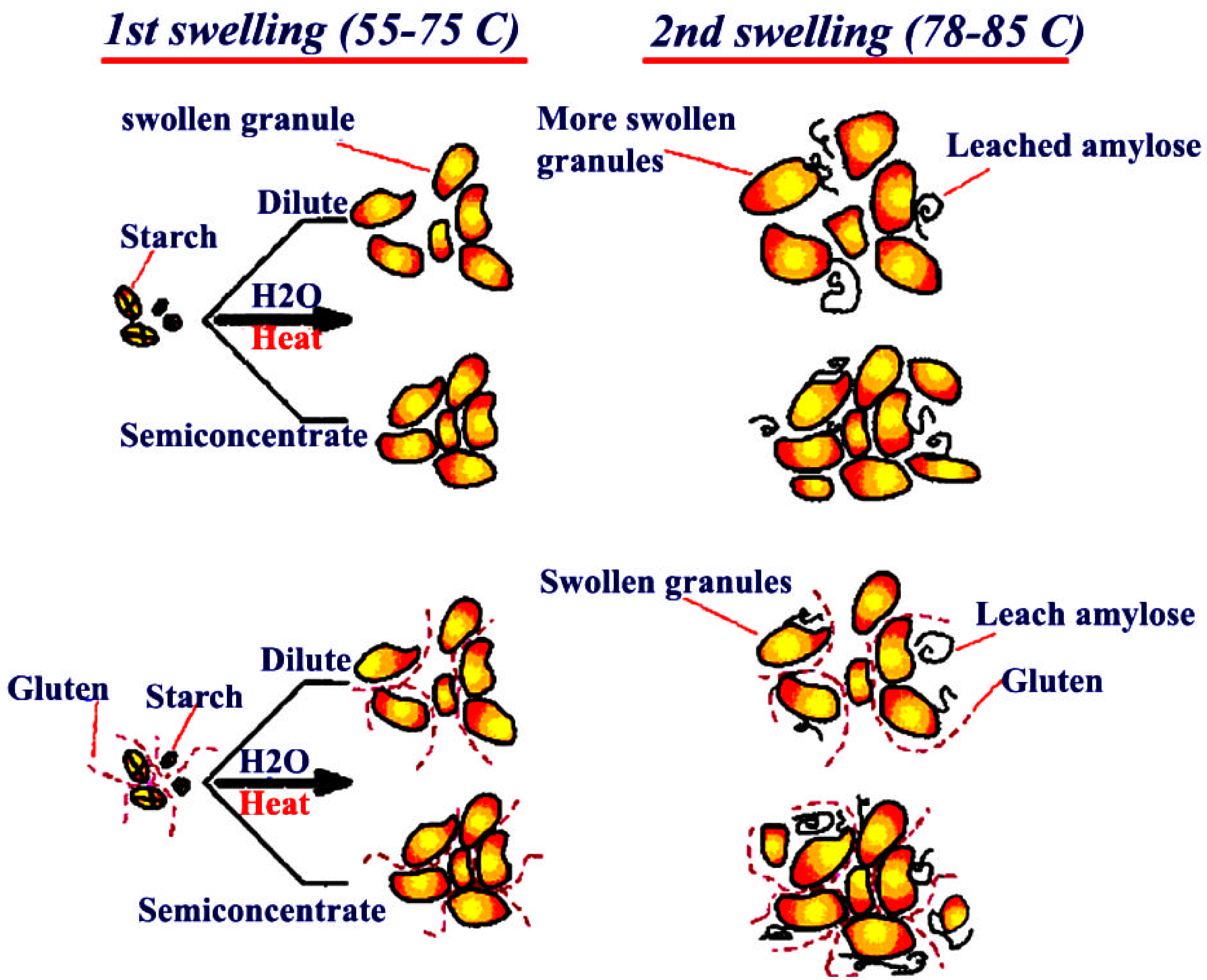

1st swelling (55-75 C)
2nd swelling (78-85 C)
swollen granule
More swollen
granules
Leached amylose
Dilute
Starch
H2O
Heat
Semiconcentrate
Swollen granules
Leach amylose
Gluten
Dilute
Gluten
Starch
H2O
Heat
Semiconcentrate

Figure 4.5: Longitudinal section images of cooked grains of 5 cultivars sampled after boiling for 15 min. (a) Mochiminori. (b) Milky Queen.(c) Koshihikari. (d) Kanto 181. (e) Hoshiyutaka.

Source: Horigane et al. (2000)

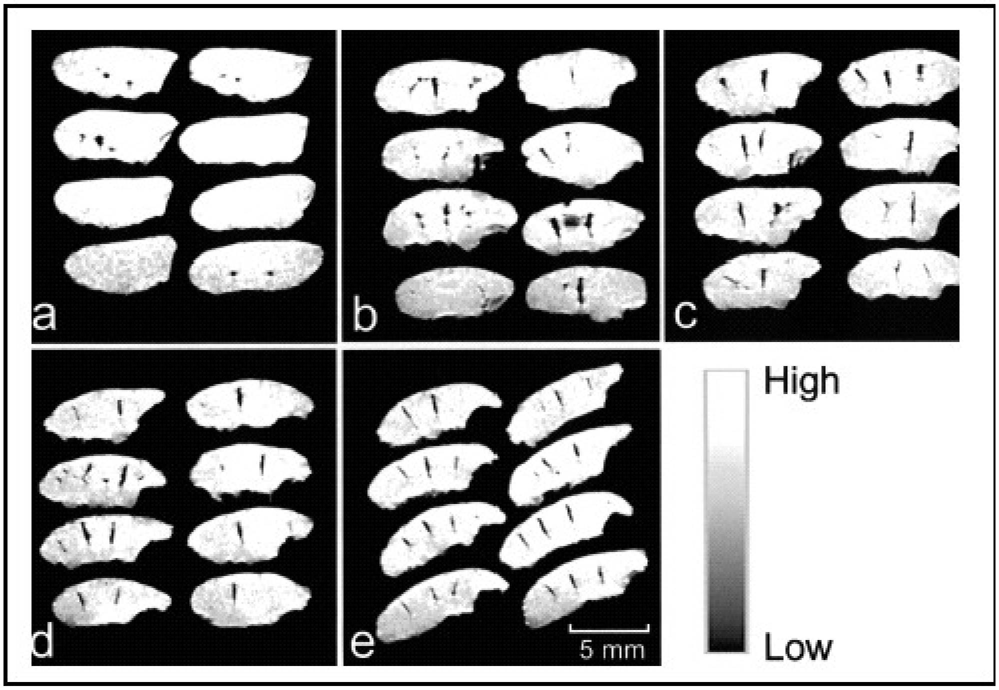

a
b
c
d
e
5 mm
High
Low

Table 4.3: The typical TPA conditions found in the recent papers

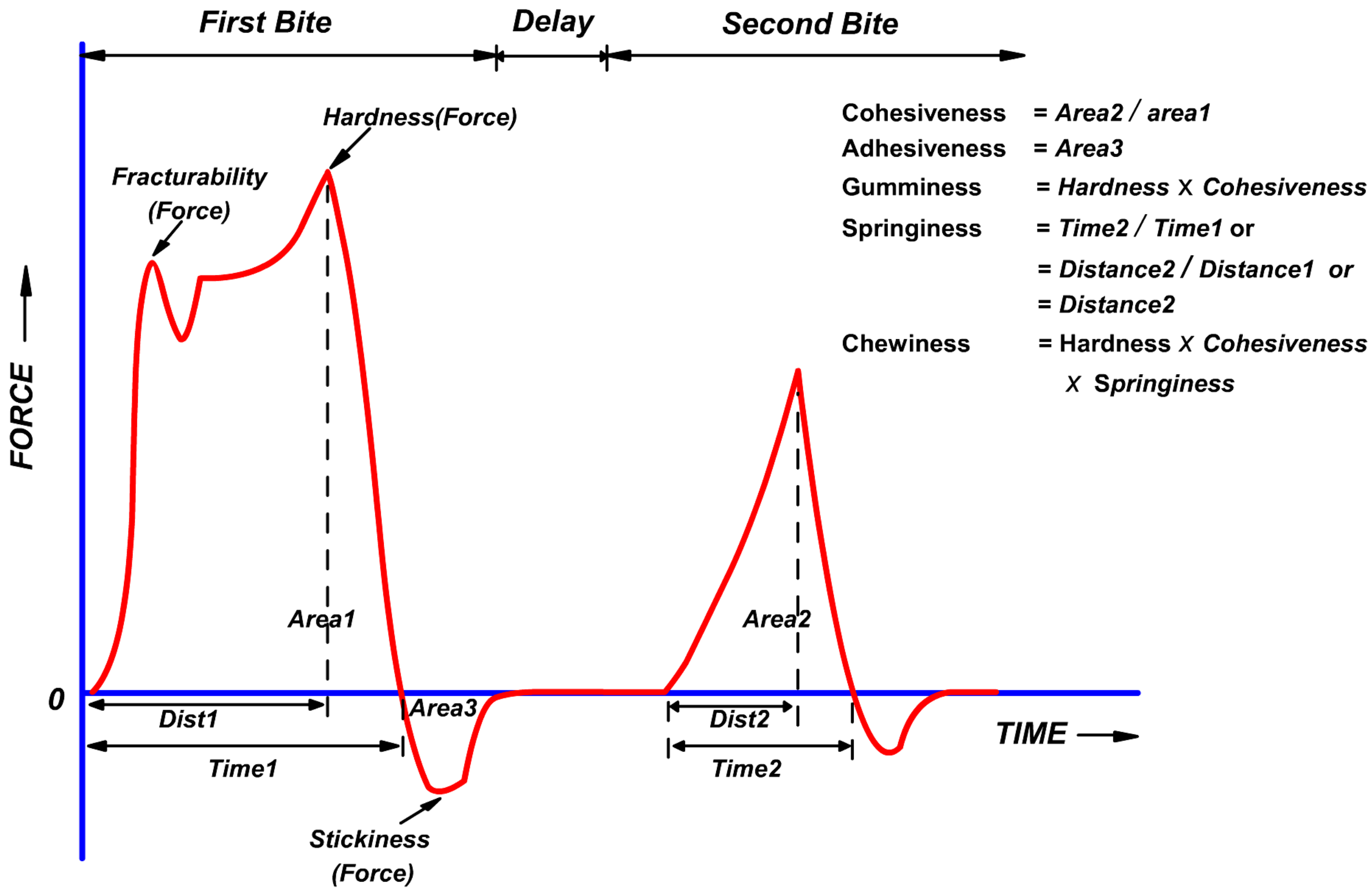
Reference	System	Sample Size (mm)	Instrument	Deformation (%)	Test Speed	Probe Size (mm)
Truong et al. (2002)	Cheddar cheeses	$15 \times 15 \times 15$ mm^3	TA-XT2	80	0.4/0.4/0.4mm/s Pause: 5 s	∅ 50
Palka (1999)	bovine (ST) muscles	∅14 mm × 15 mm	TA-XT2	50	5/2/ 2 mm/s Pause: 3 s	∅ 20
Kaur et al. (2002)	cooked potato	∅10 mm × 10 mm	Instron	75	15 mm/min.	∅ 35
Mandala et al. (2002)	xanthan–starch gel	∅16 mm × 20 mm.	Instron	75	50 mm/min.	parallel plates
Romeih et al. (2002)	fat mimetic cheese	∅34 mm × 15 mm	TA-XT2	33.33	2 mm/s	∅ 75
Lau et al. (2000)	gellan/gelatin mixed gels	∅30 mm × 20 mm	TA-XT2	70	0.5 mm/s	n/a
Lee et al. (1999)	diced tomatoes	$10 \times 10 \times 10$ mm^3	TA-XT2	75	1.0 mm/s	n/a

Table 4.3. Continued.

Reference	**System**	**Sample Size (mm)**	**Instrument**	**Deformation (%)**	**Test Speed**	**Probe Size (mm)**
Tabilo et al. (1999)	cure ham	$20 \times 20 \times 20$ mm^3	TA-XT2	20	1.0 mm/s Pause: 3 s	∅ 75
Apichartsrangkoon et al. (1998)	wheat gluten	∅30 mm $\times$ 15 mm		55	1.0 mm/s	∅ 50
Hughes et al. (1998)	Frankfurter	∅22 mm $\times$20 mm	Instron	50	50 mm/min.	n/a
Kenmegne and Hardy (1995)	Meat	$40 \times 40 \times 20$ mm^3	Instron	75	20 mm/min.	∅ 30
Gujral and Kumar (2003)	mill rice	1 grain	TA-XT2	50	10 mm/min.	∅ 40

Figure 4.6: The texture profile analysis(TPA) calculation from TA-XT2 ® curve

Redraw from: Juliano (1985); Bourne (1982); Amero and Collar (1997).


First Bite
Delay
Second Bite
Hardness(Force)
Fracturability
(Force)
FORCE
Area1
Area2
0
Dist1
Area3
Dist2
Time1
Time2
TIME
Stickiness
(Force)
Cohesiveness = Area2 / area1
Adhesiveness = Area3
Gumminess = Hardness X Cohesiveness
Springiness = Time2 / Time1 or
= Distance2 / Distance1 or
= Distance2
Chewiness = Hardness X Cohesiveness
X Springiness

CHAPTER 5

MATERIALS AND METHODS

Raw waxy rice

Carmel® waxy rice or glutinous rice (RD6 or Kheaw Ngu variety) was purchased from a local farmer's market (Atlanta,GA). The rice was imported from Thailand and sold retail in 10 lb or 25 lb bags. The rice used in this study contained less than 5% broken grains. After purchase, the rice was stored in a 4 °C cold room until used.

Rate of moisture absorption by waxy rice grains

The moisture content of waxy rice grain affects both starch gelatinization during the cooking process and the sensory properties of the cooked product. If waxy rice grains are not adequately moistened in the interior, the starch in the interior of the grain may not be fully gelatinized by heating with atmospheric steam resulting in a cooked product with a mealy texture. The grains must be soaked in water until moisture equilibrium is achieved in the grain. At equilibrium, moisture content will be uniform throughout the whole grain. The soaking time to achieve moisture equilibrium will be a function of temperature. The rate of moisture absorption by waxy rice grains was measured and fitted to a diffusion model.

Moisture content analysis

The moisture content was analyzed using the American Association of Cereal Chemists (AACC, 2000) procedure. Surface moisture was drained from the soaked rice 2 min using a wire mesh screen and the surface moisture was blotted with absorbent paper (Kimwipes®). The moisture content (dry weight basis) was calculated from the weight loss after vacuum drying at 103 ^{o}C and 20 in. Hg vacuum for 24 hr.

$$\text{Moisture content (\%MC)} = (W1-W2)/W2 \times 100$$

Where:

MC= %moisture content dry basis (db)

W1= weight of sample before drying

W2= weight of sample after oven drying

Soaking of rice at different temperatures

The milled rice (100 g/ batch) was soaked in deionized water (1:2, w/w) at different constant temperatures of 1°C, 24^{o}C, 50^{o}C, 60^{o}C, 65°C, 70^{o}C, and 75^{o}C . The mixture, contained in a 400 mL beaker, was heated on a Corning® hot plate equipped with a controller and a temperature sensor positioned inside the beaker. The water was preheated to the designated temperature and the rice grains were added. At the time of rice addition, water temperature dropped and after a short period, came back to the designated set-point. Time was started when water temperature reached the set-point. At designated time intervals, approximately 5 g samples were removed for moisture analysis.

Mathematical simulation of moisture diffusion rate during soaking of waxy rice

The solution of Fick's second law for diffusion in a finite cylinder was used to simulate moisture diffusion through rice grains soaked in water at different temperatures. The program was coded on MATLAB® 5.3 Student version (Math Work, Inc, MA), in three main programming parts:

1. Function routine, which returns the moisture ratio from equation 6. The parameters needed for this function are;
    (a) Radius of rice grain; $0.5*1.65\times10^{-3}$ m
    (b) Length of rice grain; 6.69×10^{-3} m
    (c) Diffusivity coefficient; $10^{-10} – 10^{-8}$ m^2/min. (individual value selected and incremented in subsequent iterations)
    (d) $J_{0,n}$ of the Bessel's function for n=1 to 20. The root of the function can be calculated from MATLAB function; BESSELJ(0,x), where x's are the values that return the function's value of zero.
2. Function routine, which calculates the least square of the error between data calculated from the simulation (from part 1, above) and the experimental data. The parameters needed for this function are;
    (a) Moisture ratio from the experiment at different time
    (b) Moisture ratio from the simulation of the selected diffusivity coefficient calculated in Part 1 above.

3. Function routine, which performs an iteration of the diffusivity coefficients to obtain the minimum least square in (part 2, above). It returns the best-fit diffusivity coefficient for the model.

The other parts of the code are subroutines that include plotting and labeling of data. The full code is given in the Appendix B.

Testing of different methods for cooking waxy rice

Waxy rice may be cooked by heating in an excess of water at the boiling point, by microwave, by heating with live steam at atmospheric pressure, and by heating with atmospheric steam over a conventional Thai kitchen steamer. The cooking method is expected to affect the properties of the cooked rice. Cooking time, texture and appearance of the cooked rice were observed and used as the basis for the development of an instant waxy rice production process.

Cooking of raw waxy rice by direct boiling

Raw waxy rice was cooked in boiling water. Twenty-five g of waxy rice was added to 300 mL vigorously boiling deionized water in a 500 mL beaker placed over an electric hotplate. At designated time intervals, 3 grains were removed and tested for adequate cooking. To determine if the grains were adequately cooked, a method described by Kar et al. (1999) was used. Rice kernels were pressed between two glass slides. Complete translucence and absence of an opaque center was a criterion for adequate cooking.

Cooking of soaked waxy rice by a microwave oven

Fifty grams of waxy rice grains were soaked overnight in deionized water at room temperature and drained over a wire mesh screen for 1 min. The soaked grains were placed in a 400 mL beaker and introduced into a microwave (GE®, General Electric Company, model: JE114013L, 1.5 W) oven set to high power. The cooked grains were examined using the same method for cooking by direct boiling in water as previously described.

Cooking of soaked waxy rice by steaming in a conventional steamer

Rice was soaked overnight in an excess of deionized water at room temperature. The soaked rice was then steamed at atmospheric pressure using a conventional cooking container and steamer shown in Figure 5.1-A. The rice was contained in a cone-shaped woven bamboo holder that fitted the top of the steamer, a vessel used to generate the steam. Three hundred grams of soaked rice was placed in the holder and excess water was allowed to drain for 1 minute before the holder was positioned on top of the steamer (pot). The bamboo holder was then covered by a lid (not shown). Steam percolated through the bed of rice. The steamer was a tall pot (8.5″ dia. ×9.0″) containing water 3″ deep at the bottom. Steam was generated when the pot was placed over a stove heating element. The steamer was heated on an electric kitchen stove (GE Profile® model: J BP90W V2WW, General Electric Co., USA). The timer for cooking time was started immediately after the element switch was turned to “HI”. Temperature and moisture content of the rice during cooking were determined as a function of time. The temperature was recorded (Type-T thermocouple, Fluke-Hydra® data logger Model:

2635A, Fluke Corp., WA, USA) at 3 positions in the bed of rice; 1cm from the top, at the middle, and 1cm above the lowest point of the bamboo container. Thermocouples were placed between the rice grains (not inserted inside the grain). Rice samples taken from the top, middle and bottom of the holder, were used for moisture analysis. Samples of grain kernels were removed at designated time intervals and analyzed for doneness as previously described.

Cooking of waxy rice by steaming in a laboratory steamer

The rice was soaked overnight before steaming. Three hundred grams of soaked rice was drained in a perforated container (USA Standard sieve, Number 12) for 1 min then steamed in a steam cabinet (24″ × 20″ × 20″) under atmospheric pressure (Figure 5.1-B-steam chamber). Before steaming, the cabinet was preheated by flushing with steam for 15 min. Steam was feed to the cabinet through two distributor pipes (½ ″ pipe with ¼ in perforations) positioned on two sides of the cabinet. The cooking characteristics were evaluated similar to that of a conventional steamer.

Effect of methods for drying cooked waxy rice on dried product properties

The primary hypothesis in this research is that dry instant waxy rice that would rehydrate and regelatinize within a short time of heating must have adequate starch gelatinization prior to drying and the drying method must result in intact grains to minimize leaching of starch during rehydration.

Cooked rice normally aggregates, therefore it will not be possible to separate the individual grains prior to drying. When large clumps of cooked rice are dried, the grains in the middle of the clump will not be dry even when the grains on the outside layers are dry. If the rice is cooked so that small clumps can be separated, it will be possible to thoroughly dry the clump and separate the individual dried grains.

The methods for drying discussed below were tested using waxy rice that was soaked overnight in deionized water at room temperature. The soaked rice was then cooked with live steam in a steam cabinet, as described above, for 20 min prior to drying.

Oven drying of cooked waxy rice

Cooked rice was dried in natural convection ovens under different conditions. Cooked rice samples were dried at 55°C in an oven at atmospheric pressure(Vacuum oven , VWR S/®,Sheldon MFG, Inc., OR, Model:1430MS), at 55°C and 60%RH (controlled-atmosphere oven Hotpack®, PA, Model: 435314), at 50°C and 60% RH, at 50°C and 85%RH, at 40°C with 26 inches vacuum (Vacuum oven ,VWR S/®,Sheldon MFG, Inc., OR, Model:1430MS), and at ambient conditions (approximately 25°C and 50% RH). The appearance and uniformity of dryness of the clumps were examined.

Drying of cooked waxy rice at low temperature

Cooked waxy rice was slowly dried in a walk-in cold room at 4 ± 2°C and an average of 80% RH. The small rice clumps (ca. 1.5 cm dia and 1.5 cm thick) were placed on a perforated tray with enough clearance provided on the shelf for cool air circulation around the tray. Room air was continuously recirculated by the blowers in the evaporator coil of the refrigeration system, but the tray was not placed in the direct path of the blowing air from the fans. The appearance and dryness was observed.

Development of a drying method for making the desirable instant waxy rice

The desirable instant waxy rice should have dense kernels and unblemished individual kernels. When cooking rice, the grains stick together forming clumps. These clumps were partially dried to permit separation into individual kernels followed by a final drying step. This initial partial drying step was very important because the degree of dryness and uniformity of clump moisture determines whether the clump will separate without tearing the individual grains and whether the separated grains will re-aggregate. The basic properties of the dried instant waxy rice were evaluated.

Cooking of rice in the perforated–aluminum tray

The rice was soaked overnight and then heated with live steam in the laboratory steamer (cabinet) as described earlier. However, the special designed perforated-aluminum tray (Figure 5.1-B-rice container) was used to hold the rice during cooking. The tray dimension was 12″×12″×1.5 cm and the holes were 1.5 cm in diameter. This rice holder produced cooked clumps 1.5 cm diameter and about 1.5 cm thick. A No.20 mesh stainless steel wire mesh was placed underneath the plate to support the rice grains and allow the steam to pass through during steaming. Soaked rice was filled into the holes and then the plate and wire mesh assembly was tilted about 15° from one of the edges and left in this position for 2 min to allow water to drain. The whole assembly was then transferred to the pre-heated steam cabinet. The steam cabinet was preheated by flushing with steam for 15 min immediately prior to introduction of the sample to be cooked The steam was supplied from the campus (The University of Georgia) steam plant. A steam pressure regulator in the steam feed line was set to deliver steam at 250°F. Steam was feed to the chamber through two distributor pipes (½″ pipe with ¼ in perforations) positioned on two sides of the cabinet. A vent at the top of the cabinet prevented pressure from developing so that steaming was done with saturated steam at atmospheric pressure. Enough steam was admitted to produce a saturated steam environment without having too much condensate. The rice was exposed to steam until desirable gelatinization was achieved (20 min). Prolonged heating is undesirable because the grains at the bottom of the clumps become very pasty and partly disintegrated.

Drying of cooked rice and production of the instant waxy rice product

The plate/mesh assembly was removed from the steam cabinet, cooled at room temperature for 2 min and then transferred to the walk-in cold room (4 ± 2°C, and 80% RH, avg.). The rice was allowed to slowly dry to produce dense grains. The partially dry rice clumps were punched out of the holes of the cooking tray and then transferred to another tray where they were spread out to permit more drying in the cold room. The individual grains were then separated from the clumps by crushing the clumps in a gyratory crusher (Marcy Gy-Roll Crusher®, Svedala Industry, Inc., PA, USA). The clearance between the gyrating element and the anvil was set at approximately 2-3 mm. The individual grains and remaining clumps were separated by sieving through No.4,6 and 12 mesh screens. The separated individual grains were further dried at room temperature until the desirable water activity (0.6-0.7) was achieved.

Microstructure of instant waxy rice

Individual rice grains were examined by light microscopy using an Olympus® SZ-11-CTTV (Japan) microscope equipped with COHU-222-1040 video camera. The images were captured with Image-Pro®-Plus software (Media Cybernetics® , MA, USA). Individual grains were also examined using the scanning electron microscope (SEM) at the Center for Ultrastructural Research, the University of Georgia. The SEM consisted of a LEO® 982 (Leo Electron Microscopy Ltd, Cambridge, England) and an Oxford® 6901 detector (Oxford Microanalysis Group, England). The Cryo-technique was used to prepare the samples for the SEM.. The sample rice grain was fixed on the stage and frozen in a liquid nitrogen slurry. The frozen sample was sputter-coated with gold (Oxford®-Alto 2500) before presentation to the SEM. The measuring tool feature of Adobe® Photoshop® software was used to measure the starch granule size in the grain. The distribution of granule size in an aqueous suspension of waxy rice starch was also measured by laser scanning in Malvern Mastersizer X® (Malven Instrument Inc,MA,USA.,508-480-0200). The size distribution (volume fraction vs. particle size) was recorded.

Bulk density and porosity

The porosity was evaluated according to the method describe by Peleg and Bagley (1983). Bulk density was evaluated by measuring weight and volume after filled in 250 mL graduated cylinder. The cylinder was tapped for 2 min. The density was the ratio of the grain weight to the grain volume. The solid density was measured using a helium pycnometer (QuantaChrome® ultra-pycnometer 1000, Quanta Chrome Corp. 1900

Corporate Drive, Boynton Beach, FL). The solid density was calculated from the sample weight and solid volume. From the bulk density and solids density, the porosity of the grains can be calculated as follows:

Total porosity=1-(Bulk density)/(Solid density)

Rehydration of instant waxy rice

Rehydration property of the instant waxy rice product was evaluated. One part (50 g) instant rice was soaked in two parts (100 g) deionized water at room temperature. The grain-water mixture was stirred once immediately after grains were added to the water. After a designated time, the grains were drained and blotted with absorbent paper (Kimwipes®) for 1 min. Samples soaked for different times were analyzed for moisture content by vacuum oven drying at 105ºC and 20 in Hg overnight. The extent of rehydration was defined by the moisture content of the grain. First order mathematical modeling was used to measure the rate constant of rehydration.

$$-dX/dt = K_r(X-X_e)$$

Where $\boldsymbol{X}$ is the grain moisture content (g/g db), $\boldsymbol{X_e}$ is the moisture content of the grain when it reaches equilibrium after soaking, K_r is the rehydration rate constant (min^{-1}), and $\boldsymbol{t}$ is the rehydration time (min). The integrated form of the above equation was used to estimate the rehydration rate constant (K_r):

$$\ln\left(\frac{X_e - X_{(t)}}{X_e - X_{ini}}\right) = -K_r t$$

Where: X_{ini} is the initial moisture content of the grain (g/g dry basis). The rate constant, K_r, was calculated by linear regression of values of the logarithmic expression on the left hand of the preceding equation against time of soaking.

Evaluation of starch gelatinization by differential scanning calorimetry (DSC)

Gelatinization of starch in the rice kernel is crucial to the attainment of desirable properties in the instant waxy rice product. The gelatinization process is a thermal transition that requires the application of heat (endothermic) therefore, it can be observed with DSC. The onset temperature is where some granules start to gelatinize. Gelatinization of a population of granules occurs over a temperature range. The peak temperature is where most of the granules make the transition. The energy of the transition (dH) reflects the degree of cooking which can be expressed as a per cent gelatinization when calculated relative to the dH of the uncooked starch. DSC scans were conducted on isolated waxy rice starch and on whole grains.

The DSC was a Perkin-Elmer® DSC-7 (Perkin-Elmer Corporation, CN, USA) calorimeter. An ice-water mixture was used as the cooling medium and Indium was the calibration standard. The sample tray capacity was 50 uL (Perkin0Elmer®). For the isolated starch, a 1:9 starch-water mixture of starch to water was analyzed. The sample weight was 20-30 mg. The heating rate was 10°C per min.

DSC scans were conducted on whole waxy rice grains soaked at room temperature in deionized water for 0 (raw), 1, 2.5, 3.5, and 12 hrs. A single rice kernel sample was blotted with absorbent paper, transferred to a pressure resistant DSC pan and sealed. The weight of the kernel was measured by subtracting the tare weight of the pan from the weight of the filled pan. The transition energy (dH, J/g) was read from the DSC curve and corrected for the weight of the kernel. The onset and peak temperatures were calculated by the DSC data analysis software provided by Perkin-Elmer.

DSC scans were also conducted on waxy rice soaked overnight in deionized water at room temperature and cooked in live atmospheric steam in the laboratory steamer. The rice was steamed (cooked) for 0 (raw),5,15,20, 25,30,35,40 min, and 3 hr. At the designated time, the sample was pulled out of the steamer and allowed to cool for 2 min. at room temperature. The sample was then transferred to a plastic cup and covered with parafilm. Samples were held at room temperature until the last sample (cooked for 40 min) were prepared and DSC scans were conducted on all samples at the same time within one hr of preparation. Only the 3 hr cooked sample was taken out of the steamer after the DSC scans of the other samples were completed. After cooling, the sample was subjected to DSC analysis within 30 min of cooking. Sample weight and transition energy were calculated as with the soaked samples above.

Rice starch isolation

Starch was isolated according to the method described by Singh and Dodhi (2003). The milled rice was steeped 24 hr in 0.2 % NaOH (1:5 wt/wt ratio). The liquid was drained and the rice was ground in a mortar and pestle. The slurry was diluted with 0.2 % NaOH back to the same volume before draining. After stirring 10 min, the starch was allowed to settle overnight. The supernatant was drained off. The sediment was diluted with 0.2% NaOH solution, allowed to settle and the supernatant was decanted. The process was repeated until the supernatant was negative for protein by the Biuret test. The starch was then suspended in distilled water, stirred, allowed to settle and the supernatant was decanted. The process was repeated until the suspension had a neutral pH as indicated by phenolphthalein solution. The final sediment (starch) was dried in vacuum oven at 20 in Hg, vacuum at 40 °C. The isolated starch was used to measure granule size distribution by the Malvern, and was used as the reference in the DSC analysis of cooked whole rice grains.

Analysis of Amylose-Amylopectin ratio in waxy rice starch

The amylose-amylopectin ratio in waxy rice starch was determined according to the method described by Juliano et. al (1981). A solution of 0.2% iodine in 2.0 % potassium iodide was used to form the iodine-starch binding complex. The absorbance of the complex was read at 620 nm with a spectrophotometer (Spectronic® Genesis™ 2, Spectronic Instrument Inc., NY,USA).

A 100.0 mg starch sample was weighed in a 100 mL volumetric flask then 9mL of 1M NaOH was added. The mixture was heated in boiling water for 10 min. After cooling to about 50 ºC, the volume was adjusted to 100 mL using room temperature deionized water. To disperse the starch, the solution was vigorously mixed 10 min using a magnetic stirrer. The solution was diluted 10 times before the iodine-binding reagent was added. A 5 mL aliquot of the solution was taken, and mixed with 1.0 mL of 1M acetic acid. Two mL of iodine solution was added and the mixture was allowed to stand for 20 min before reading the absorbance. Solutions containing mixtures of amylose (from potato, Sigma®:, USA) and amylopectin (from maize, Fluka, Switzerland) in designated ratios were prepared in the same manner as the sample starch and used as standards.

Degree of gelatinization (DG) of cooked waxy rice grain

The effect of cooking time on the degree of gelatinization (DG) of starch was analyzed using a method described by Guraya and Toledo (1993). Raw waxy rice flour was prepared by milling overnight-soaked rice in a high speed stone mill (Masuko® Supermasscolloilder, Masuko Sangyo Co., Ltd., Japan). The flour suspension was then filtered through cheesecloth and the filtrate was vacuum dried at 55 ^{o}C. The gelatinized flour was prepared by boiling an 80% moisture rice flour suspension 20 min. The paste was vacuum dried (20 at 55^{o}C. Gelatinized flour was prepared by grinding the dried paste in the high speed stone mill. A standard curve for mixtures with different proportions of gelatinized and ungelatinized starch was constructed using the amylopectin-iodine complex at 540 nm (peak absorbance for the complex under the experimental conditions). Samples containing known proportions of raw and gelatinized flour were made. 0.2 grams was added to 15 mL 0.2N KOH. The suspension was stirred in a vortex for 15 min then the pH was adjusted to 5.5 using 2N phosphoric acid. The volume was adjusted to 100 mL with distilled water. A 0.1 mL aliquot was diluted to 5 mL and then 0.05 mL of 0.1 N standard iodine solution (AOAC 50.018, 1982) was added. The absorbance of the complex was read at 540 nm with a spectrophotometer (Spectronic® Genesys™2). The blank was prepared from raw rice flour and the same reagents. Samples of cooked waxy rice grains were prepared by grinding the soaked/cooked product in a mortar and pestle. The samples were analyzed for DG using the same method as the standards.

Quality evaluation of instant waxy rice

The instant waxy rice product was analyzed for quality attributes to determine if the selected process produced the desired product characteristics. Instrumental texture analysis and sensory tests were used.

Texture profile analysis (TPA) of cooked rice

Textural attributes of the rehydrated/cooked instant waxy rice product were analyzed according to the method described in the application manual of the TA-XT2 ™ (Stable Micro System Ltd.,GB) instrument. A 35 mm aluminum cylinder probe and a 25 kg load cell were used. The TPA force-deformation curve was obtained using a 2 cycle-compression test. The instrument was set-up with a pre-test speed of 2.0 mm/s, test speed of 0.5 mm/s, post-test speed of 2.0 mm/s, probe travel distance of 1.2 mm, pause time of 5.0 s, and a trigger value of 5.0 g. Three individual rice grains were placed on the aluminum plate base under the center of the probe. The probe was positioned 3.0 mm above the base. When the test is started, the force- deformation curve is not recorded until the probe touches the sample and the force equals the "trigger" value. Values of the TPA profile parameters were calculated using a macro (See Appendix A) which was coded by Amorsin (2003) in the syntax of a programming language (Stable Micro System) used in a similar macro provided with the instrument. It was necessary to write a new macro because the one that came with the instrument does not calculate all of the TPA parameters and because of it's inefficiency, a user has to spend a lot of time in calculating the TPA parameters. In addition, the instrument provided macro could not be used to determine user defined parameters. Our macro calculated the TPA parameters of hardness, stickiness, cohesiveness, adhesiveness, gumminess, springiness and chewiness (Pon and Fiszman,1996; Bourne,1978; Szczesniak,1975; Juliano,1985, Lau et al, 2000; Amero and Colla,1997). In our macro program, springiness and chewiness can be calculated 3 ways from the same set of data. There was very high correlation ($r^2 > 0.9$) between values obtained by the three methods. However, standard error and CV were lower among the values calculated using the time ratio of 2 full peaks. We report values for springiness as the ratio of areas of the two full peaks.

The TPA analysis was performed as soon as the cooked rice samples were cool, which took 1-2 min after cooking. To prevent drying of samples while awaiting the test, all samples were placed in plastic cups covered with parafilm. Cooking was done in the vicinity of the TA-XT2™ instrument using a 500 mL beaker with water placed over a hot plate to generate steam. The sample to be cooked was placed on a cheese cloth positioned over the beaker and a glass funnel was placed over the cheese cloth to channel the steam through the kernels. When testing the instant waxy rice product, the dried kernels were soaked in cold water for 5 min drained and immediately cooked by streaming for 0,5,10, 15, and 20 min. When testing the conventionally cooked waxy rice, the dry kernels were first soaked overnight (12 hr), drained, and steamed for 0, 5, 10, 15 and 20 min. Unsoaked instant rice samples steamed 0, 5, 10, 20 min. were also analyzed. Samples steamed for the same time (sets of three) were steamed simultaneously.

Sensory evaluation of instant rice product

Consumer acceptability of the instant rice product was tested by a consumer panel. The product was presented to the panel as a cooked product flavored with coconut milk powder. The ingredients used to prepare the instant waxy rice product were (1) instant rice (14.4% moisture, wet basis) 40 g, (2) coconut powder (Chao Thai Brand, KornThai Co.,Thailand) 5 g, (3) sugar 5 g, (4) salt 1 g, and (5) water 120 g. The cooked rice was prepared by heating the water to boiling, adding the instant rice product, and holding 2 min with continued heating and with continuous stirring to promote uniform heating. The rest of the ingredients were added and stirring was continued for 3 min. Before serving, the thickened product was cooled in a water bath to a temperature of 20-25 ºC (approx. room temperature). The instant rice product was presented to the panel along with a control sample made from waxy rice. The control sample ingredients were as follows: (1) steamed waxy rice (soaked overnight, and steamed 20 min., 40% moisture, wet basis) 56.5 g, (2) coconut powder 5 g, (3) sugar 5 g, (4) salt 1 g, and (5) water 103.5 g. The water was heated to boiling and coconut powder, sugar and salt were added followed by heating for 2 min with stirring. Then the cooked rice was added followed by stirring and heating an additional 3 min. The cooked rice was then cooled in a water bath to room temperature before serving. The amount of sample prepared for the control and instant rice product was approximately 90 g each.

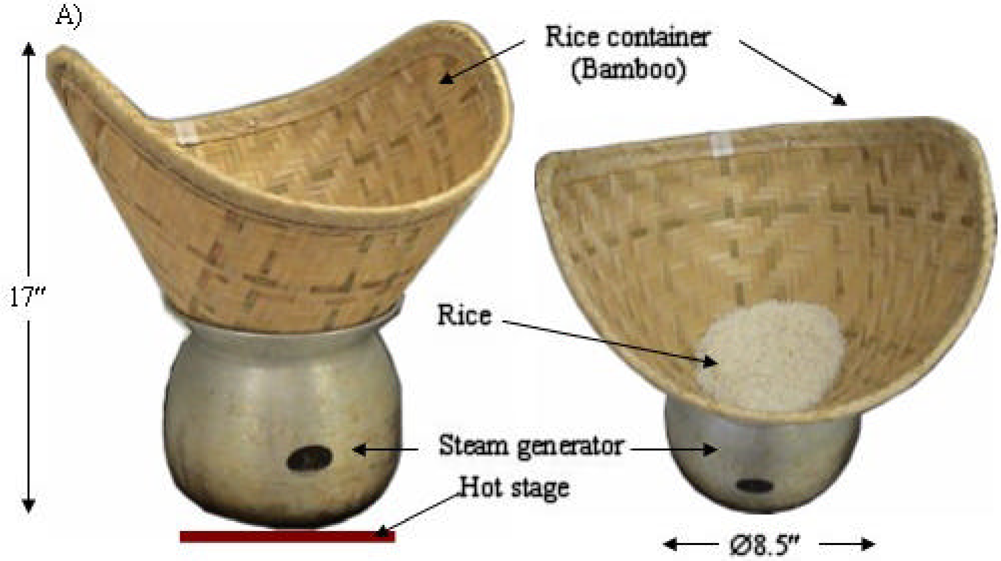
A hedonic scale was used for sensory evaluation, where a score of 1 was designated for extremely dislike and 9 for extremely like. The quality attributes evaluated included color, odor, texture, taste and overall acceptability. The evaluation was conducted within 3 hr of the time the samples were prepared. A set of 30 panelists participated. Data were analyzed using the non-parametric Wilcoxon 2-sample-comparison test on the SAS® (version 6.12) statistical software.

Figure 5.1: Rice steamer

A) A conventional waxy rice steamer in Thailand

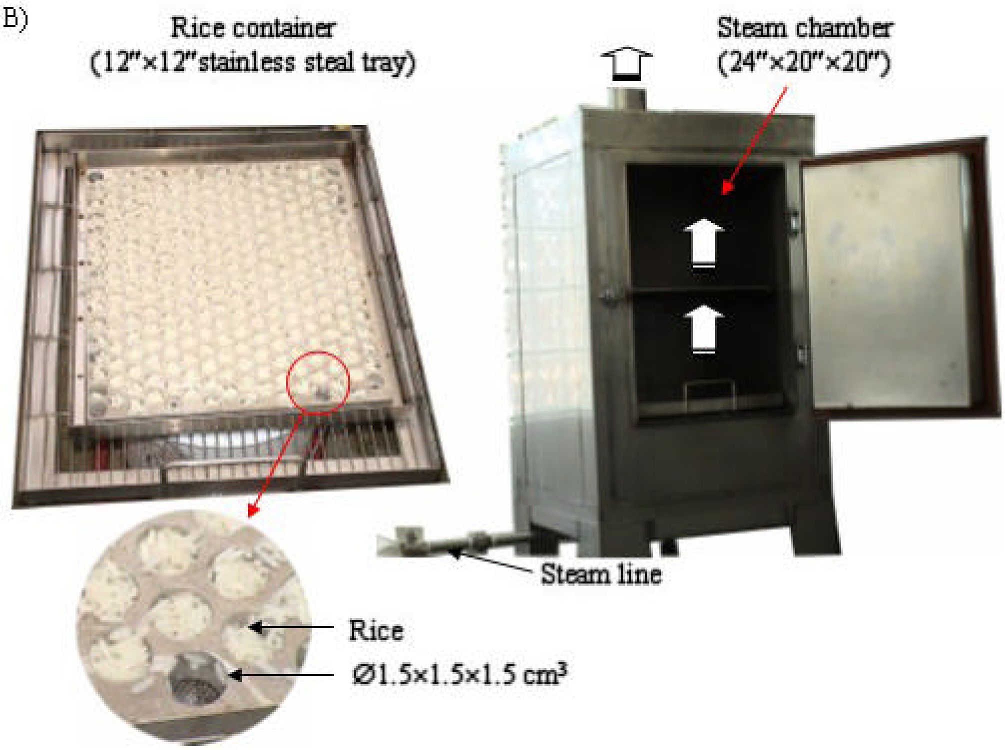
B) Experimental rice steamer

A)



Rice container
(Bamboo)
17″
Rice
Steam generator
Hot stage
Ø8.5″

B)



Rice container
(12″×12″stainless steal tray)
Steam chamber
(24″×20″×20″)
Steam line
Rice
Ø1.5×1.5×1.5 cm³

CHAPTER 6

RESULTS AND DISCUSSION

Overview

The primary objective of this research was to develop a process for producing an instant waxy rice product. The properties of the desirable instant product were defined as those which closely resemble attributes of conventionally cooked waxy rice upon reconstitution. A literature review provided information on how instant non-waxy rice products are made. What is clear is that the starch in the rice grain must be completely gelatinized before drying to minimize time for reconstitution of the instant rice product. The literature also showed major physical and chemical differences between waxy and non-waxy rice, therefore procedures used for producing instant non-waxy rice may not be applicable for the waxy rice. For example, non-waxy rice contains primarily amylose in the starch granule. Amylose easily leaches out of the granule into the liquid surrounding the kernel during starch gelatinization therefore there is no interference with moisture absorption if the dry kernel is heated directly in water. In contrast, the predominantly amylopectin component of the starch granules in waxy rice stays in the vicinity of the granule during gelatinization thus forming a moisture impervious layer which prevents moisture migration into the interior of the grain(Ong and Blanshard,1995). Gelatinized amylose also undergoes rapid retrogradation, a process which decreases the adhesive properties and water binding of the gelatinized starch. Thus, clumping of non-waxy rice can be minimized if the heating process is followed by a chilling step prior to drying. The low rate of starch retrogradation in the large amylopectin molecules and the strong tendency of cooked waxy rice kernels to stick to each other are impediments to the use of a rapid drying process for the cooked waxy rice kernels. The following discussion details proof of the step by step hypotheses presented in the introduction that led to the selection of a process for producing an instant waxy rice product that meets the criteria defined for a desirable product.

Evaluating rate of moisture absorption in soaked waxy rice

Hypothesis 1. Moisture absorption during soaking of the dry grain prior to cooking can be accelerated by increasing the soaking temperature. What will be the required soaking time at different temperatures to result in a moisture content that will permit adequate starch gelatinization when the grains are cooked in steam was investigated.

The moisture content of raw waxy rice at the time of cooking determines the properties of the cooked waxy rice. Experience with the traditional method of cooking waxy rice indicates that unlike non-waxy rice which can be cooked by heating in an excess of water, waxy rice cooked in the same manner can become very pasty or sticky but uncooked in the center of some kernels. To obtain desirable properties of cooked waxy rice, the dry rice kernels must be soaked in water at least 12 hr before heating. The moisture content of the soaked waxy rice prior to cooking in the traditional Thai method of cooking waxy rice is 56% dry basis. This is the equilibrium moisture content obtained when the rice is soaked 12 hr at room temperature. We measured moisture absorption at different temperatures, modeled moisture absorption, estimated effective moisture diffusivity in the rice grain, and determined that the diffusion model that could be used to predict the moisture content in the grain during soaking. The data can be used to establish the optimum time of soaking to reach the moisture content in the grain that would permit full starch gelatinization on heating.

Effect of temperature and time on water absorption by soaked rice.

Water absorption into rice was followed by measuring the moisture content (MC, % dry basis). Data are presented in Figure 6.1. As expected, the rate of absorption, especially in the initial stage, increased with increasing soak water temperature. It took shorter soaking time to reach a MC of 56% with increasing temperature. However, when the rice was soaked at very high temperature such as 70 ºC for 60 min, the starch gelatinized and the rice kernels absorbed water to reach MC>100% db. At a soaking temperature of 65 ºC, starch gelatinization occurred and the rice kernels stuck together and the water in contact with the grain became viscous. Thus, the soaking step in the preparation of waxy rice should not use water at a temperature higher than the starch gelatinization temperature. When soaked at room temperature (24^{o}C), moisture gain to 56 % (db) required at least 12 hr of soaking. The initial moisture content of rice and the age post harvest could also affect water absorption. The rate of absorption was very slow in the later stage of soaking as shown in Figure 6.1. Soaking at temperature higher than room temperature resulted in a faster moisture gain towards the desirable moisture content. It took 60 and 30 min, respectively, to reach MC=56% at 50 , and 60 ºC. To minimize soaking time, waxy rice may be soaked at 60^{o}C for 30-45 min.

Moisture diffusion into waxy rice by mathematical simulation

The moisture content profile of soaked rice samples at T < TG (TG =60 to 75^{o}C for waxy rice starch) was fitted very well by the mathematical model based on Fick's second law of diffusion. At T > TG however, the correlation between simulated and observed data was very poor. This may be caused by a departure from the assumptions used in the model when the starch had gelatinized. The interactions between starch granules and water as the starch gelatinized, decreased the rate of moisture absorption. The gelatinized starch near the outer periphery of the grain and non-gelatinized starch near the center became a heterogeneous structure not consistent with the assumption of uniform product physical properties. Prolonged soaking at high temperature made the grain lose structural integrity. Tiny fractures developed in the grain as the starch granules swelled and starch leaked into surrounding liquid. However, all these physical and chemical changes have not occurred during the earlier stages of soaking at T>TG; therefore the fit is good between simulated and experimental data for a short period after the start of the soaking process. The calculated effective moisture diffusivity coefficients are listed in Table 6.1. The target equilibrium moisture content of 56 % was used to calculate the diffusivity of rice soaked at temperature 50^{o}C and lower. At temperature 60^{o}C and higher, the equilibrium moisture was the moisture at the longest time used in the simulation. Interpolation of required soaking time at temperatures other than those used in these tests can be done by expressing the moisture diffusivity as an Arrhenius equation, as follows:

$$D_T = 5.78667 \times 10^{-6} \cdot e^{(\frac{-2187.08596}{T})}$$

(r^2= 0.91)

Where:

D_T = Effective diffusivity coefficient (m^2/min) at temperature T (Kelvin or °C +273.15)

The parameters for this equation was calculated for the temperature range of 1 to 60^{o}C , assuming that no starch gelatinization occurred. The above equation for the temperature dependence of the effective diffusivity does not apply to soaked grain at T>60 ºC because the equilibrium moisture content is different and the grain became heterogeneous at the high temperature range. At T>TG, however, the calculated moisture diffusivity could still be used to predict the moisture content of the soaked grain for very short soaking times.

Our calculated values of the effective moisture diffusivity in the dry rice grain soaked in water ranged from 6.37 to 6.9 x 10^{-9} cm^2/s at 40 to 60 ºC. These values compare with 4.06 to 6.65 x 10^{-9} cm^2/s at 39 to 55 ºC reported by Steffe and Singh (1980) for short grain non-waxy rice. The authors were drying the grains therefore the values are for desorption (drying) as opposed to our values which were for absorption (soaking). Our values and those of Steffe and Singh (1980), however, are in the same order of magnitude and are similar, particularly at the higher temperatures.

Cooking of waxy rice by different methods

Hypothesis 2. There is a suitable cooking process to gelatinize starch in the waxy rice grain such that all grains in a clump will be cooked uniformly. Different methods were tried to prove this hypothesis.

Cooking of raw waxy rice by direct boiling

Dry waxy rice boiled in an excess of water (1:2 rice/water ratio), first exhibited an increase in viscosity of the water and an individual grain was covered by a slimy film. With prolonged heating, the whole mass became a thick paste before the center of the grain was completely gelatinized as evidenced by the presence of a chalky white spot when tested by the glass slide press technique. The outer layer of the grain appeared to have disintegrated while the starch at the core of the grain was still uncooked. The gelatinized outer layer may behave like a barrier, which reduced rate of diffusion of free water to the center of the grain. Another reason might be that the very high water binding properties of the gelatinized starch bound most of the water entering the grain thus reducing the driving force for diffusion. The thoroughness of starch gelatinization evaluated by the glass slide press technique (no chalky spot) was achieved at 12 min boiling. The cooked waxy rice kernels became very sticky and the cooking water became a paste. This slimy mass of cooked grain was not suitable for drying because the dried clump became very hard making it difficult to separate individual grains.

Soaked waxy rice can be boiled in water for 2 min without the kernels losing integrity. However, we observed fissures (cracks) on the grains, which weakened the kernels and a large percentage broke when the clumps were partially dried and the kernels separated from the clump. The gains became very soft after 5 min boiling and the liquid became viscous indicating that a significant amount of starch has leached from the kernels into the water. The soaked waxy rice cooked by boiling in an excess of water, appeared opaque (white) as opposed to the translucent appearance of the steam cooked product. The opacity could be attributed to either the presence of some ungelatinized starch granules dispersed within the grain or minute void spaces, or both.

Cooking of soaked waxy rice in a microwave oven

Cooking of dry rice in a microwave oven produced browned and burned grains. Microwave heating of soaked rice allowed starch to gelatinize within 1 min (50 g sample) However water evaporated from the kernel very quickly producing numerous fissures along the grain. The cooked rice was hard and dry, probably as a result of rapid loss of moisture that prevented complete starch gelatinization. Prolonged cooking of soaked rice in the microwave oven also resulted in browned and burned kernels. Thus microwave cooking was ruled out as a means of cooking the waxy rice prior to dehydration.

Cooking of soaked waxy rice by steaming in a conventional steamer

During steaming of soaked waxy rice in the conventional Thai steamer, the temperature was different at different positions in the bamboo container at the beginning of heating. However, the temperature became uniform in the later heating stages reaching the 98 to 100°C temperature of a saturated-steam environment. The actual internal temperature inside the grain might be lower than that measured between the grains. It was found that adequate starch gelatinization evaluated by the glass slide press technique was achieved only 5 min after development of the saturated steam environment. However, at this point the grains were still hard and difficult to squeeze between two glass slides. By comparison, the same degree of starch gelatinization for dry waxy rice boiled in water was achieved in 12 min. Thus, moisture penetration to the core of a kernel was slow when starting with dry kernels, therefore cooking time was prolonged even when excess water was available outside the grain.

During steaming in a conventional Thai steamer, only a small amount of moisture was transferred from steam to the rice (Figure 6.6-B). Therefore, soaking the rice to an adequate moisture content before steaming is an important part of the process for producing instant waxy rice. The moisture content of steamed waxy rice was 64.8±1.6 %. This was only 10% more than the moisture content at the start of steaming.

In addition to the subjective slide press technique for testing adequate starch gelatinization, the technique using absorbance of the starch-iodine complex was also used. The data are shown in Figure 6.7. DG vs. time was exhibited as two line segments, a line with steeper slope in the early stages flowed by an almost flat line with prolonged heating. The intersection of the two lines was considered the time for maximum gelatinization. This time was 16 min of steaming in the traditional Thai steamer. Actually, there are still traces of raw starch present in some of the grains at this time when tested using the glass slide press technique. The 20 to 30 min used for cooking in the traditional Thai steamer is longer than the calculated time for 100% DG. Additional time after 100% DG might be needed to further soften the grain to produce a desirable texture. Grain structure breakdown with prolonged heating occurs slowly in steam compared to boiling water, therefore it is possible to extend the exposure time to steam with no undesirable consequences on product quality. At 30 min, steaming, the kernels remained intact except at the bottom part of the bamboo container where the kernels were very soft and slimy. This may be attributed to steam condensation and the presence of an excess of water around the grains at this point in the steamer.

Soaked rice kernels heated in steam did not exhibit fissures in the grain. It appears that during the process of soaking the kernels swelled as water was absorbed and the pressure of expanding starch granules and protein produced tiny fractures in the grain. Thus, the soaked kernels appeared opaque white as opposed to the translucent appearance of the unsoaked kernel. Steaming appeared to seal these fractures while boiling tended to magnify them, thus the steamed kernels appeared translucent while the boiled ones retained their opacity.

Cooking of waxy rice with live steam in a laboratory steamer

Soaked waxy rice exposed to live steam in a laboratory steam cabinet for 20 min had similar appearance, stickiness, and softness as those produced in the traditional Thai steamer. The soaked kernels were distributed in a thin layer on a No. 12 sieve. The temperature distribution was uniform throughout the rice kernels. The temperature measured at the space between the rice kernels reached saturated steam temperature at atmospheric pressure (100 ºC) within 2 min. However, a few kernels at the bottom of the screen have the slimy appearance of overcooked rice while those at the top layers retained the translucent appearance of full gelatinized intact kernels. Soaked waxy rice may be cooked in live steam when processing instant waxy rice because of convenience, process consistency, and cooked product attributes are similar to those obtained in the traditional Thai steamer.

Effect of drying methods on cooked waxy rice

Hypothesis 3. Cooking the waxy rice grains will inevitably result in the grains forming clumps of cooked grains. A drying method can be developed such that all grains in a clump will dry adequately and the dried clump can be separated into individual grains. Since the process objective is for the product to closely resemble the traditionally cooked waxy rice, it is important that the drying process will result in minimal breaking of the grains and the dried product will have a translucent appearance to make it attractive. Product microstructure will be used to evaluate process result.

Drying of cooked rice in natural convection ovens

Drying of coked waxy rice in an oven at 55°C took approximately 8 to 10 hr to achieve a water activity of 0.5 and a MC of 13.6% db. However, numerous fissures were observed in individual grains on the surface of the clump, and the clump was hard. Furthermore, the kernels in the middle of the clump were still moist while those at the surface were already hard and dry. It was difficult to separate the clump into individual kernels. We attempted to dry at a slower rate by raising the relative humidity (%RH) of the drying chamber. Drying the cooked rice at 55°C and 60%RH reduced the fissures on the dried kernels. However it took a long time to dry. The problem of undried kernels in the center of the clump still persisted. Drying at 50°C and 85%RH induced negligible fissures on the kernels, but drying time was more than 72 hr, the center of the clump was still moist while the kernels at the surface were hard, and it was difficult to separate individual kernels from a clump. Drying of the cooked rice at room temperature produced similar results as the oven drying experiments. These experiences indicated that dried fissure-free kernels could be produced using a slow drying process. Faster drying rate may produce a hardened layer at the surface of individual kernels. This hardened layer may have formed as surface cells collapsed because of very large moisture gradient near the surface. This case hardening prevented moisture from leaving the kernel. The water vapor inside the kernel may exert pressure and when this pressure reaches a critical value, the grain will break producing the fissures. This could happen among individual kernels within a clump. On the other hand, the layer of dried kernels on the surface of the clump could also caseharden and prevent drying of kernels in the middle of the clump. At a lower drying rate, however, liquid water and vapor, could diffuse slowly towards the surface minimizing moisture gradients within the kernel thereby avoiding the development of fissures in the kernel. Uniform drying of a clump, even at a slow rate, was difficult to achieve at temperatures between 24 and 50 ºC. The drying of smaller and more uniform shaped clumps could be a solution to the non-uniformity of drying.

Drying of cooked rice in the cold room

Cooked rice dried in a cold room, 1-4°C, consisted of rubbery and dense kernels. The kernels became harder and drier with longer drying time. The grains could not be dried to a shelf-stable water activity in the cold room. However, we found that the kernels in a clump dried uniformly. Adhesion between the kernels in a clump was not so strong and individual kernels can be separated from the clump. It appears that at the surface of the grain, the dilute low molecular weight amylopectin gel may have been retrograded at the low temperature. This gel, which was the adhesive between the kernels, might have been weakened by the retrogradation. Even though waxy rice starch is less susceptible to retrogradation compared to non-waxy rice starch (Juliano, 1985), retrogradation rate is highest at refrigerator temperature (4-7°C; Kim et al., 1997) and a small amount of the waxy rice starch may have retrograded. The dilute soluble starch molecules that leached out of the kernels (by condensate) during steaming might re-associate precipitating a small amount of insoluble starch (Whistler and Paschall, 1965). This associating molecules release water decreasing hydrogen bonds and decrease adhesion between the kernels. Drying in the cool room could be used as a first drying step to produce dense non-fissured kernels and make possible the separation of individual kernels from the clump of cooked rice.

The optimum process for instant waxy rice product

Data from the previous studies were the basis for design of the process to produce instant waxy rice. The rice was soaked to an optimum moisture content steaming (approximately 56% db). Rice could be soaked overnight at room temperature, or using an accelerated process at 60°C for 45 min. The soaked rice then was gelatinized by heating in live atmospheric steam for 20 min, and then drying the cooked clumped kernels slowly in a cold room.

Cooking of rice in the perforated aluminum plate

A specially designed tray was used to hold the rice kernels during cooking to produce uniform size clumps. The smaller and uniform size clumps dried uniformly in the cold room. The larger surface area of the smaller clumps increased the drying rate and facilitated the separation of individual kernels from the clump.

A 300 g batch of soaked rice was cooked in the special tray inside a steam cabinet (figure 5.1(B). A uniform temperature distribution of 99-100°C in the rice inside the holes on the plate was reached very quickly (2 min after the steam was introduced to the chamber). The rice was steamed for 20 min, which produced translucent grain kernels without cracks or fissures. The rice remained in the tray while drying 48 to 72 hr in a cold room at 1 to4°C.

Drying of cooked rice and production of instant waxy rice.

After 49 hr in the cold room, the rice clumps were punched out of the holes in the tray transferred to another perforated tray and dried an additional 24 hr in the cold room. The clumps must have a moisture content of 30±2 % (db) in order to separate individual kernels from the clump. At this moisture content, the force needed to separate the individual kernels by mechanical means was 50 to 80 Newtons (by: TA-XT2™). The separated grain kernels may be dried slowly at room temperature or in a fluidized bed or at 40°C in a vacuum oven to a final water activity $a_w =$ 0.6-0.7. This corresponds to a moisture content of 14-16% db. The yield of instant waxy rice produced with the above process was 85±5%, db. The major loss occurred during the separation of individual kernels from the clump. Some of the kernels broke and some clumps containing 3+

kernels could not be separated. If the moisture content of the rice clumps was too high during the separation step the kernels pressing against each other will be compacted and individual kernels can no longer be separated. The desirable instant waxy rice product will have separate dense kernels with only a few double or triple-kernel clumps. The individual kernels have a more appealing look and will rehydrate readily.

Defects associated with rapid drying of the cooked rice include breaks or fissures in the kernel or the kernel may be hollow inside. The kernel with internal hollow cavity will have a tightly packed layer near the surface which could retard moisture absorption during reconstitution. Although moisture may easily enter these hollow cavities the tightly packed layers surrounding these cavities may not absorb water readily resulting in hard spots in the reconstituted kernel. These hollow cavities were observed under the cryo-scanning electron microscope (cryo-SEM). Figure 6.22 shows the flow chart for instant waxy rice production.

Microstructure of instant waxy rice

The macrostructure of rice was studied by measuring dimensions (mean ± std. err. millimeters) of rice samples using a venier caliper (Royal Brand). Long grain waxy rice might be categorized as cylindrical in shape (Ece and Cihan,1993). The dimensions of rice shown in table 6.2 show that the length of cooked rice was significantly higher (α=0.05) than that of raw rice. Actually, this expansion of the rice kernel is already evident in the soaked rice. The soaked rice seems to have multiple small cracks or fissures along its length, which may have been caused by the swelling of starch granules or the proteins, thus cell walls separate along weak spots in the grain. These weak spots and cracks may be magnified during drying. The crack lines in the soaked kernels however, could not be observed with the naked eyes once the rice is cooked. The gelatinization of starch during cooking produces an adhesive paste, which could seal these cracks. These same observations were reported by Horigame (2000). Figure 6.11-A shows macroscopic pictures of raw waxy rice, which was originally opaque but turns translucent when cooked and dried Figure 6.11-B,C,D. The opaque color is due to air spaces between the starch granules and its micro-pores. Instant waxy rice was yellowish and a darker off-white in color compared with raw rice. The Hunter color (L-a -b) values of instant and raw rice are shown in Table 6.2.

Drying of cooked rice could produce numerous fissures in the grain (Figure 6.11-C). These fissures appear as small cracks on the outside but may actually be hollow cavities inside the grain. Horigane et al. (2000) developed a technique using NMR Micro imaging to measure the volume of the hollows inside rice kernels. They also concluded that for some Japanese rice cultivars (short grain) the hollow cavities that are formed during cooking are the effect of cracks formed during soaking (Figure 4.5). However, for the waxy rice (RD-6) that we used, the hollow cavities developed after the cooked rice was dried. These fissured kernels were considered desirable for instant rice as the fissures were believed to improve rehydration. However, our data indicate that the microstructure of the walls of these hollow cavities appeared compacted thus hard sections may remain upon reconstitution. The procedures for making such fissures in the grain are documented in the patent literature for instant rice. However, we expect our instant waxy rice to have an appearance similar to regular raw rice, which are dense grains. The dense grain also looks more appealing. Actually a dense dry instant waxy rice grain was more difficult to produce than grains with fissures. Figure 6.13 shows the hollow cavities of instant rice under the scanning electron microscope (SEM). The dry-cooked rice could have up to 6 hollow cavities per grain. The SEM micrographs reveal the presence of very tight-distorted cell structure in kernels having internal hollow cavities (Figure 6.13, 6.14). On the other hand, dense kernels have more organized and looser cells (Figure 6.15). This structure could actually promote rehydration in contrast to a tightly packed structure of hollow kernels. The ordered arrangement of the internal structure of dense instant wxy rice kernels is similar to that of the raw rice (Figure 16.12.) The SEM images show the crack lines in the cross-sectional view of the raw grain. This cracking could be the weak spot, the point in the grain where cracking or fissuring occurs. The hollow cavities inside the fast dried (high temperature, large moisture gradient) grain might result from the pressure of liquid water and vapor inside the kernel which were prevented from leaving the kernel by a casehardened outer layer. The outer layer of the grain, which dried fast, formed the casehardened skin that prevented moisture from escaping the kernel. The water vapor and trapped air, will force the cells towards the surface compressing the cell structure thus forming the internal hollow cavities. Figure 6.16-B shows the near perfect shape of starch granules still present (A) in the instant waxy rice even after steaming for 20 min However, the polygonal shape of starch granule (Figure 6.16-A) disappeared, and the granules had swelled and packed closer to each other. The shape of starch granules altered by gelatinization is distorted flattened and flaked (C). The protein body (Figure 6.16-B, D), are round shape 2-3.5 μm diameter (Juliano,1985). Similar to starch granules, the protein bodies in the instant waxy rice are still intact. The waxy rice granules have 0.5 μm pores ((Juliano,1985), which we can also be observed in Figure 6.16-A(circle) and 6.16 (B). The densities of raw rice, dense instant rice and hollow-instant rice were 1.60, 1.62 and 1.47 g/cm^3 respectively. The presence of hollow cavities is evident in the lower density of the hollow rice grains. The porosity of raw rice and dense instant rice was 0.46 and 0.52. The porosity of hollow-instant rice could not be measured because the individual rice kernels can not be separated from the hard clumps of a fast dried cooked rice.

Rehydration of instant waxy rice

Rehydration of the instant waxy rice was studied in order to obtain recommendations for reconstitution of the instant waxy rice.

The prepared instant waxy rice was rehydrated at room temperature and its moisture content was determined. Figure 6.8 shows moisture content of the instant waxy rice soaked at 24 °C. It was found that within 4 min the grains absorbed moisture to approximately 65 % (db). This value was the average moisture content of conventionally cooked waxy rice. The rate of moisture uptake diminishes after 5 min and some grains lost their structural integrity when left soaking longer than 10 min. First order mathematical modeling was used to simulate the moisture content for the first 9 min of rehydration at room temperature which resulted in the equation below.

$$X_{(t)}=X_e-(X_e-X_{ini})e^{-0.5876\cdot(t)}$$

The variable X($\boldsymbol{t}$) is the moisture content at time $\boldsymbol{t}$ (min). Data in this experiment, showed a final moisture content, X_e of 75.4 % and an initial moisture content X_{ini} of 24.42% .

These values were used in the model. The model was a poor fit (r^2= 0.78). However, it might be useful to characterize the rehydration of the instant waxy rice for short soaking time as was used when soaking raw rice at T>TG. The rehydration rate and target moisture content are necessary parameters for determining how much water must be present in the solution used for reconstitution and the length of heating necessary to reconstitute the instant rice to a form suitable for consumption. The instant waxy rice will require only 5 min of soaking before steaming.

Observation of starch gelatinization by differential scanning calorimetry (DSC)

Hypothesis 4: The extent of starch gelatinization during cooking can be used to determine the adequacy of cooking needed for producing the instant rice product. Starch gelatinization can be observed by Differential Scanning Calorimetry.

The DSC curve provides information on the temperature range for gelatinization and the energy (enthalpy) involved in the transformation. Gelatinization is an endothermic process, which requires energy (heat) to be added to the system. The rice grain is a complex system and starch gelatinization depends on other components present such as water, protein, lipid and fiber. Therefore, the DSC experiments were conducted using the whole rice grain.

DSC characteristics of waxy rice at different degrees of soaking

The presence of adequate moisture is needed to obtain cooked rice with desirable texture. Although the cooking time is normally 20-30 min by conventional steaming, the cooking time need to obtain the optimal texture will be dependent upon the moisture content of the soaked rice. Figure 6.9 shows DSC patterns of waxy rice soaked for different times. The thermal transition curves for gelatinization were not symmetrical bell-shaped curves in contrast to patterns for the isolated starch suspension from the same grain. The DSC of whole grains had a higher onset and peak temperature for the transition compared to that of isolated starch prepared from the same grain. The onset of gelatinization of isolated starch was 52°C and the peak was at 62°C. The ratio of amylopectin to amylose in waxy rice starch was greater than 99%. In contrast, rice grain DSC shows onset temperature of gelatinization at 63 ± 3 °C, while the peak was at 70 ± 1 °C. The gelatinization range of the grin covered approximately 10 °C. These onset and peak temperatures for gelatinization were not significantly different (a=0.05) among grains soaked different times (different absorbed moisture). However, the enthalpy associated with the transition in J/g was lower when the rice had higher moisture content. The transition enthalpy was an exponential function of the soaking time as follows:

$$dH = 0.72e^{(-0.1376t)}$$

$$R^2=0.708$$

Where dH = area (gelatinization energy) from DSC curve (J/g dry solid)

t = soaking time in hr

This gelatinization energy (dH) could explain why a longer cooking time in steam is required when the waxy rice has a lower moisture content at the start of steaming. The traditional method for cooking waxy rice requires overnight soaking to obtain the desirable moisture content (approx. 56±1 % db). Our data indicate that soaking may be shortened to 45 min when the soaking was done at 60 °C. The onset temperature of

63°C is significant because our data indicate non-uniform moisture absorption (moisture gradients in the kernel when the soaking temperature exceeded TG. Accelerated soaking should not be done at T > 60 °C. The grains could lose their integrity and become a paste.

DSC characteristics of waxy rice at different degrees of cooking

Figure 6.10-A shows that soaked rice that was steamed for 3 hr still exhibits the gelatinization transition curve in the DSC. The energy contributing to this transition might include gelatinization of remaining raw starch as well as the transition of other components present in the grain. However, the peak temperature and dH trend to decrease (Figure 6.10-B) in the 3 hr cooked rice. This indicates that most of the transition energy may have been absorbed by starch that had the highest TG in the population. Nevertheless, the linear trend between cooking time and the transition parameters had a relatively low correlation. r^2 was 0.65 and 0.45, respectively, for peak temperature and dH . Waxy rice steamed longer than the optimum time might not have all starch granules completely gelatinized. The SEM micrograph in Figure 6.16-B shows the near perfect shape of a swelled starch granules in the instant waxy rice. This indicates that some starch granules remain intact in the instant waxy rice product in spite of the cooking and drying process used for its manufacture.

The DSC data reinforces the importance of the soaking step in the cooking process for the waxy rice. The starch in low moisture rice grain takes more energy to gelatinize therefore a moisture gradient in the grain during heating can result in some portions of the grain to be overcooked while some portions would be uncooked. DSC patterns explained very well the observations made when dry waxy rice was cooked by boiling in water. The DSC data also shows that a small fraction of ungelatinized starch is acceptable in the instant waxy rice product. A few granules may have swelled but remain ungelatinized thus gelatinization transitions are still exhibited in the DSC patterns.

Quality evaluation of instant waxy rice

Hypothesis 5: The reconstituted instant waxy rice product will resemble the traditionally cooked waxy rice starch in mechanical properties related to texture and sensory properties. Instrumental texture profile analysis (TPA) and sensory evaluation can be used to make the comparison between the traditionally cooked and reconstituted instant waxy rice product.

Normally, cooked, plain-instant waxy rice has no distinct flavor. Therefore, the texture profile would be the primary quality attribute. The instrumental texture profile analysis (TPA) technique was used to evaluate the textural quality of instant rice. The TPA parameters of both reconstituted instant waxy rice and conventionally cooked waxy rice can be compared to determine if the two products have similar textural attributes Sensory properties were also compared between the reconstituted instant waxy rice product and the conventional cooked waxy rice.

Texture profile analysis (TPA) of cooked rice

The typical TPA curve as shown in Figure 6.17-A exhibits a sharp peak and the maximum force occurred at the maximum distance traveled on the down stroke. Fracturability was exhibited by cooked waxy rice and reconstituted instant waxy rice, however, the force was small compared to the magnitude of the hardness parameter. Figure 6.17 to 20 shows the TPA parameter values of cooked waxy rice samples. Unless soaked, just steaming the instant waxy rice did produce a cooked product with the equivalent TPA parameters values of hardness, stickiness, cohesiveness, adhesiveness, gumminess, springiness and chewiness as those exhibited by waxy rice soaked and steamed for 20 min. This is because the moisture pickup by the instant waxy rice product was minimal during the steaming process. The rehydration during steaming of the pre-gelatinized starch on the surface also created a moisture barrier, which prevented moisture migration to the center of the kernel. Parameter values of gumminess and springiness have high correlation (r > 0.99). As suggested by Szczesniak (1963), either gumminess(semi-solid) or chewiness(solid) can be used as a TPA descriptor. The cooked rice behaves more like a solid food rather than a semisolid food. The TPA parameter values for instant waxy rice soaked for 5 min before steaming were similar to those of the conventionally cooked waxy rice (control). Soaked instant rice, which was steamed 5 min (S5) exhibited properties of hardness, stickiness, cohesiveness, gumminess, springiness, and chewiness which were not significantly different (α=0.05) from those of the conventionally cooked rice (C20). Except for springiness, it was also found that control rice cooked for 15 to 20 min (C15 and C20) share similar TPA parameter values. Therefore, steaming the control rice longer might not result in significantly different texture profiles. Soaked instant rice have similar properties as control when steamed longer than 5 min. We concluded that when reconstituting the instant waxy rice the dry product should be soaked 5 min, then cooked for 5 min to obtain TPA attributes similar to those of control.

Sample preparation for the TPA analysis was done with small sample size to have better control of heating uniformity. Reconstituting the product in a household may require a slightly longer cooking time than the 5 min mentioned above.

Sensory evaluation of an instant rice product

Cooked flavored instant rice was compared with similarly flavored regular rice using a sensory panel. A 9-point hedonic scale was used for scoring major attributes of color, odor, texture and overall acceptability . Figure 6.21 shows that the average scores of the attributes were higher than average (5=neither like nor dislike), which indicated that panelists found the flavored reconstituted instant waxy rice product acceptable. The non-parametric Wilcoxon comparison showed that there were no significant differences ($p > 0.05$) among the attributes of the two samples compared. However, the texture of the instant rice product had significantly higher score than regular waxy rice at the confidence level of 89.4 % ($p>0.106$). Nevertheless, the texture scores were just above the average. Panelists commented that the texture was too soft. This may be because of the excess water in the formula. Panelists favored the color of both instant rice pudding (7.45±1.72) and regular rice pudding. The white color of coconut powder, however, might mask the true color of the rice. The color of dry instant rice is translucent-yellow-brown, which was similar to the rice cooked from old rice (long storage). The color of newer harvested rice is translucent-white. The instant rice in this experiment was produced from old rice (>1 year storage at 4°C). There was no evidence of hollow cavities in the grains of the reconstituted instant rice although hollow cavities were found in the dry-instant-waxy rice grains. Rehydration of the grain may have expanded the starch molecules, which filled up the void. Rearrangements of the starch molecule and remaining granules may have also been responsible for filling up most of empty spaces in the grain. Hollow cavities in the dry instant waxy rice grains are not desirable because of the poor appearance of the dry grains. The dry instant waxy rice should be similar to the dry waxy rice grain. Dense grains might appeal to consumers than hollow or cracked grains. The overall acceptability score was just above 5 (positive trend) (Figure 6.21). Panelists commented about the product's lack of flavor and taste. The formula should be modified to increase rice aroma and coconut flavor such as using artificial rice and coconut flavor. Actually the formula used for the test products was intended to be served with sweet fruit; therefore, the pudding was less sweet than expected by some panelists.

Table 6.1: Diffusivity of waxy rice soaked at different temperatures and the parameter used in simulation.

Temperature (^{o}C)	Initial moisture (%db)	Final Moisture (%db)	Diffusivity ($\times 10^{-9}$ m^2/min)	Correlation
1	13.9	56.0	1.8512	0.983
24	14.4	56.0	3.8810	0.995
40	14.7	56.0	6.3685	0.996
45	13.6	56.0	5.0551	0.997
50	15.3	56.0	7.9605	0.999
60	14.9	62.9@120 min	6.9058	0.996
65	12.3	71.1 @120 min	4.4278	0.991
70	14.9	105.7 @ 45 min	4.5840	0.989
75	13.5	219.7 @ 60 min	4.6980	0.994

Average initial moisture content =14.0 % (db)

Table 6.2 Some physical properties of raw rice and instant waxy rice (Thai's RD6)

Properties	Raw	Soaked (MC=56% db)	Steam-cooked (20min)	Instant rice
Dimensions				
Height (mm)	1.605± 0.024	1.69±0.038	1.605±0.049	1.345±0.026
Width	2.265±0.0154	2.4±0.034	2.33±0.051	2.00±0.021
Length	6.695±0.154	7.325±0.308	7.945±0.1612	7.56±0.054
Color*				
L	81.48±.028	-	-	67.5±0.25
a	-0.05±0.002	-	-	-0.45±0.02
b	13.42±0.09	-	-	14.66±0.06

*Hunter color (L-a -b) values (Minolta® color meter model CR-410D, Minolta corp., NJ)

Figure 6.1: Moisture content of waxy rice soaked at different temperatures.

—•— Soaking temperature 70°C

—■— Soaking temperature 60°C

—∆— Soaking temperature 50°C

—×— Soaking temperature 40°C

—*— Soaking temperature 24°C

—●— Soaking temperature 1°C

Note: Please see figure 6.2-4 for more details.

Moisture content of waxy rice soaked at different temperatures

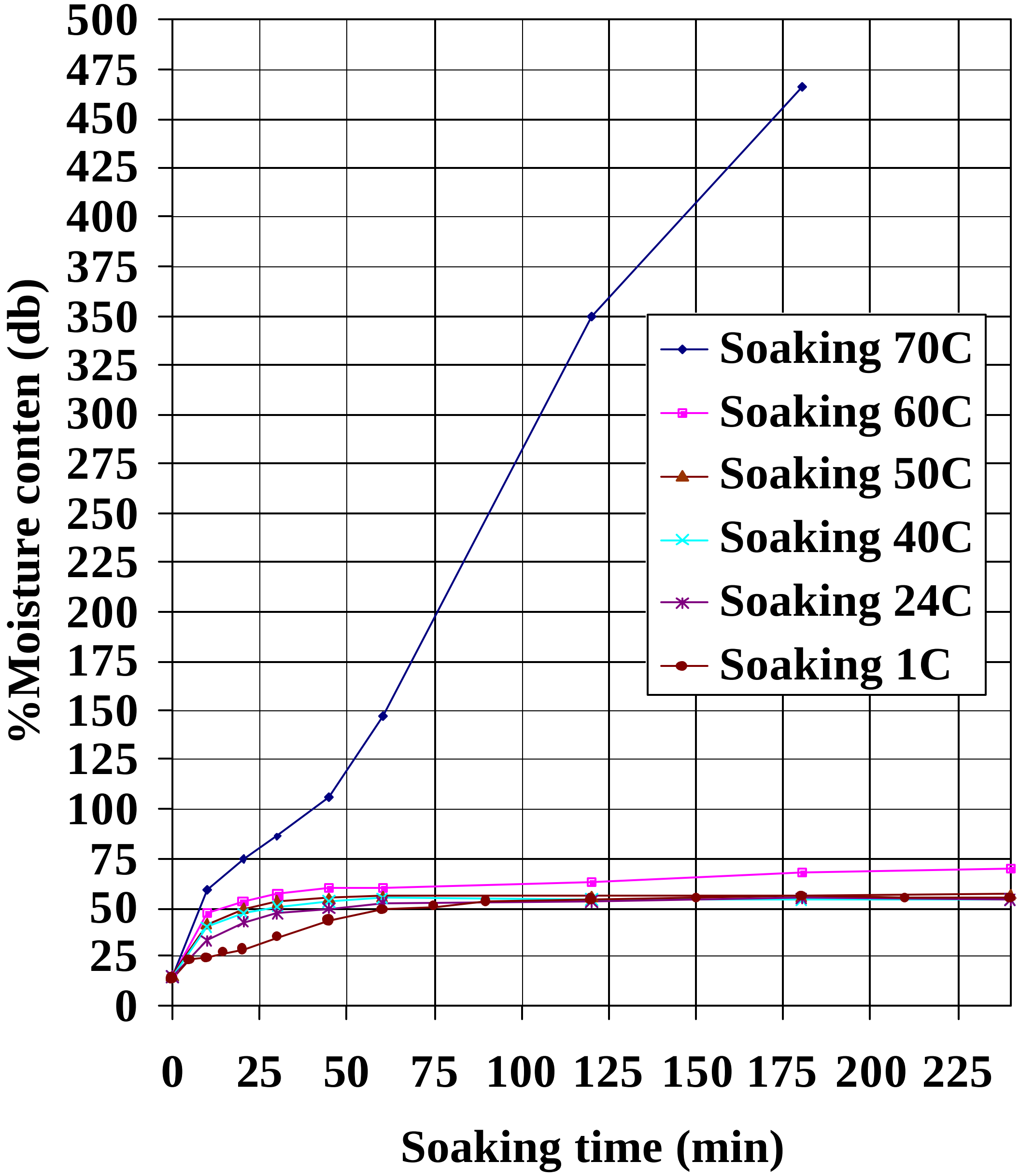


Figure 6.2: Computer-simulated moisture content of soaked rice soaked at 24, 40, 50 and 60°C.

A) The simulation model of the rice soaked at 24°C.

B) The simulation model of the rice soaked at 40°C.

C) The simulation model of the rice soaked at 50°C.

D) The simulation model of the rice soaked at 60°C.

—— Simulated data

o Experimental data

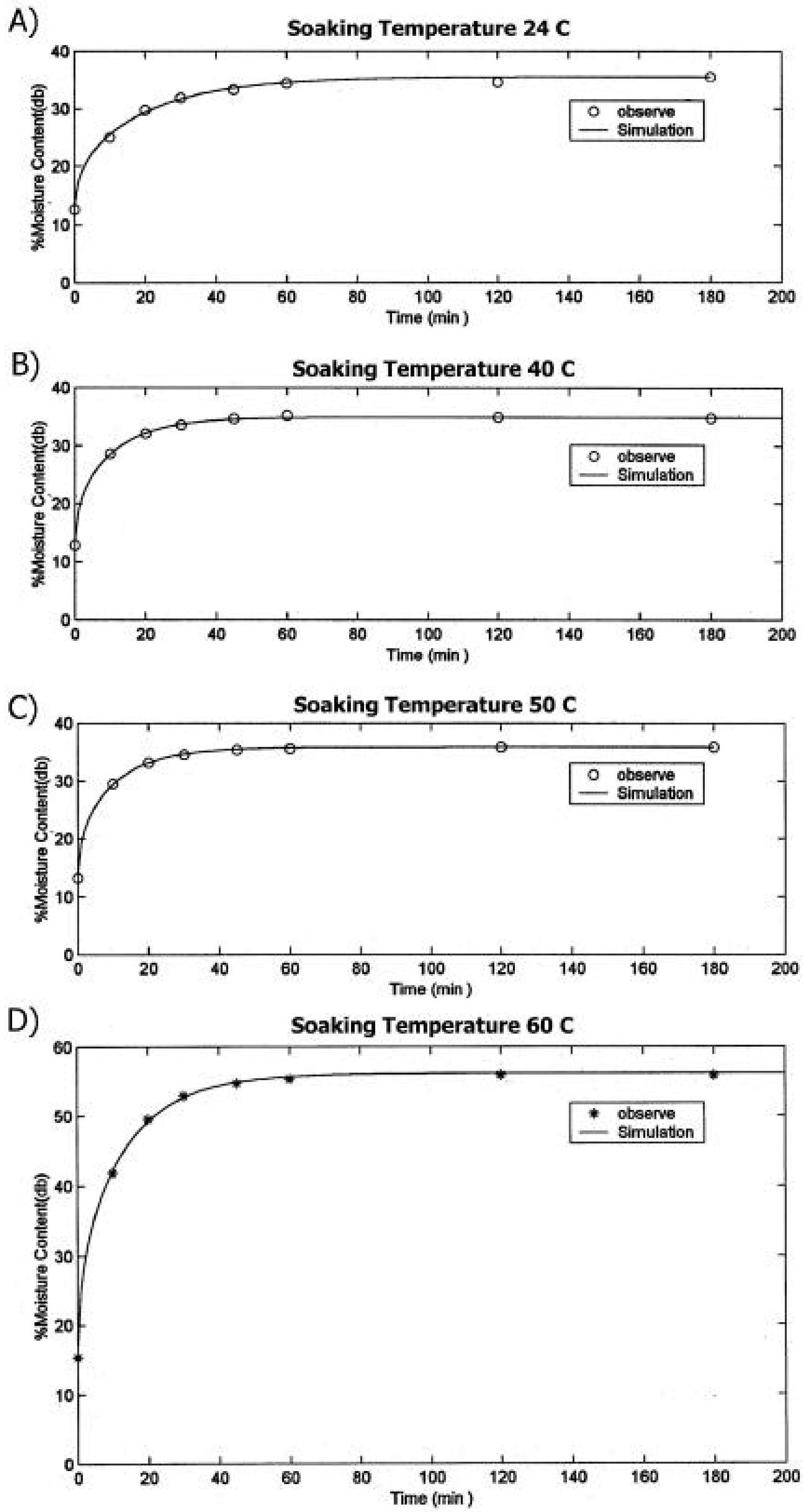

A)
Soaking Temperature 24 C
observe
Simulation
%Moisture Content(db)
Time (min)
B)
Soaking Temperature 40 C
observe
Simulation
%Moisture Content(db)
Time (min)
C)
Soaking Temperature 50 C
observe
Simulation
%Moisture Content(db)
Time (min)
D)
Soaking Temperature 60 C
observe
Simulation
%Moisture Content(db)
Time (min)

Figure 6.3: Computer-simulated moisture content of soaked rice soaked at 65 °C.

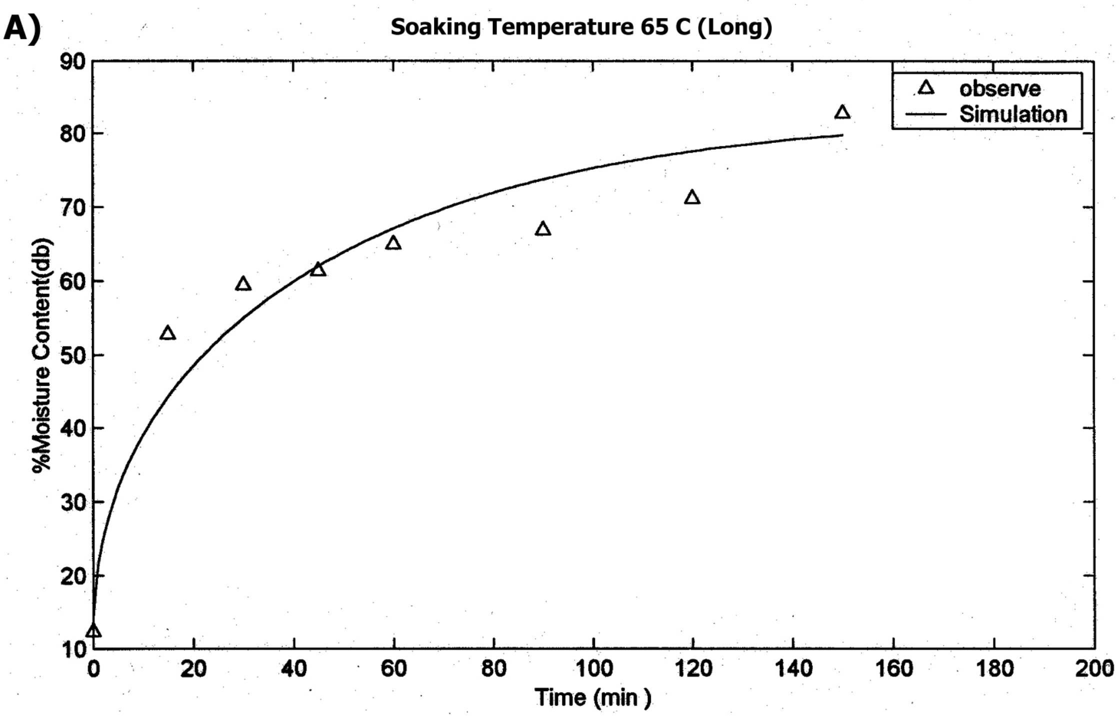
A) The simulation that used most of the data point longer than 120 min soaking, which poorly fitted the model.

B) The simulation that used data point up to120 min, which fitted the model better.

—— Simulated data

∇ Experimental (observed) data

A)


Soaking Temperature 65 C (Long)
observe
Simulation
%Moisture Content(db)
Time (min)
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
120
140
160
180
200

B)

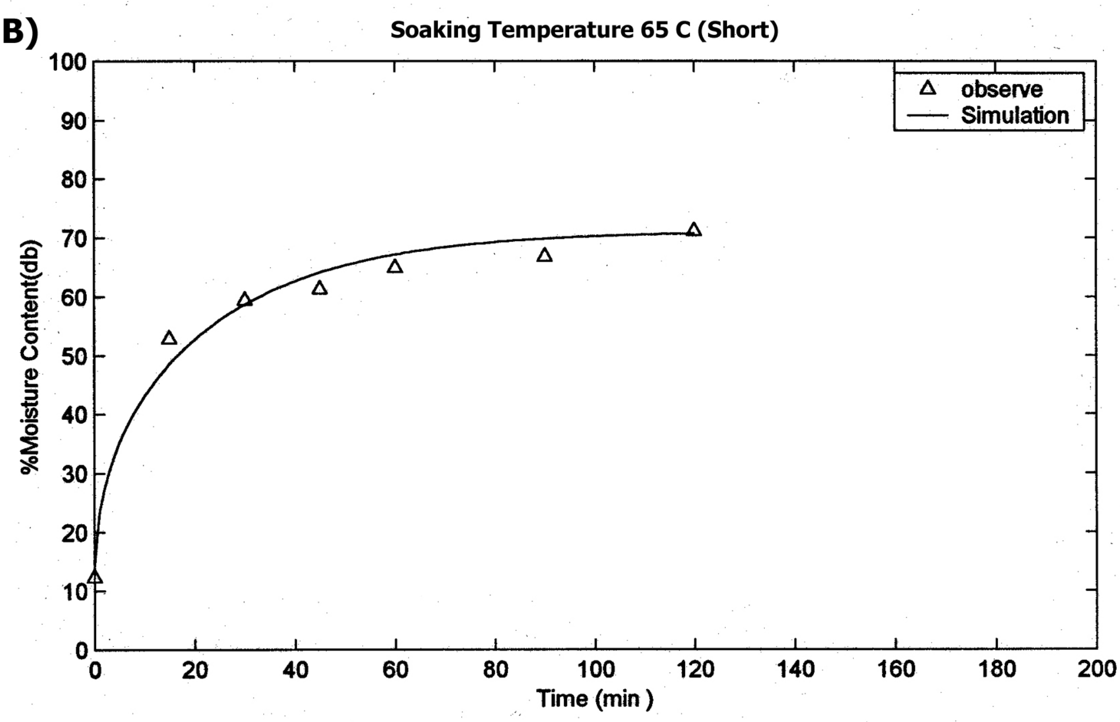

Soaking Temperature 65 C (Short)
observe
Simulation
%Moisture Content(db)
Time (min)
100
90
80
70
60
50
40
30
20
10
0
0
20
40
60
80
100
120
140
160
180
200

Figure 6.4: Computer-simulated moisture content of soaked rice.

A) The simulation that used most of the data point of the rice soaking at 70°C , which poorly fitted the model.

B) The simulation that used only the beginning data point of the rice soaked at 70°C, which fitted the model better.

C) The simulation that used only the beginning data point of the rice soaked at 75°C.

—— Simulated data

\+ Experimental (observed) data of the rice soaking at 70°C

∇ Experimental (observed) data of the rice soaking at 75°C

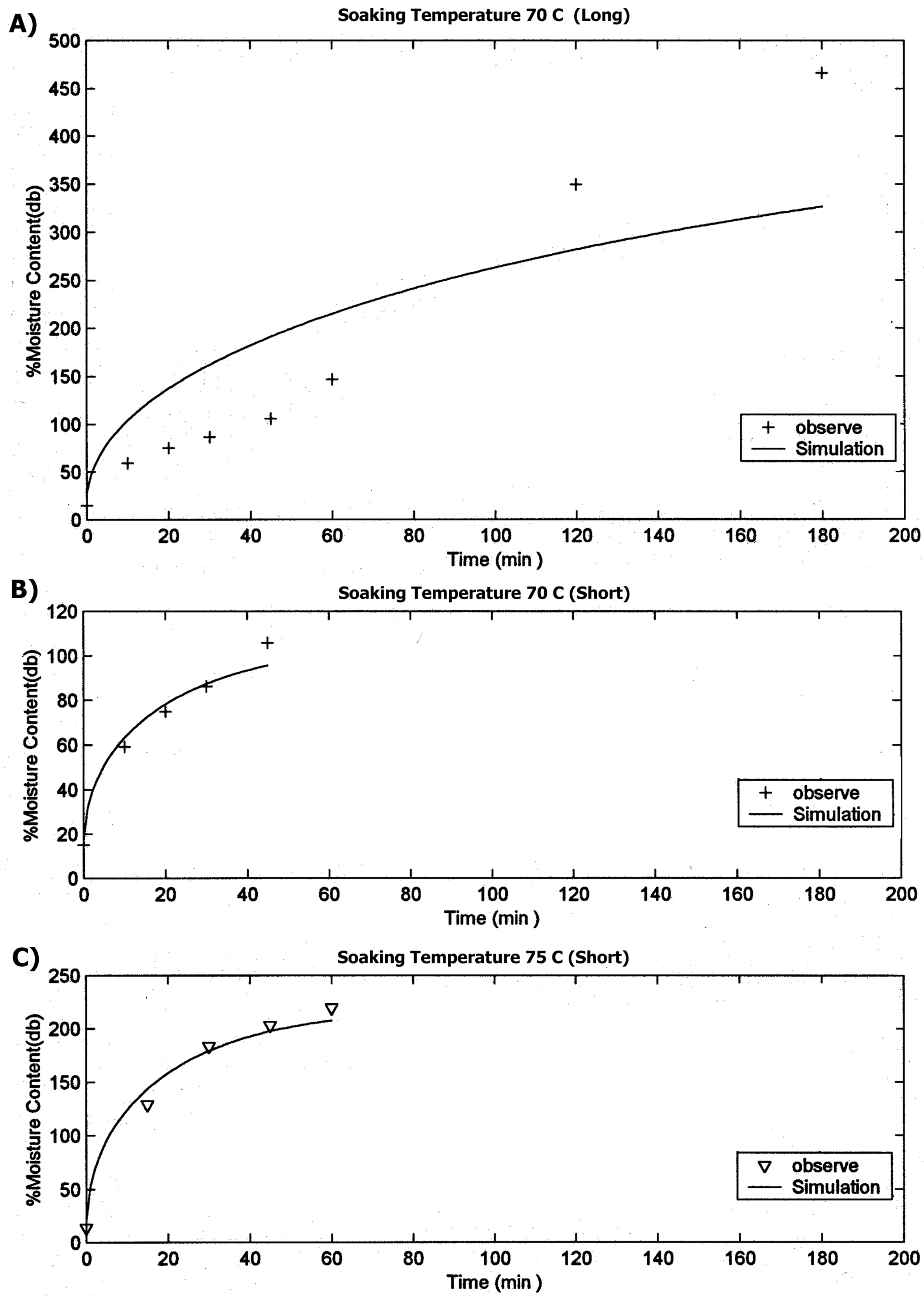

A)
Soaking Temperature 70 C (Long)
%Moisture Content(db)
Time (min)
observe
Simulation
B)
Soaking Temperature 70 C (Short)
%Moisture Content(db)
Time (min)
observe
Simulation
C)
Soaking Temperature 75 C (Short)
%Moisture Content(db)
Time (min)
observe
Simulation

Figure 6.5: Effective moisture diffusivity as the function of temperature according to Arrhenius equation for the temperature range of 1-60 °C. Note, the temperature used in equation is in Kelvin.

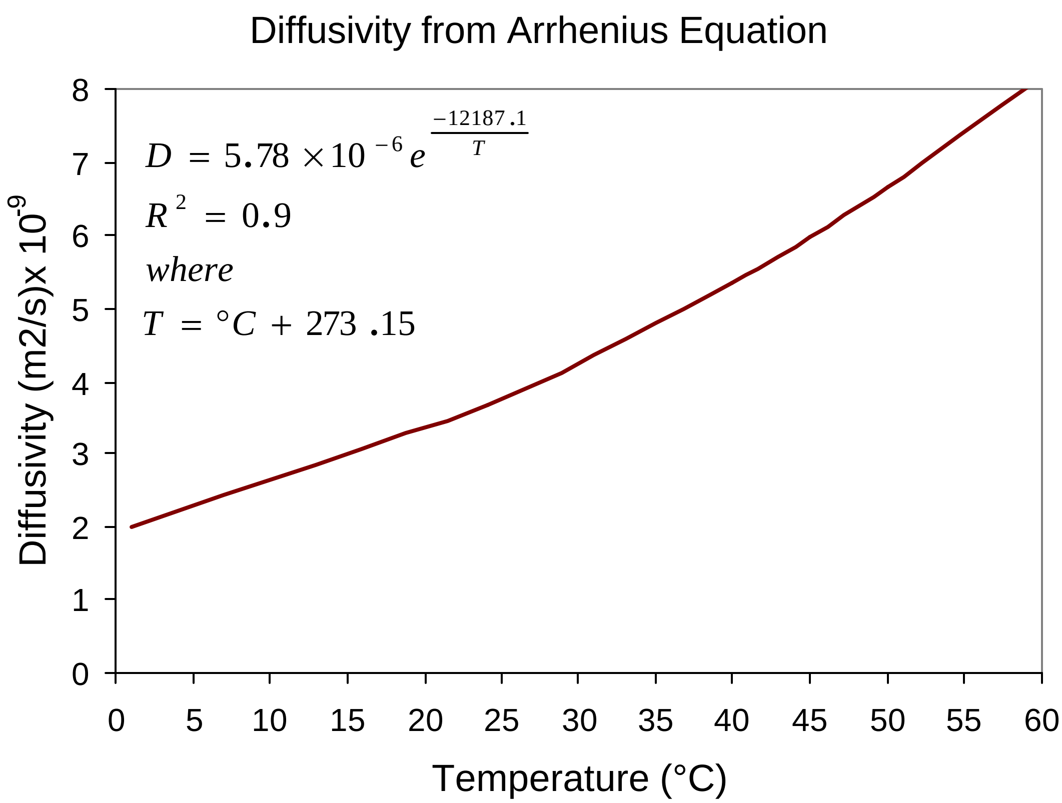

Diffusivity from Arrhenius Equation
$D = 5.78 \times 10^{-6} e^{\frac{-12187.1}{T}}$
$R^2 = 0.9$
where
$T = °C + 273.15$
Diffusivity (m2/s)x 10-9
Temperature (°C)
0
1
2
3
4
5
6
7
8
0
5
10
15
20
25
30
35
40
45
50
55
60

Figure 6.6: Waxy rice cooked under conventional steaming.

A) The temperature profile.

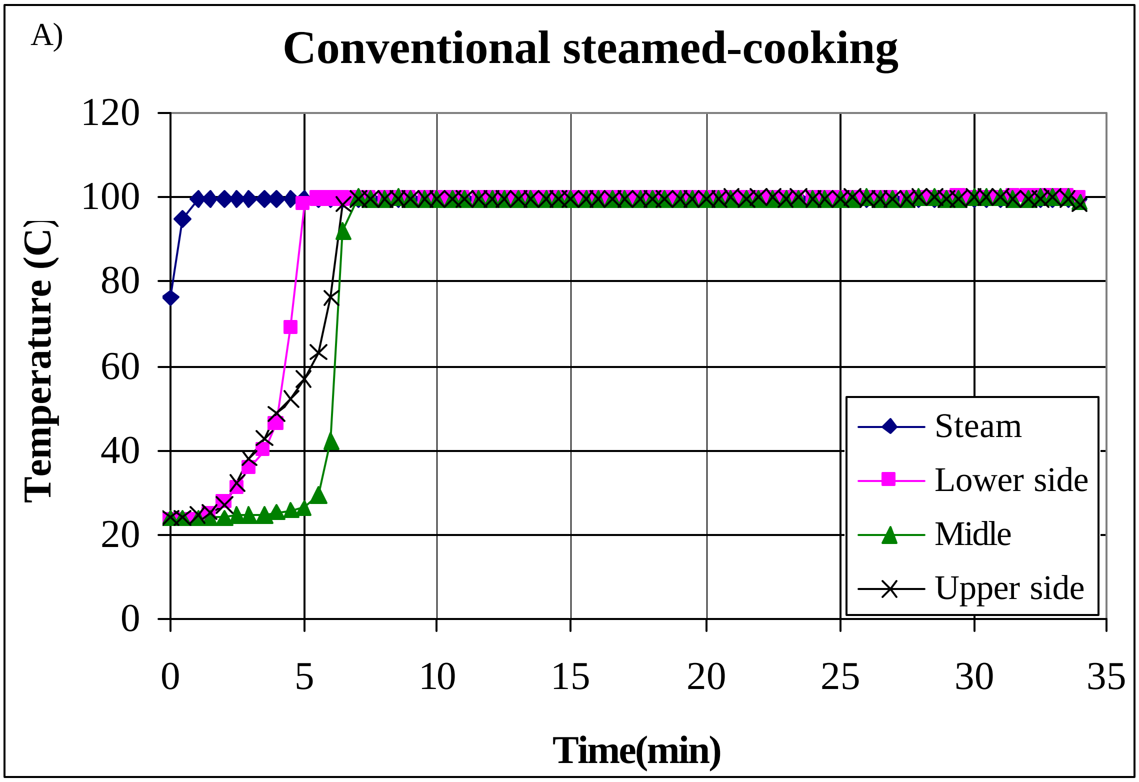
—●— Steam temperature

—■— The temperature of rice measured at the lower side of the steamer.

—Δ— The temperature of rice measured at the middle of the steamer.

—×— The temperature of rice measured at the upper side of the steamer.

B) Moisture content (%db) of waxy rice cooked at different times. Note: the samples were taken from the rice at middle of the steamer.


A)
Conventional steamed-cooking
Temperature (C)
Time(min)
Steam
Lower side
Midle
Upper side
120
100
80
60
40
20
0
0
5
10
15
20
25
30
35

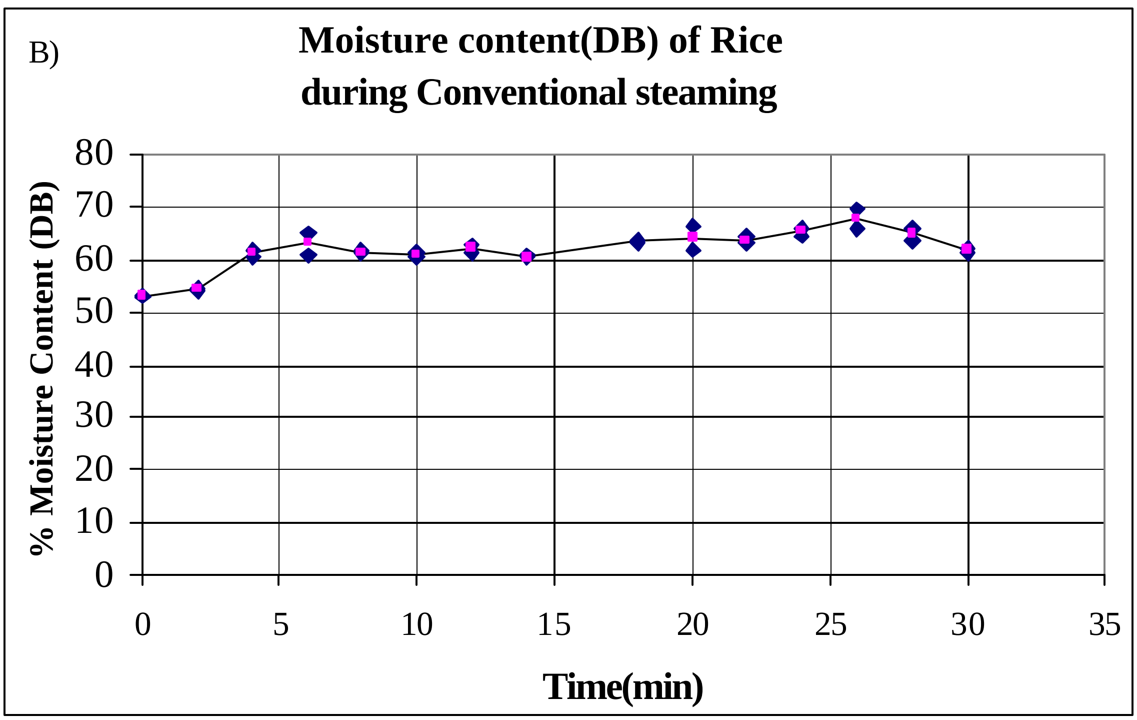
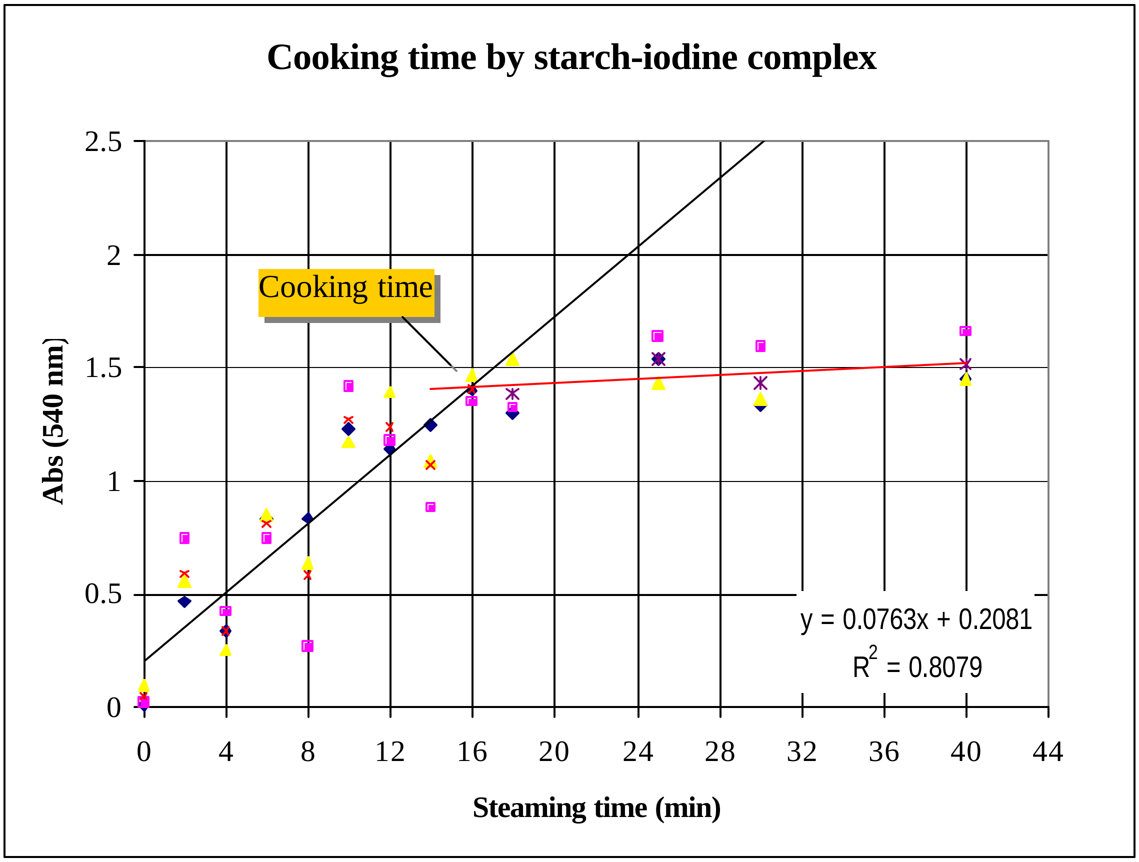

B)
Moisture content(DB) of Rice
during Conventional steaming
% Moisture Content (DB)
Time(min)
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35

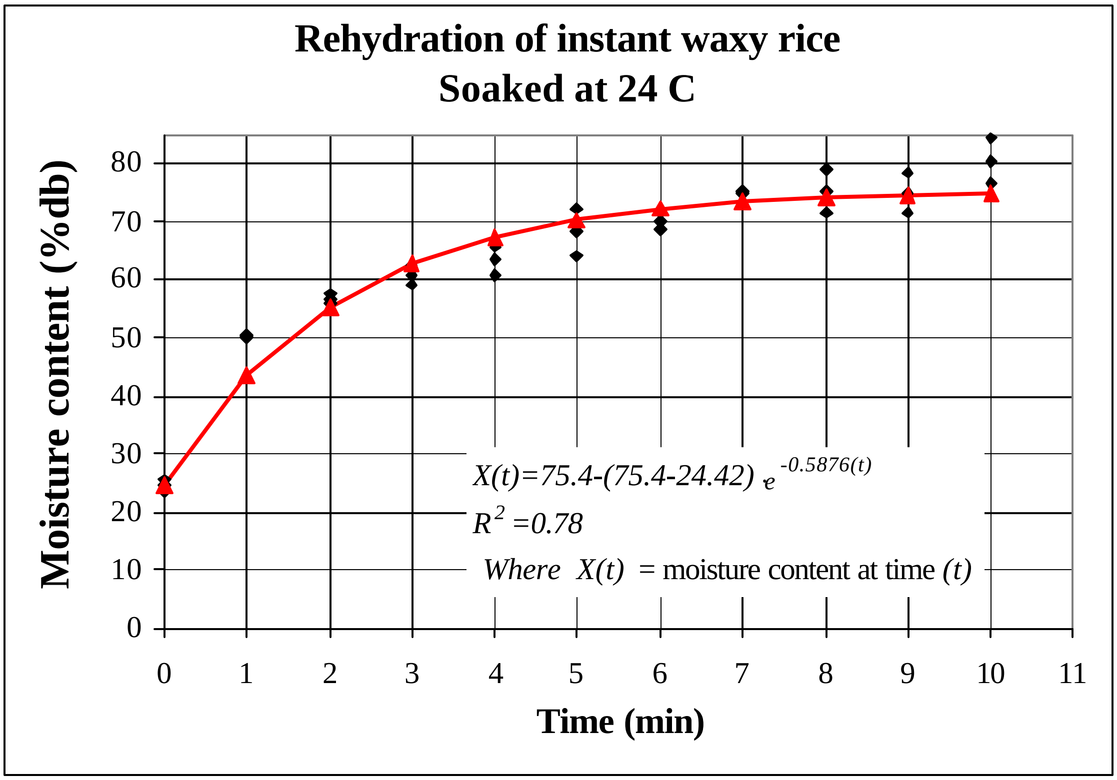
Figure 6.7: Cooking of waxy rice: steaming time determined by starch-iodine complex.



Cooking time by starch-iodine complex
Abs (540 nm)
2.5
2
1.5
1
0.5
0
Cooking time
y = 0.0763x + 0.2081
R2 = 0.8079
0
4
8
12
16
20
24
28
32
36
40
44
Steaming time (min)

Figure 6.8: Rehydration of instant waxy rice at 24°C.

The solid line is the simulated data.



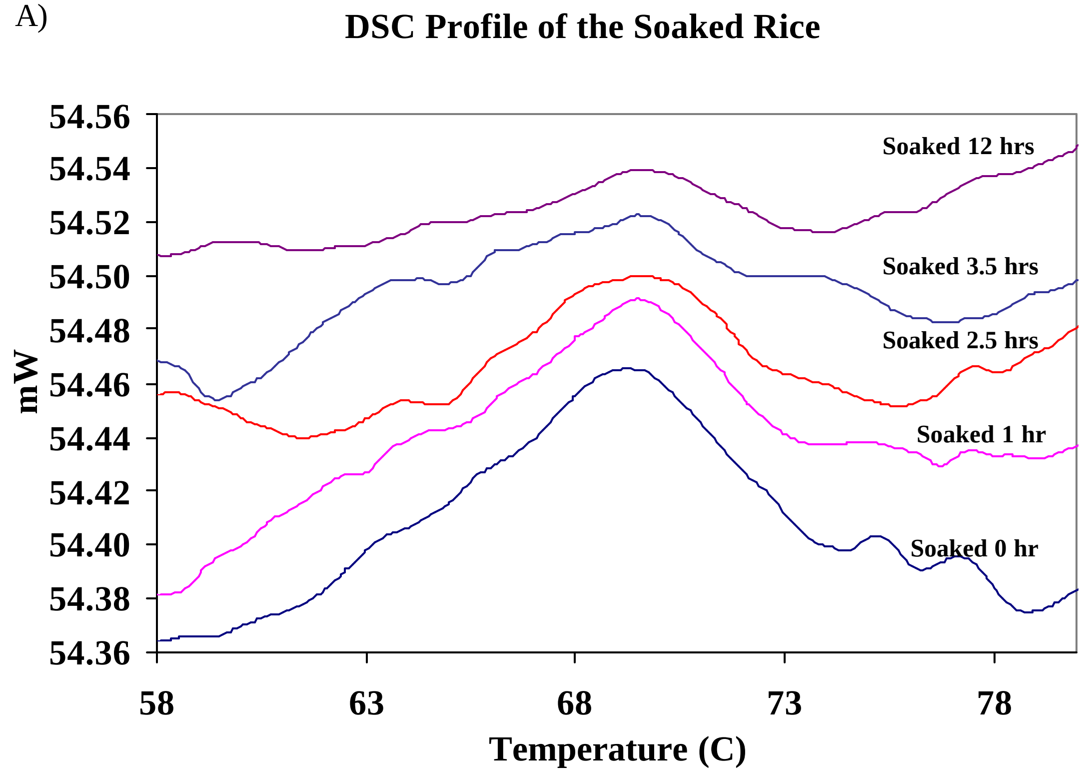
Rehydration of instant waxy rice
Soaked at 24 C
Moisture content (%db)
80
70
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
8
9
10
11
Time (min)
X(t)=75.4-(75.4-24.42) e -0.5876(t)
R2 =0.78
Where X(t) = moisture content at time (t)

Figure 6.9: DSC of uncooked rice soaked for different times.

(A) DSC profile of the gelatinization transition

(B) Onset temperature, peak temperature and dH of the gelatinization transition

A)


DSC Profile of the Soaked Rice
54.56
54.54
54.52
54.50
54.48
54.46
54.44
54.42
54.40
54.38
54.36
mW
Soaked 12 hrs
Soaked 3.5 hrs
Soaked 2.5 hrs
Soaked 1 hr
Soaked 0 hr
58
63
68
73
78
Temperature (C)

B)

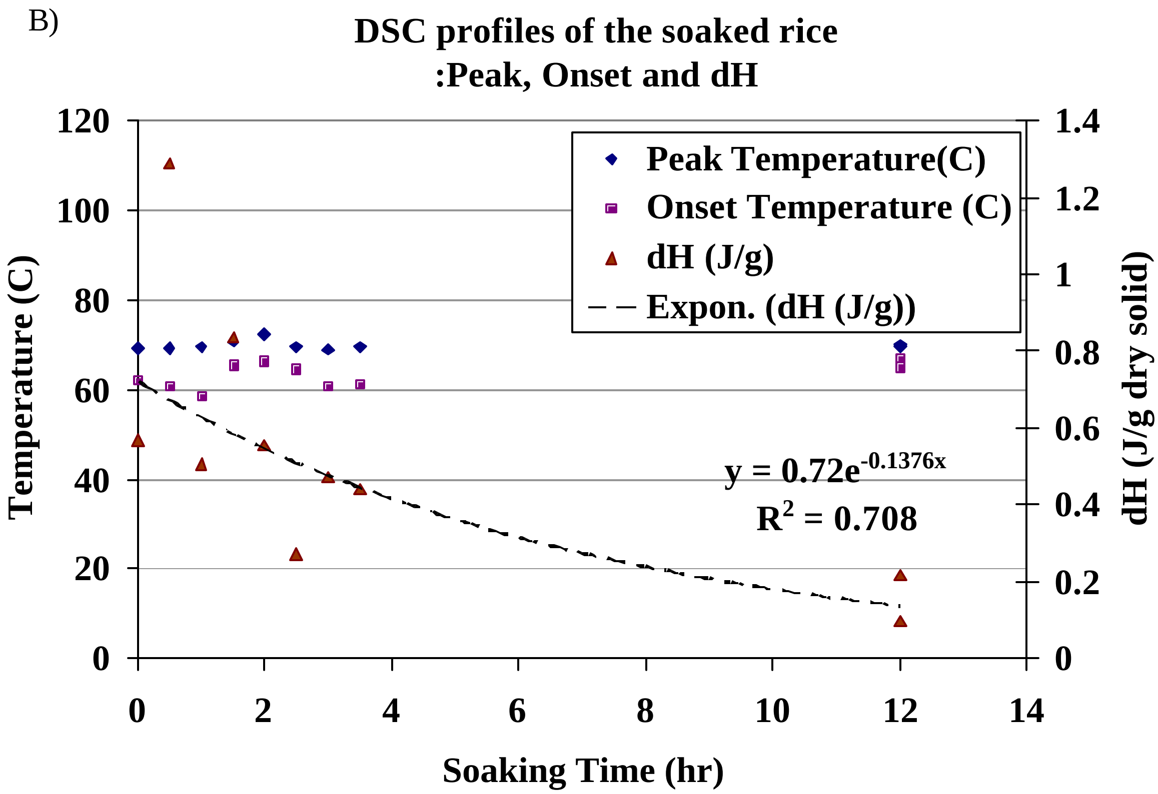
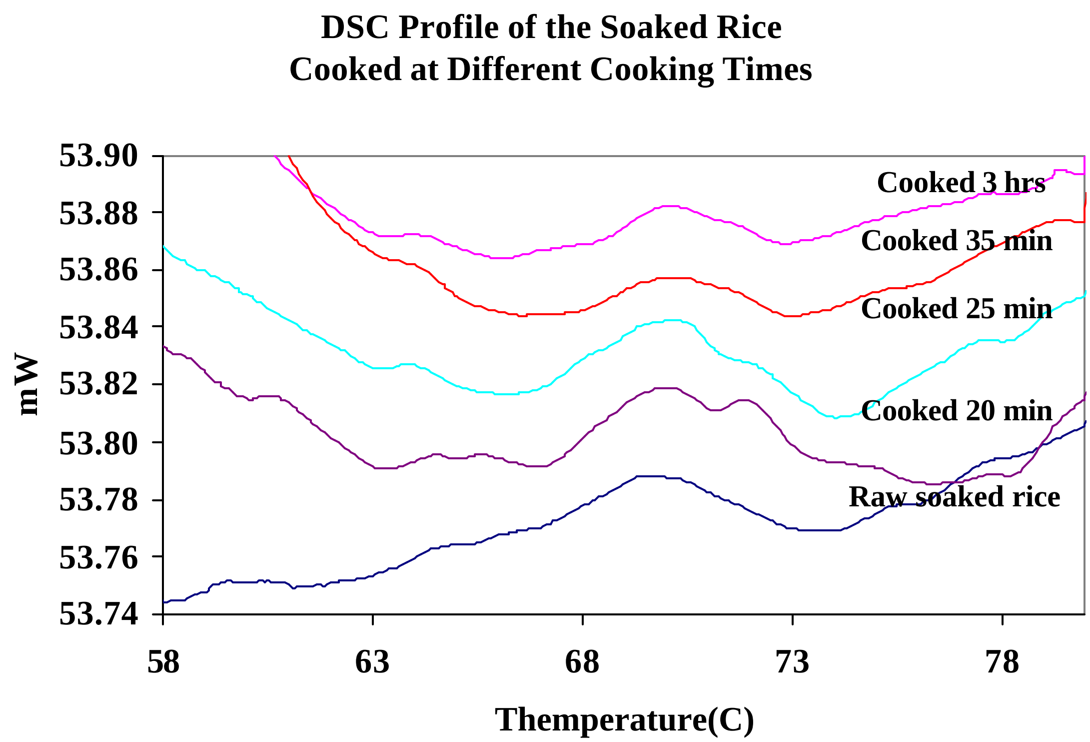

DSC profiles of the soaked rice
:Peak, Onset and dH
120
100
80
60
40
20
0
Temperature (C)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
dH (J/g dry solid)
Peak Temperature(C)
Onset Temperature (C)
dH (J/g)
Expon. (dH (J/g))
y = 0.72e^-0.1376x
R^2 = 0.708
0
2
4
6
8
10
12
14
Soaking Time (hr)

Figure 6.10: DSC profile of soaked rice cooked for different times in steam.

(A) DSC profile of steam-cooked waxy rice.

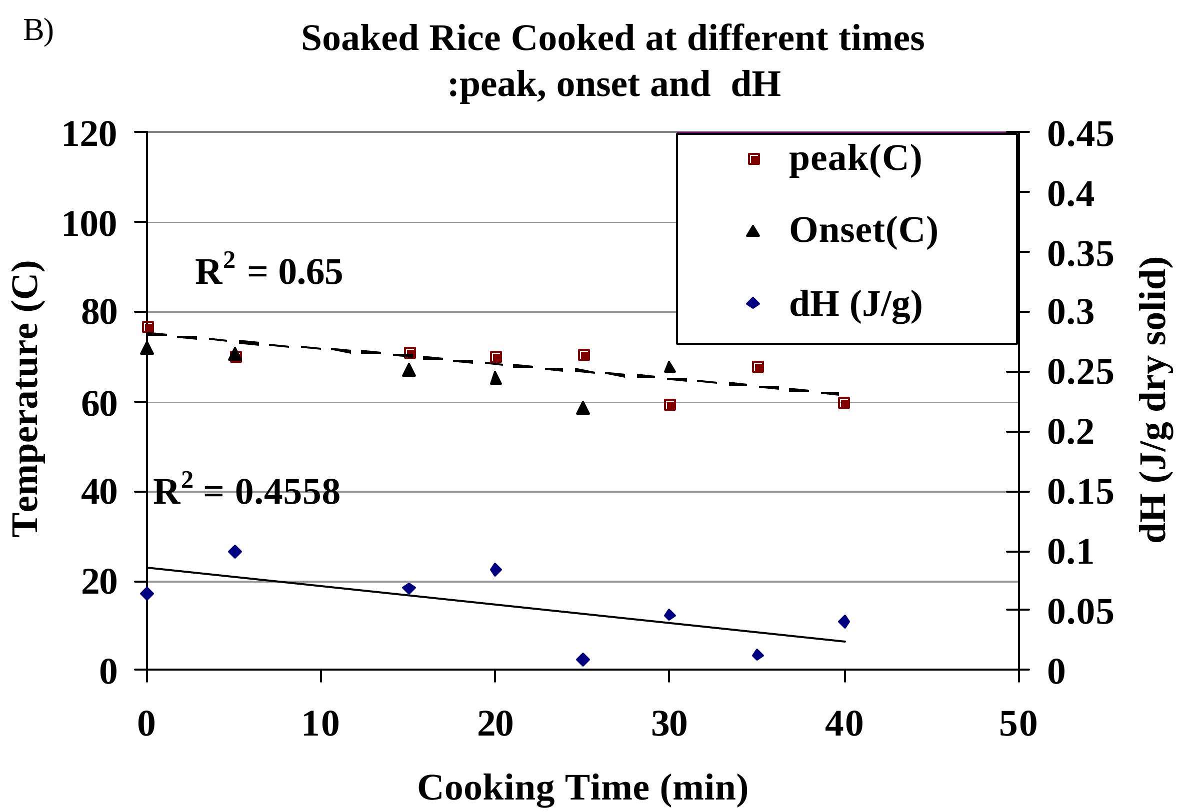
(B) Onset temperature, peak temperature and dH of the DSC curves of cooked waxy rice.

A)



DSC Profile of the Soaked Rice
Cooked at Different Cooking Times
mW
53.90
53.88
53.86
53.84
53.82
53.80
53.78
53.76
53.74
58
63
68
73
78
Themperature(C)
Cooked 3 hrs
Cooked 35 min
Cooked 25 min
Cooked 20 min
Raw soaked rice

B)



Soaked Rice Cooked at different times
:peak, onset and dH
Temperature (C)
dH (J/g dry solid)
Cooking Time (min)
peak(C)
Onset(C)
dH (J/g)
R2 = 0.65
R2 = 0.4558
120
100
80
60
40
20
0
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
10
20
30
40
50

Figure 6.11: Light microscope image of raw, steam cooked and dry instant rice

A) Raw waxy rice

B) Soaked waxy rice after steaming.

C) Fast-dried instant waxy rice showing the fissures in the grain.

D) Slow (cold room) dried instant waxy rice showing the dense grain.

Note: The intense yellowish color was the effect of the microscope light source which was enhanced to reveal cracks on the grain. The actual color was an off-white and slightly translucent.

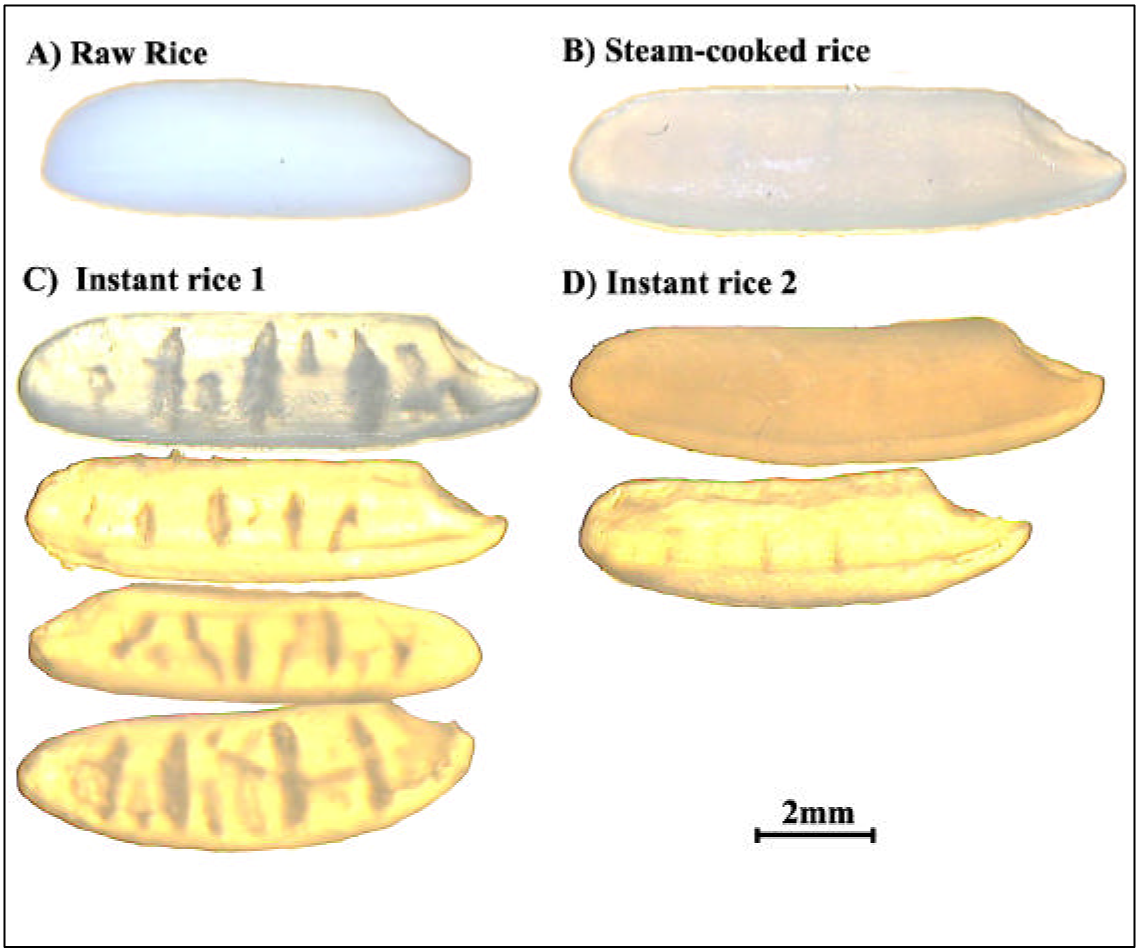
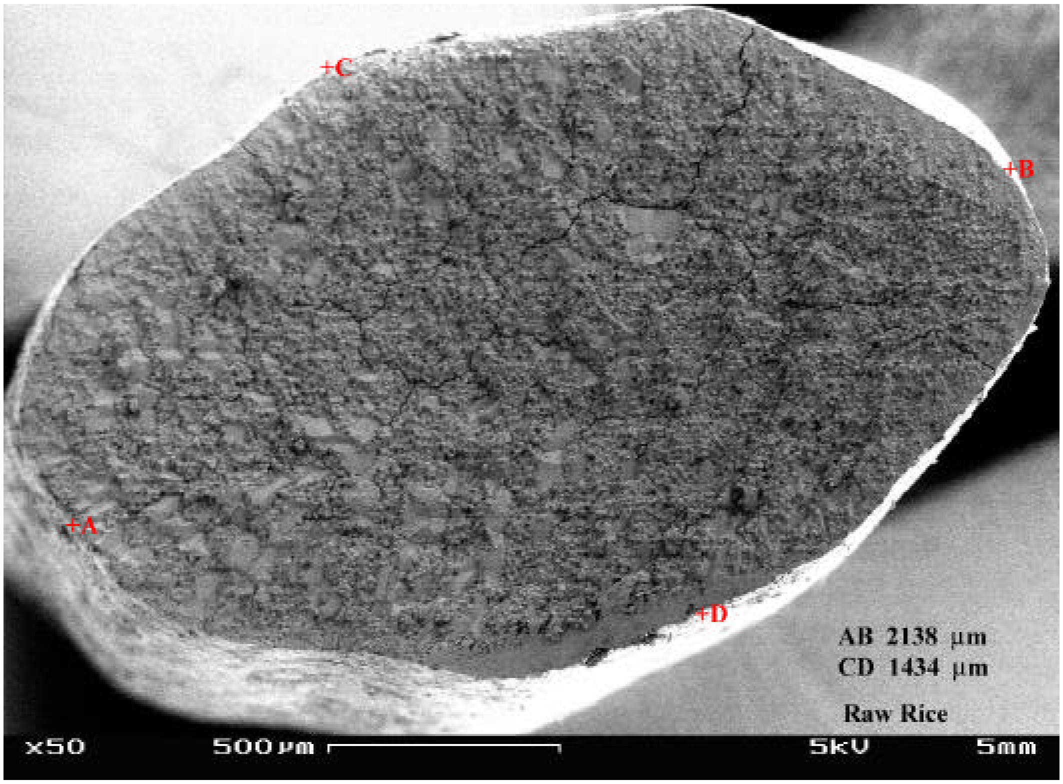

A) Raw Rice
B) Steam-cooked rice
C) Instant rice 1
D) Instant rice 2
2mm

Figure 6.12: The SEM images of raw waxy rice.

A) Cross-sectional view shows radiate cell arrangement and the cracking lines.

B) The enlargement of (A) near the surface of the grain showing the polygonal shape of starch granules.

Note: The size of granule was 4-13 μm measured by Measuring Tool in Adobe's Photoshop® version. 7.0 (SEM scale as a calibrator). The particle size distribution of prepared rice starch measured by Mastersizer ® was 2-50 μm, the maximum peak was 8 μm.


+C
+B
+A
+D
AB 2138 µm
CD 1434 µm
Raw Rice
x50
500µm
5kV
5mm

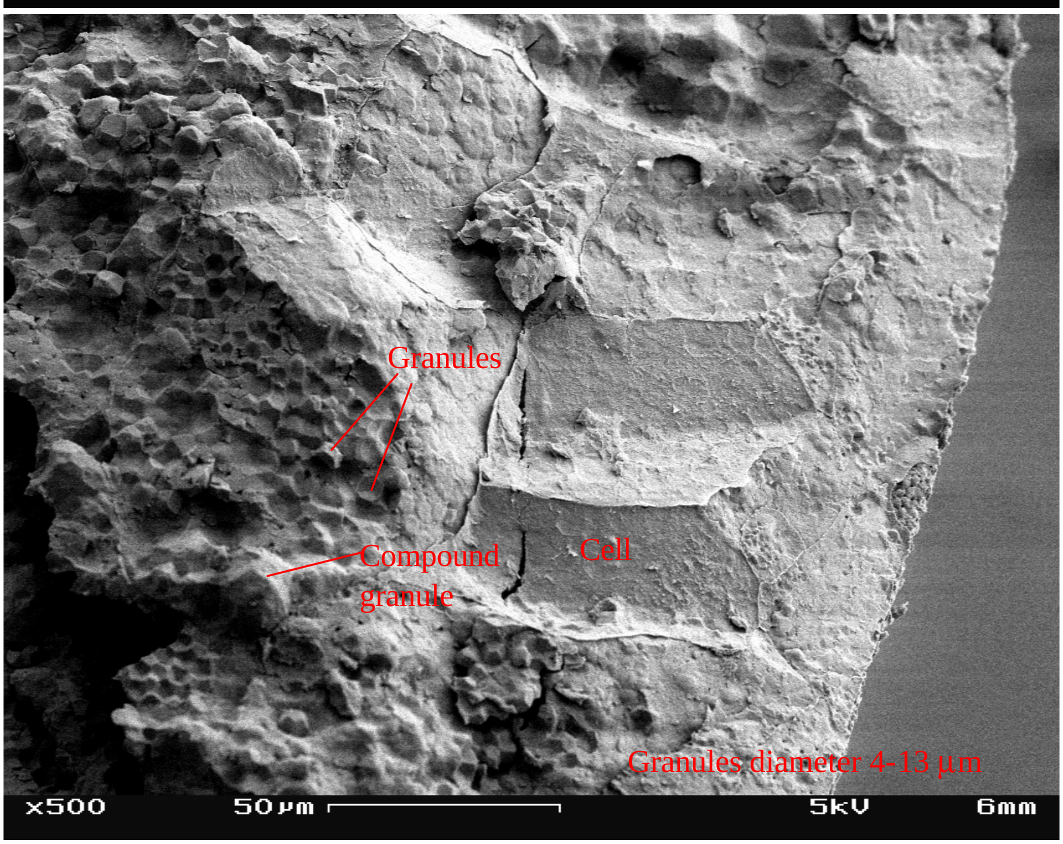

Granules
Compound
granule
Cell
Granules diameter 4-13 µm
x500
50µm
5kV
6mm

Figure 6.13: The SEM images showing the hollow cavity(ies) in the fast-dried instant rice grain

A) Cross- sectional view.

B) Longitudinal view.

Note: The smooth area in the lower edge of the image was the artificial mask of the fixing solution (sugar) for the SEM preparation.

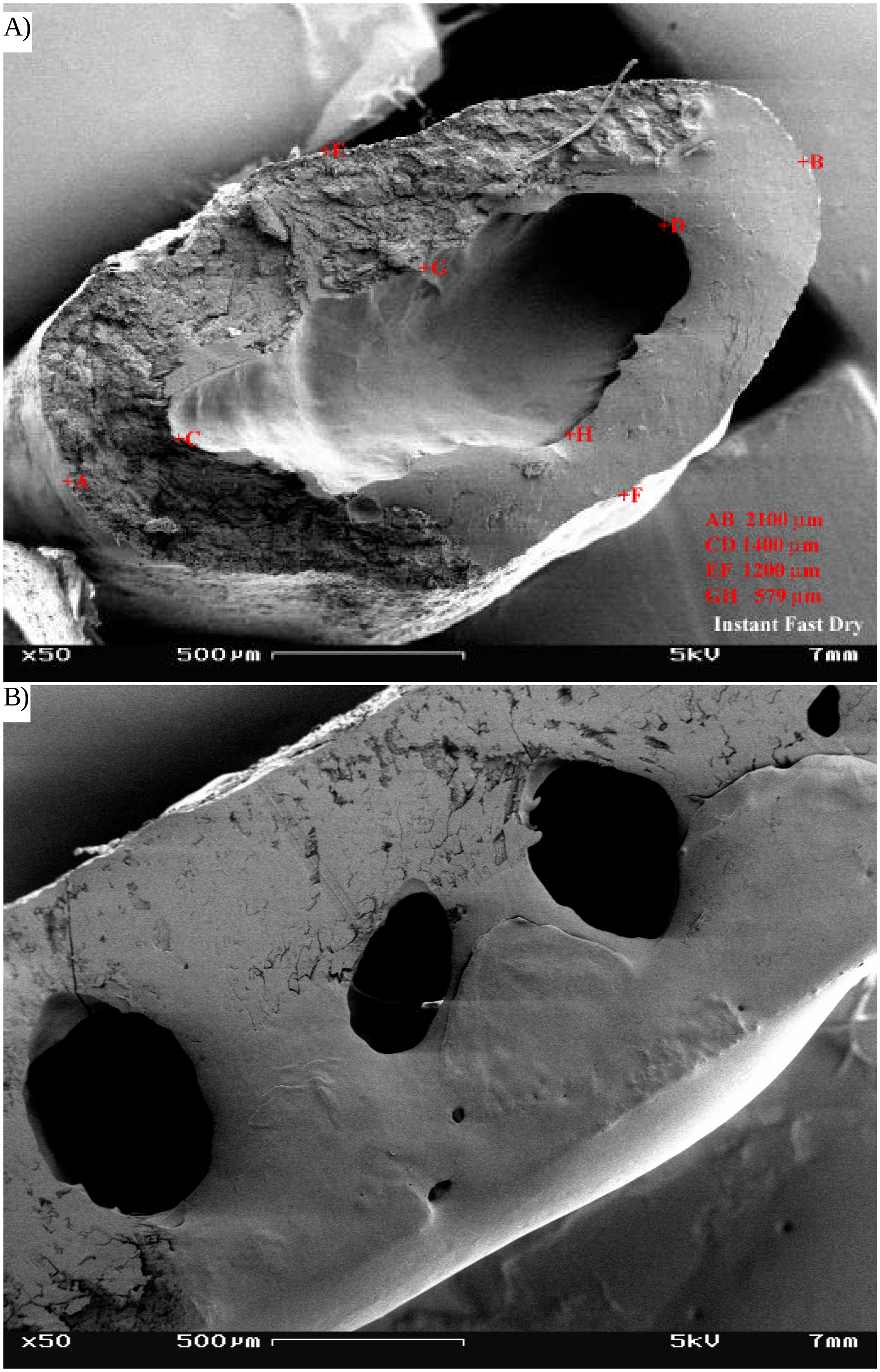

A)
+E
+B
+D
+G
+C
+H
+A
+F
AB 2100 µm
CD 1400 µm
EF 1200 µm
GH 579 µm
Instant Fast Dry
x50 500µm 5kV 7mm
B)
x50 500µm 5kV 7mm

Figure 6.14: The SEM images of instant waxy rice produced by fast drying rate.

A) Cross-sectional view shows the tight-packed cell arrangement.

B) Showing the smooth surface of the hollow.

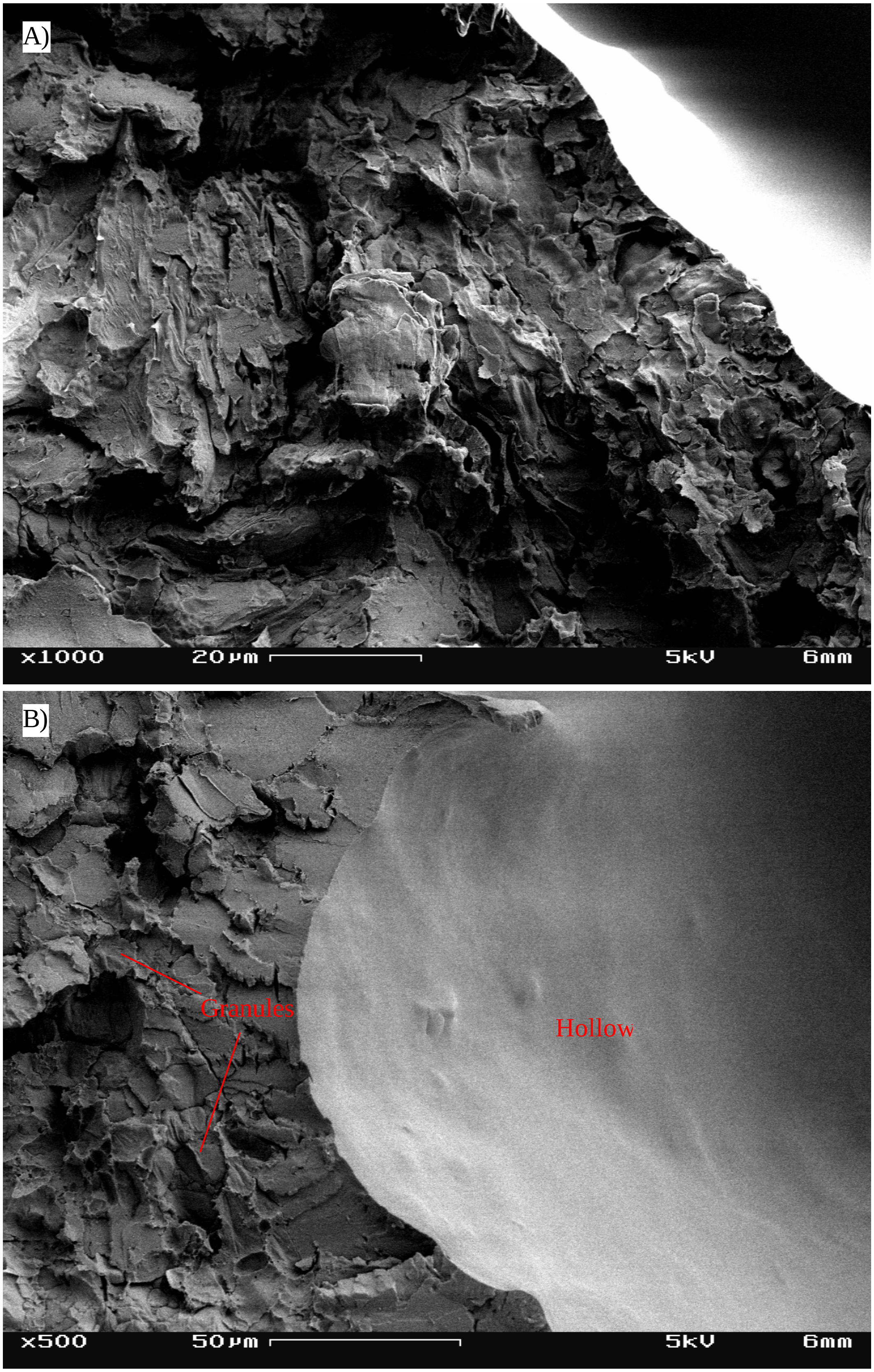

A)
x1000 20μm 5kV 6mm
B)
Granules
Hollow
x500 50μm 5kV 6mm

Figure 6.15: The SEM images of instant waxy rice produced by a slow drying rate (chilled-dried).

A) Cross-sectional view shows ordered-cell arrangement radiating from the center.

B) Image enlargement of (A).

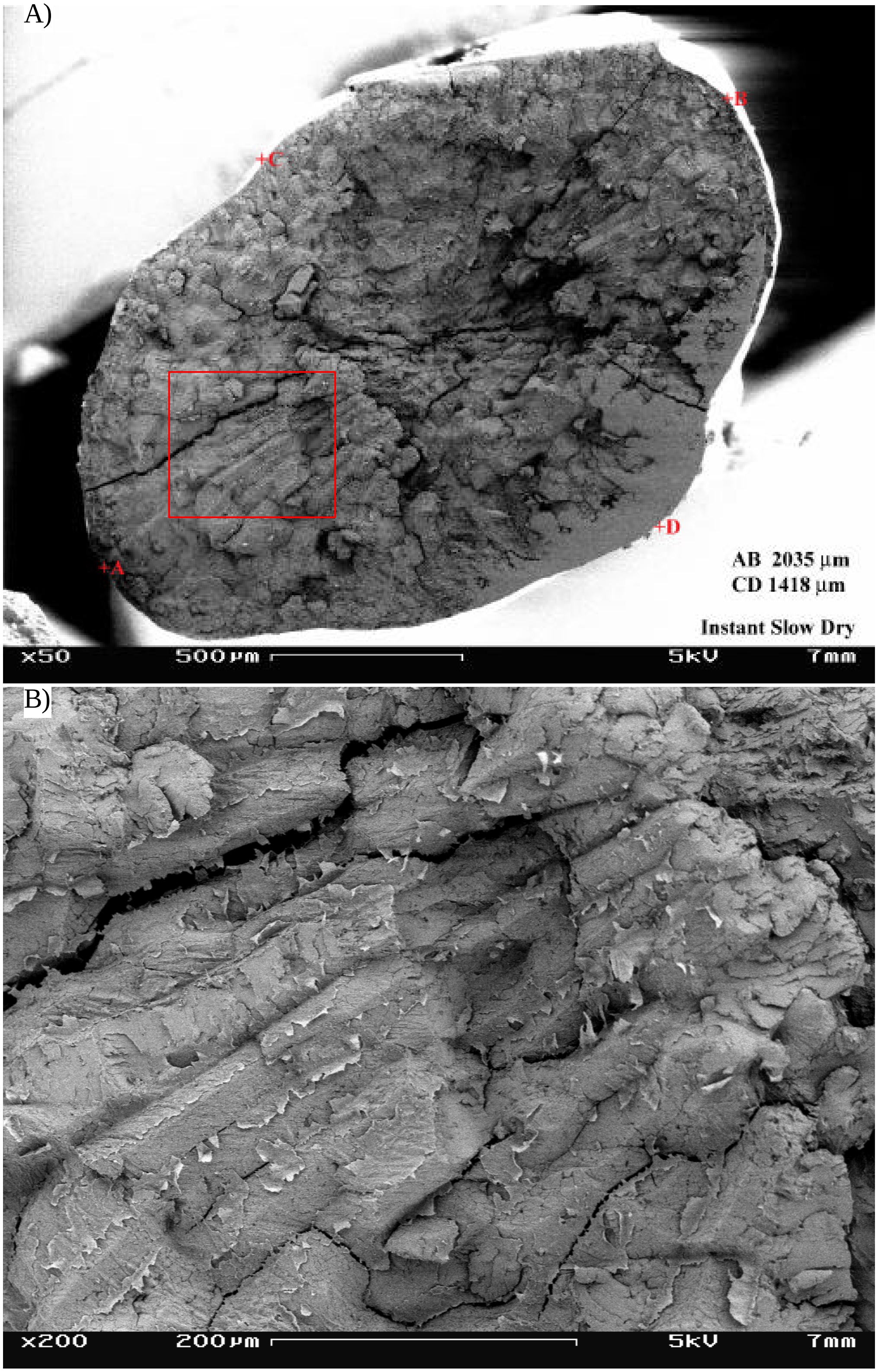

A)
+B
+C
+D
+A
AB 2035 µm
CD 1418 µm
Instant Slow Dry
x50 500µm 5kV 7mm
B)
x200 200µm 5kV 7mm

Figure 6.16: The SEM micrographs of starch granules in waxy rice.

A) Polygonal shape of the granule and cell arrangement near the surface (cross-sectional view) of raw waxy rice. The circle shows a cavity (pore) in the rice grain.

B) Starch granules of instant waxy rice altered by gelatinization; A=larger-expanded granule, B=protein body, C= granules disrupted by gelatinization, D=the cavity (pore) of waxy rice granule.

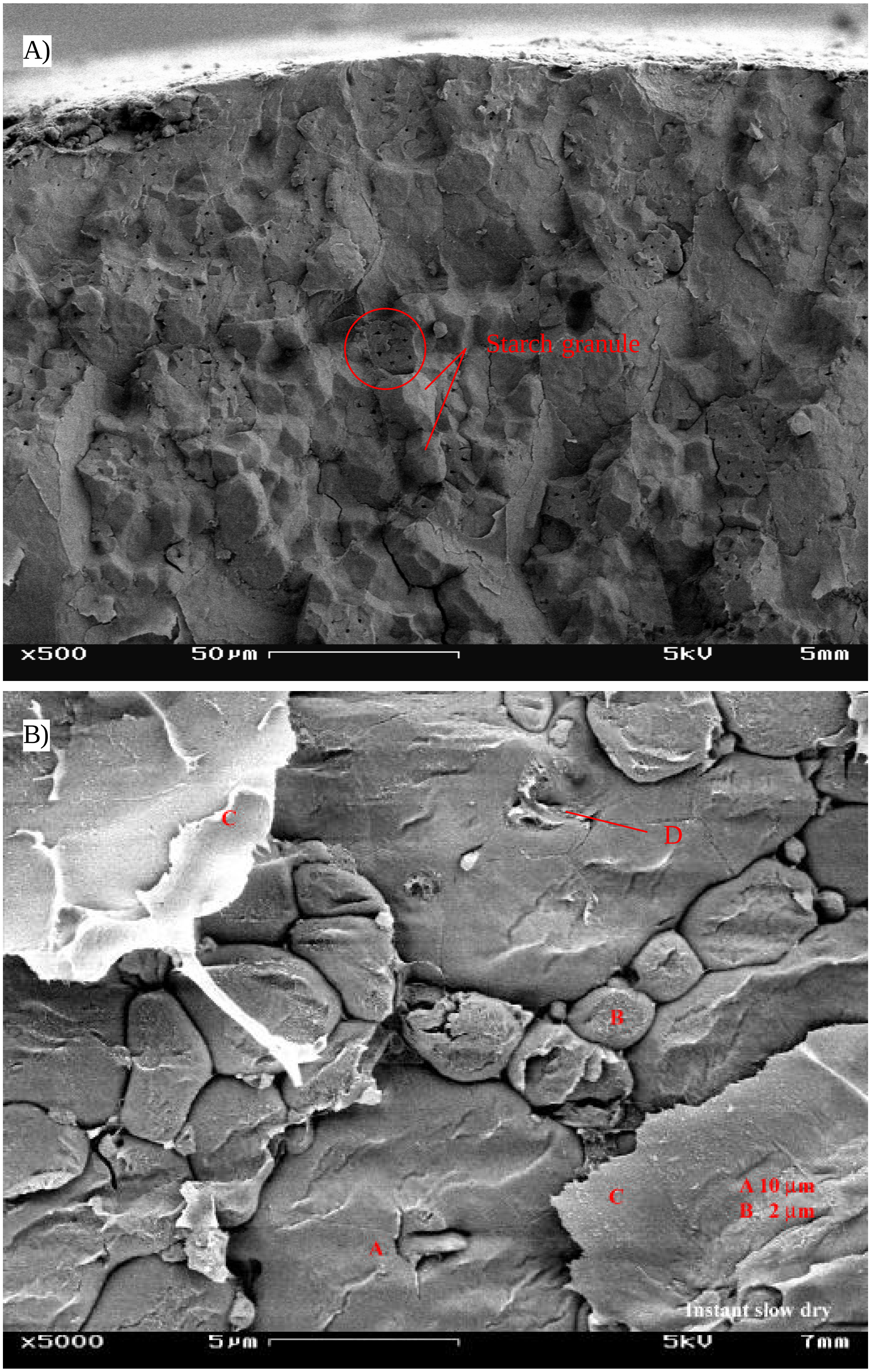

A)
Starch granule
x500
50μm
5kV
5mm
B)
C
D
B
C
A 10 μm
B 2 μm
A
Instant slow dry
x5000
5μm
5kV
7mm

Figure 6.17: Texture profile analysis on cooked waxy rice.

A) A typical TPA profile of cooked waxy rice.

B) Hardness.

C) Stickiness.

D) Cohesiveness.

N0=Instant waxy rice was **not** soaked, was not steamed.

N5=Instant waxy rice was **not** soaked, steamed for 5 min

N10=Instant waxy rice was **not** soaked, steamed for 10 min

N15=Instant waxy rice was **not** soaked, steamed for 15 min

N20=Instant waxy rice was **not** soaked, steamed for 20 min

S0=Instant waxy rice was soaked for 5 min, was not steamed

S5=Instant waxy rice was soaked for 5 min, steamed for 5 min

S10=Instant waxy rice was soaked for 5 min, steamed for 10 min

S15=Instant waxy rice was soaked for 5 min, steamed for 15 min

S20=Instant waxy rice was soaked for 5 min, steamed for 20 min

C0=Raw waxy rice was soaked overnight, was not steamed

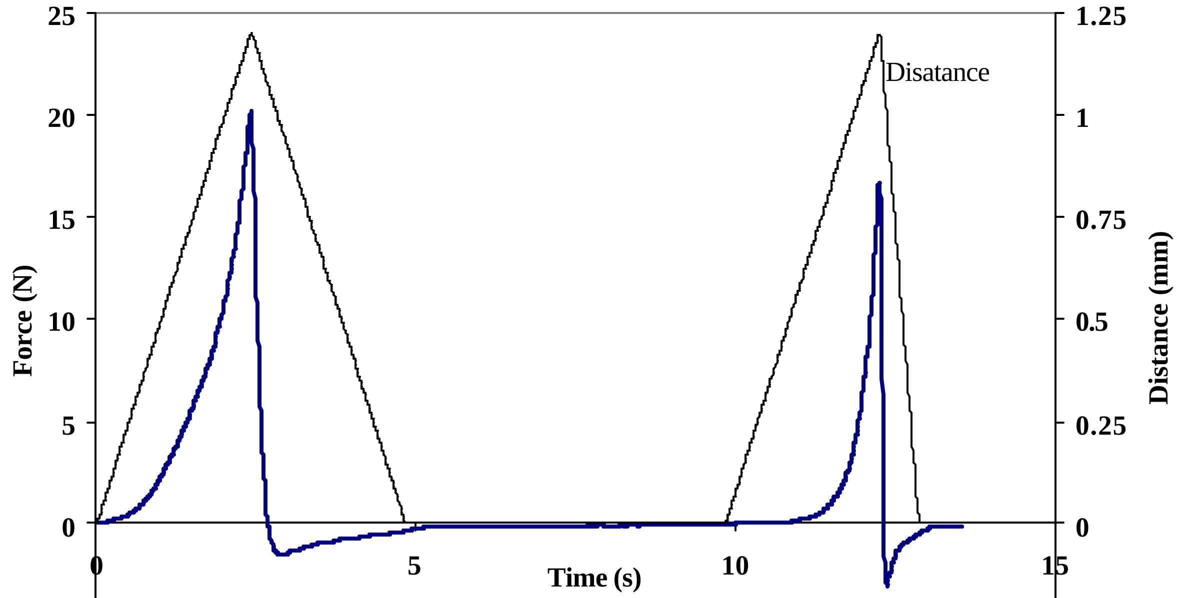
C5= Raw waxy rice was soaked overnight, steamed for 5 min

C10= Raw waxy rice was soaked overnight,, steamed for 10 min

C15= Raw waxy rice was soaked overnight, steamed for 15 min

C20= Raw waxy rice was soaked overnight, steamed for 20 min

A)


A Typical TPA Profile of Cooked Waxy rice
Disatance
Force (N)
Distance (mm)
Time (s)
25
20
15
10
5
0
-5
1.25
1
0.75
0.5
0.25
0
-0.25
0
5
10
15

B)

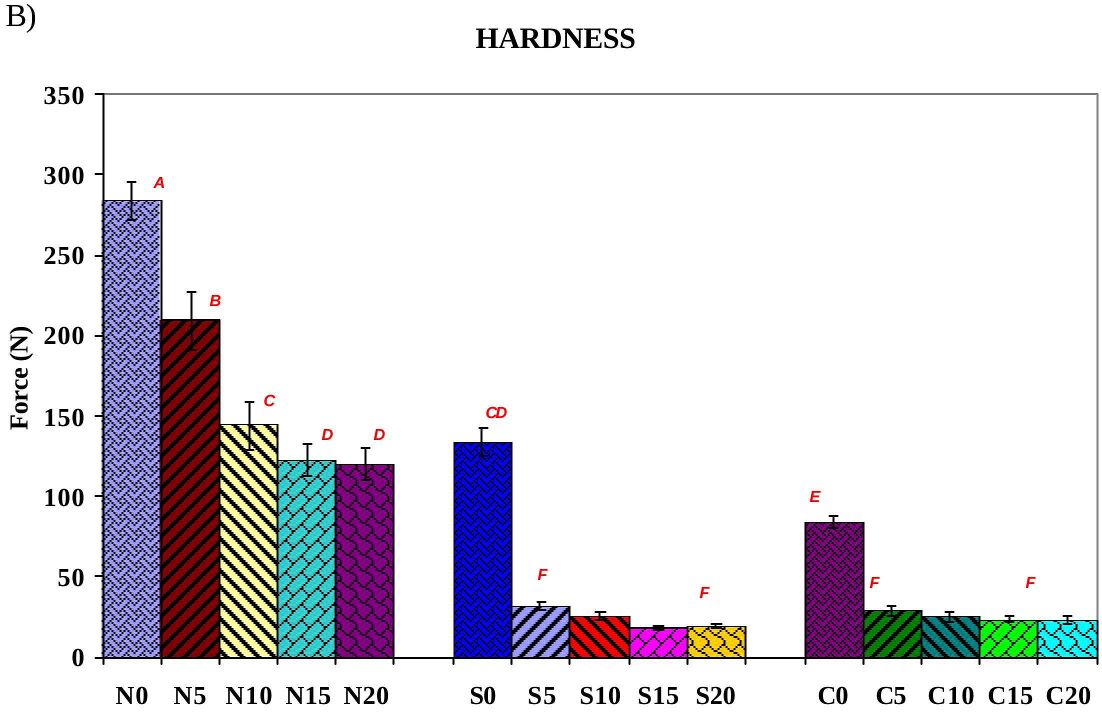

HARDNESS
Force (N)
350
300
250
200
150
100
50
0
A
B
C
D
D
CD
F
F
E
F
F
N0
N5
N10
N15
N20
S0
S5
S10
S15
S20
C0
C5
C10
C15
C20

Figure 6.18: Texture profile analysis on cooked waxy rice.

C) Stickiness.

D) Cohesiveness.

N0=Instant waxy rice was **not** soaked, was not steamed.

N5=Instant waxy rice was **not** soaked, steamed for 5 min

N10=Instant waxy rice was **not** soaked, steamed for 10 min

N15=Instant waxy rice was **not** soaked, steamed for 15 min

N20=Instant waxy rice was **not** soaked, steamed for 20 min

S0=Instant waxy rice was soaked for 5 min, was not steamed

S5=Instant waxy rice was soaked for 5 min, steamed for 5 min

S10=Instant waxy rice was soaked for 5 min, steamed for 10 min

S15=Instant waxy rice was soaked for 5 min, steamed for 15 min

S20=Instant waxy rice was soaked for 5 min, steamed for 20 min

C0=Raw waxy rice was soaked overnight, was not steamed

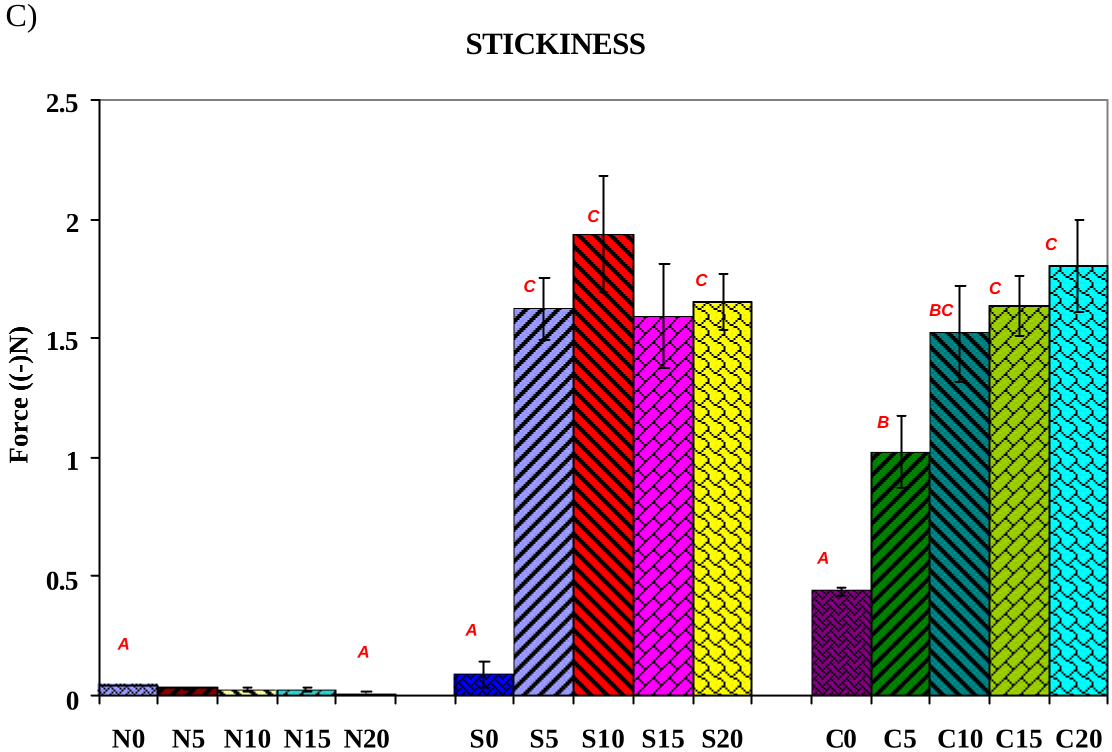
C5= Raw waxy rice was soaked overnight, steamed for 5 min

C10= Raw waxy rice was soaked overnight,, steamed for 10 min

C15= Raw waxy rice was soaked overnight, steamed for 15 min

C20= Raw waxy rice was soaked overnight, steamed for 20 min

C)


STICKINESS
Force ((-)N)
2.5
2
1.5
1
0.5
0
A
A
A
C
C
C
A
B
BC
C
C
N0
N5
N10
N15
N20
S0
S5
S10
S15
S20
C0
C5
C10
C15
C20

D)

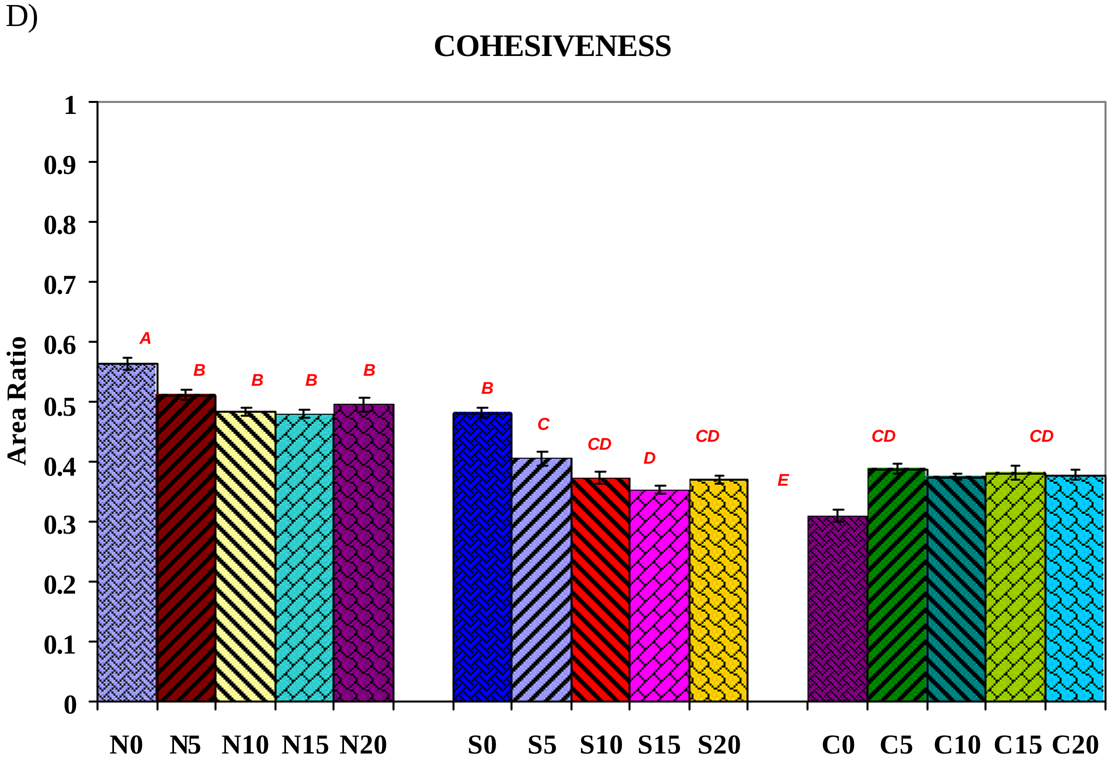

COHESIVENESS
Area Ratio
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
A
B
B
B
B
B
C
CD
D
CD
E
CD
CD
N0
N5
N10
N15
N20
S0
S5
S10
S15
S20
C0
C5
C10
C15
C20

Figure 6.19: Texture profile analysis on cooked waxy rice.

E) Adhesiveness.

F) Gumminess.

N0=Instant waxy rice was **not** soaked, was not steamed.

N5=Instant waxy rice was **not** soaked, steamed for 5 min

N10=Instant waxy rice was **not** soaked, steamed for 10 min

N15=Instant waxy rice was **not** soaked, steamed for 15 min

N20=Instant waxy rice was **not** soaked, steamed for 20 min

S0=Instant waxy rice was soaked for 5 min, was not steamed

S5=Instant waxy rice was soaked for 5 min, steamed for 5 min

S10=Instant waxy rice was soaked for 5 min, steamed for 10 min

S15=Instant waxy rice was soaked for 5 min, steamed for 15 min

S20=Instant waxy rice was soaked for 5 min, steamed for 20 min

C0=Raw waxy rice was soaked overnight, was not steamed

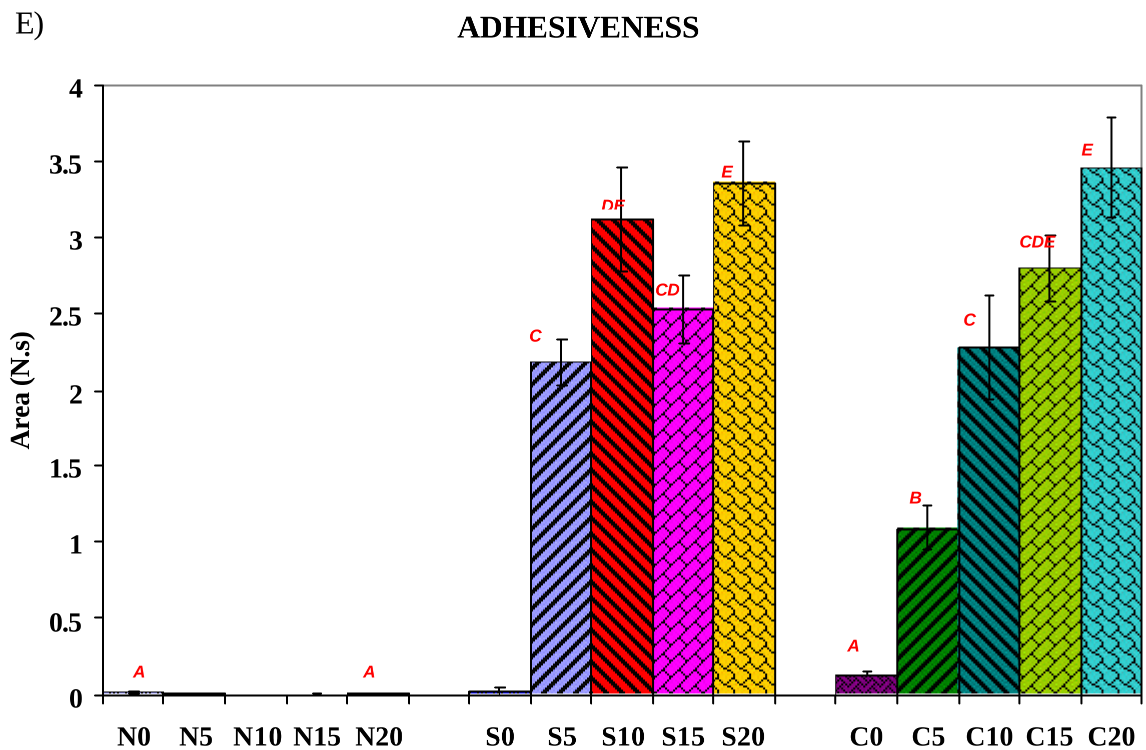
C5= Raw waxy rice was soaked overnight, steamed for 5 min

C10= Raw waxy rice was soaked overnight,, steamed for 10 min

C15= Raw waxy rice was soaked overnight, steamed for 15 min

C20= Raw waxy rice was soaked overnight, steamed for 20 min

E)


ADHESIVENESS
Area (N.s)
0
0.5
1
1.5
2
2.5
3
3.5
4
A
A
C
DE
CD
E
A
B
C
CDE
E
N0
N5
N10
N15
N20
S0
S5
S10
S15
S20
C0
C5
C10
C15
C20

F)

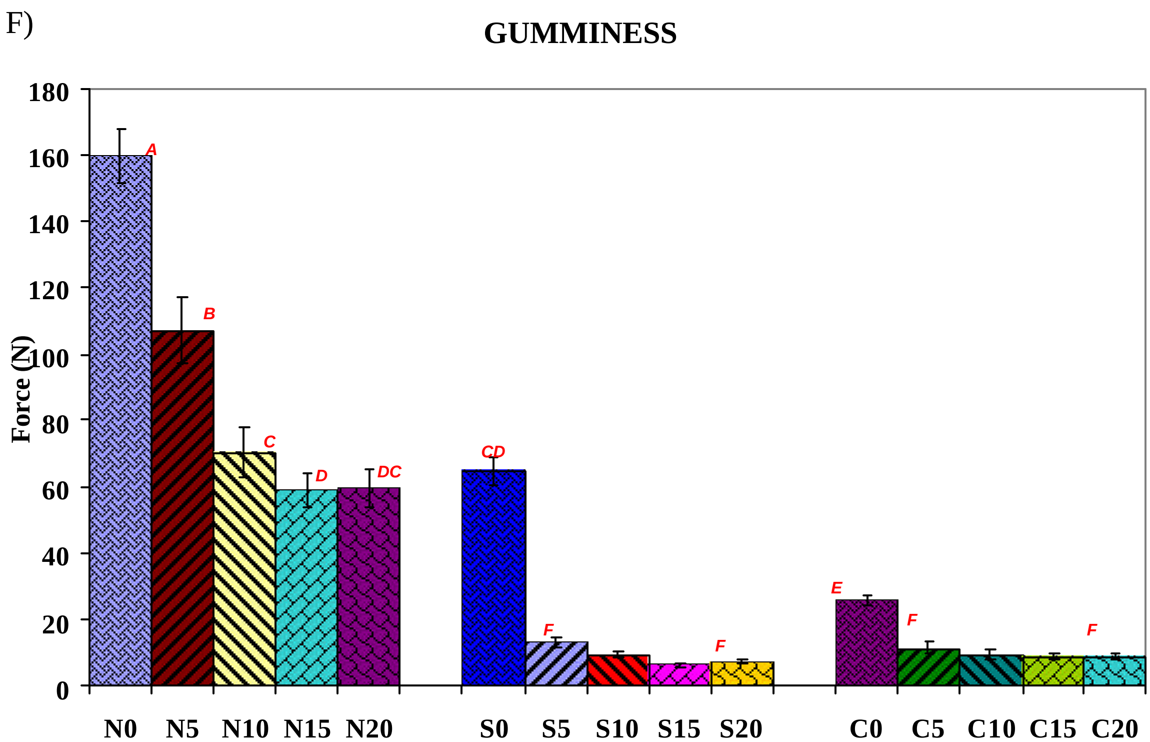

GUMMINESS
Force (N)
0
20
40
60
80
100
120
140
160
180
A
B
C
D
DC
CD
F
F
E
F
F
N0
N5
N10
N15
N20
S0
S5
S10
S15
S20
C0
C5
C10
C15
C20

Figure 6.20: Texture profile analysis on cooked waxy rice.

G) Springiness.

H) Chewiness.

N0=Instant waxy rice was **not** soaked, was not steamed.

N5=Instant waxy rice was **not** soaked, steamed for 5 min

N10=Instant waxy rice was **not** soaked, steamed for 10 min

N15=Instant waxy rice was **not** soaked, steamed for 15 min

N20=Instant waxy rice was **not** soaked, steamed for 20 min

S0=Instant waxy rice was soaked for 5 min, was not steamed

S5=Instant waxy rice was soaked for 5 min, steamed for 5 min

S10=Instant waxy rice was soaked for 5 min, steamed for 10 min

S15=Instant waxy rice was soaked for 5 min, steamed for 15 min

S20=Instant waxy rice was soaked for 5 min, steamed for 20 min

C0=Raw waxy rice was soaked overnight, was not steamed

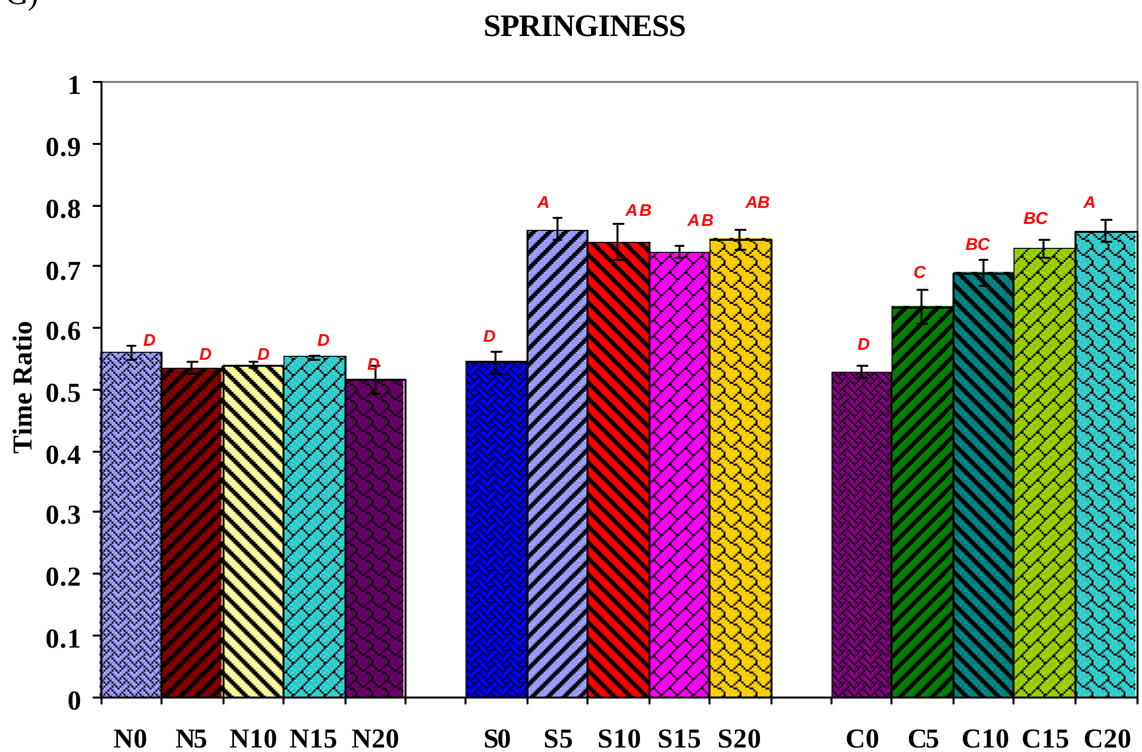
C5= Raw waxy rice was soaked overnight, steamed for 5 min

C10= Raw waxy rice was soaked overnight,, steamed for 10 min

C15= Raw waxy rice was soaked overnight, steamed for 15 min

C20= Raw waxy rice was soaked overnight, steamed for 20 min

G)


SPRINGINESS
Time Ratio
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
N0 N5 N10 N15 N20
S0 S5 S10 S15 S20
C0 C5 C10 C15 C20
D D D D D
D A AB AB AB
D C BC BC A

H)

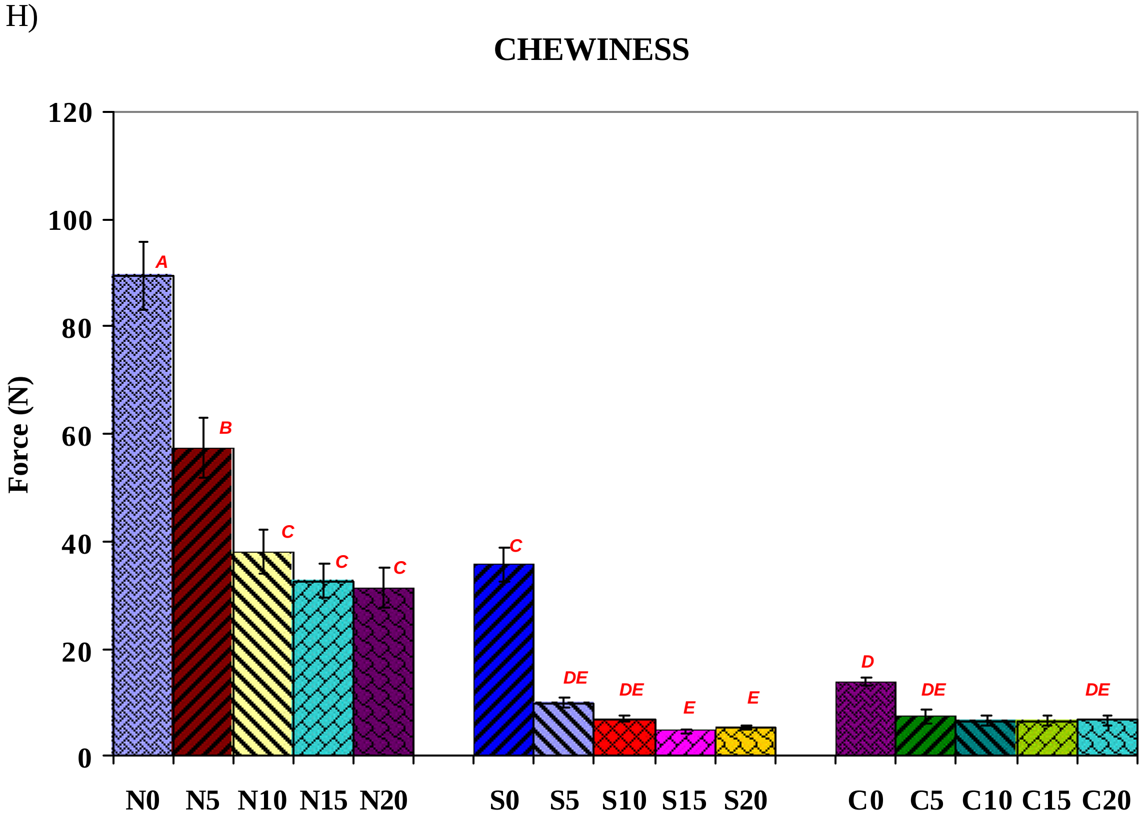
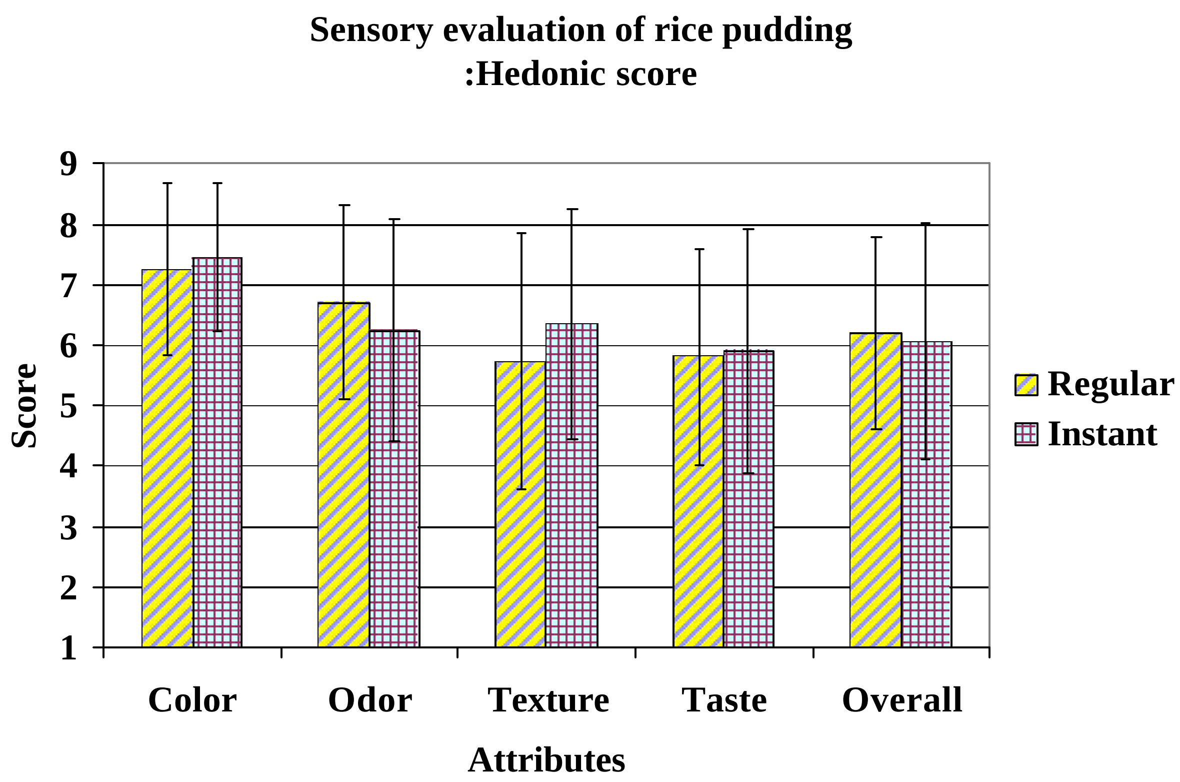

CHEWINESS
Force (N)
120
100
80
60
40
20
0
N0 N5 N10 N15 N20
S0 S5 S10 S15 S20
C0 C5 C10 C15 C20
A B C C C
C DE DE E E
D DE DE

Figure 6.21: Hedonic scores of rice puddings prepared from conventional steamed-cooked waxy rice and rice pudding prepared from instant waxy rice.

`



Sensory evaluation of rice pudding
:Hedonic score
9
8
7
6
5
4
3
2
1
Score
Regular
Instant
Color
Odor
Texture
Taste
Overall
Attributes

Figure 6.22: The flow chart of the instant rice process

Mill rice

–

Soaked in water (45 min @ 60 °C or overnight)

–

Steaming for 20 min

–

Drying at 1-4 °C for 48-72 hr

(MC = 30±2 % db)

–

Crushing to separate individual grains

–

Screening to separate the remaining clumps

– ® **Clumps**

Fluidized drying at room temperature for 48-72 hr

Or 40°C in vacuum oven for 12-24 hr

(Target aw = 0.6-0.7)

–

Packed

CHAPTER 7

CONCLUSIONS

The essential properties of waxy rice that could play a role in the process development for making instant waxy rice were studied. These properties were measured and trends between material characteristics and processing conditions were later used as a basis for designing the optimal process. The observations led to the following conclusions:

1 The moisture absorption rate of raw rice soaked in the water increased with increasing soak water temperature up to 60°C. The relation of moisture diffusivity coefficient and temperature fitted the Arrhenius model (R^2=0.91) from 1- 60°C. For the practical process, raw waxy rice will require at least 45 min soaking at 60°C to obtain the optimum moisture content (56% db) needed in the conventional cooking process by steaming. Soaking for at least 3 hr is required when the rice was soaked at room temperature (24°C).

2 Very little moisture absorption occurs during steam cooking of soaked rice (approximately 10% increase in moisture content, db). The desirable properties of steamed waxy rice depends on the initial moisture content just before steaming.

3 From the DSC curve of whole grain samples, the starch gelatinization temperature range was approximately 58-67°C and the peak temperature was 69-72°C. The gelatinization transition was still exhibited by rice was cooked 3 hr. Energy absorbed by the starch gelatinization transition was lowest in samples with the

highest moisture content and highest when samples had the least moisture content. The transition energy exponentially decreased with soaking time (R^2=0.73).

4 Instant rice was produced by drying steam-cooked waxy rice. A fast drying process resulted in fissures and hollow cavities in the dried grain. These imperfections in the grain can be observed under the scanning electron microscope, Surface manifestations of the fissures are visible under a light microscope. These hollow cavities were minimized when cooked rice was dried at a slow rate. To obtain desirable-dense grains cooked rice was slowly dried at low temperature. When viewed under the scanning electron microscope the slow-dried dense instant waxy rice grain contained more loosely packed cells compared to the fast-dried grains containing hollow cavities. The nearly perfect shape of starch granules could be observed in the instant rice grains.

5 The instant waxy rice could be produced by a process that can be summarized as: "Soak-Steam-Chill-Separate-and Dry" method. The desirable instant rice was dense and translucent without internal hollow voids.

6 The produced instant rice exhibited desirable texture (TPA) characteristics comparable to those of conventionally produced waxy rice, when it was reconstituted by soaking for 5 min and then steamed for 5 min. This compares with at least 12 hr soaking and 20 min steaming for conventional waxy rice.

7 Flavored reconstituted instant waxy rice could be prepared from a packaged dry product within 5 min. Sensory attributes of the reconstituted product was not significantly different from a similarly flavored conventional waxy rice. The

average scores were higher than medium (5), which indicated a positive acceptance of the product.

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APPENDICES

APPENDIX A

TA-XT2® MACRO PROGRAMMING FOR TPA

The macro was programmed and tested on TA-XT2® software version 2.61. Notice that the springiness could be calculated from more than 1 methods. The data printouts, however, provide the force, distance, and time, that can be manipulated. Remark, the unit of the area(N.mm) from assigned macro's variable might not display correctly (N.m). This is the bug from the software. I already reported to Stablemicro Systems Company and it has not been fixed at the time being.

```
Stable Micro Systems - Texture Expert Exceed Macro
** Macro Comment ** Programmed by Aswin Amornsin 02/01/2003
** Macro Comment ** Springiness could be calculated from:
** Macro Comment ** (1) Time ratio from 2 full peaks (aswin)
** Macro Comment ** (2)Distance ratio from 2 half peaks
** Macro Comment ** (3) Distance from 2nd half peaks
Clear Graph Results
Redraw
Change Y Axis Type Force
Change Units... Force N
Change X Axis Type Time
** Macro Comment ** delete 2 lines below for unit area N.s
Change X Axis Type Distance
Change Units... Distance mm
Go to Min. Time
Drop Anchor
Search Forwards
** Macro Comment ** change threshold if peak not max.
Set Threshold...Force 5 N
```

Go to Peak +ve Value Force

Mark Value... Force Hardness Record Value.

Mark Value... Distance S4 Record Value.

Mark Value... Time Record Value.

Search Forwards

Go to..Force 0 N

Drop Anchor

Mark Value... Distance S1 Record Value.

Mark Value... Time T1 Record Value.

Area A1 Record Value.

Set Threshold...Force 10 g

Go to Peak -ve Value Force

Mark Value... Force Stickiness Record Value.

Mark Value... Distance Record Value.

Mark Value... Time Record Value.

Go to..Distance 0 mm

Drop Anchor

Area Adhesive Record Value.

Set Threshold...Force 3 N

Go to Peak +ve Value Force

Mark Value... Force Record Value.

Mark Value... Distance S5 Record Value.

Mark Value... Time Record Value.

Search Backwards

Go to..Force 0 g

Drop Anchor

Mark Value... Distance S2 Record Value.

Mark Value... Time T2 Record Value.

Search Forwards

Go to..Force 0 g

Drop Anchor

Mark Value... Distance S3 Record Value.

Mark Value... Time T3 Record Value.

Area A2 Record Value.

Cohesive = A2 / A1

Gummy = Hardness * Cohesive

ta2 = T3 - T2

Spring1 = ta2 / T1

Tsp2 = S5 - S2

Spring2 = Tsp2 / S4

Spring(Distance) = S5 - S2

Chewy1 = Gummy * Spring1

Chewy2= Gummy * Spring2

Chewy(distance) = Gummy * Spring(Distance)

Change X Axis Type Time

Store Variable Hardness

Store Variable Stickiness

Store Variable Cohesive

Store Variable Adhesive

Store Variable Gummy

Store Variable Spring1 As Spring(TimeFullPeaks)

Store Variable Spring2 As Spring(DistanceHalfPeaks)

Store Variable Spring(Distance) As Spring(Distance2ndPeak)

Store Variable Chewy1 As Chewy(TimeFullPeaks)

Store Variable Chewy2 As Chewy(DistanceHalfPeaks)

Store Variable Chewy(distance) As Chewy(Distance2ndPeak)

APPENDIX B

MATLAB® PROGRAMMING FOR MOISTURE DIFFUSIVITY

Matlab® student version 5.3 was used to calculate and simulate the moisture diffusivity in soaked rice. The simulation composed of series of dependent macroes and functions that tied together in oder to work propery. The entrance of the program was "Soakeddat.m".

1. MathLab source code for file Soakeddat.m

```
%soakdat.m
%macro
d24=[0 10 20 30 45 60 120 180;12.60449155 25.01943 29.73592 31.91769 33.33236 34.45618 34.64572 35.54966 ]';
d40=[0 10 20 30 45 60 120 180 240;12.84909759 28.62113 32.10023 33.60999 34.68784 35.26979 34.98324 34.85155 34.9387143]';
d50=[0 10 20 30 45 60 120 180 ;13.29477513 29.50773 33.10708 34.60418 35.36145 35.62593 35.87795 35.84414 ]';
d60=[0 10 20 30 45 60 120 180 240;13.01069091 32.10389 34.79979 35.98829 37.39805 37.57602 38.64046 40.45937
41.02608304]';
d70=[0 10 20 30 45 60 120 180 ;13.03263013 37.19266 42.802 46.30862 51.38128 59.29518 77.75638 82.32124 ]';
rad=0.5*1.65e-3
len=6.695e-3
s24=asw_lsq(d24,rad,len,1e-10,2e-8,'bo','b')
s40=asw_lsq(d40,rad,len,1e-10,2e-8,'rs','r')
s50=asw_lsq(d50,rad,len,1e-10,2e-8,'m*','m')
s60=asw_lsq(d60,rad,len,1e-10,2e-8,'gd','g')
s70=asw_lsq(d70,rad,len,1e-10,2e-8,'k+','k')
R=[s24;s40;s50;s60;s70]
figure(3)
plot([24 40 50 60 70],R(:,1),'r')
```

2. MathLab source code for file asw_lsq.m

```
function w=asw_lsq(data_tc,rad,len,lb,ub,color,color2)
%w=asw_lsq(data_tc,radius,lenght,lowerbound,upperbound)

[t E]=mr(data_tc);
L=length(t);
j=1;
i=lb;
h=(ub-lb)/100;
dim=size(lb:h:ub);
row=dim(2)-1;
Res=zeros(1,row);
D=zeros(1,row);
T=zeros(1,row);

while i<=ub
   ep=fickcylf(rad,len,t(1:L),i,20);
   er=E-ep;
   er2=er.^2;
   ser2=sum(er2);
   Res(j)=ser2;
   D(j)=i;
   %disp(D(j));
   i=i+h;
   j=j+1;
end
R=[D' Res'];
[y index]=min(R(:,2));
x=R(index,1);
ex=fickcylf(rad,len,t(1:L),x,20);
corr=CORRCOEF(E,ex');
info1=strcat('Diffusivity = ',NUM2STR(x),' m2/s');
info2=strcat('Residual    = ',NUM2STR(y));
info3=strcat('Correlation = ',NUM2STR(corr(2)));
```

```
figure(1);
hold on;
plot(D',Res');
TITLE('Least square profile');
XLABEL('Moisture diffusivity');
YLABEL('Sum square Error');
hold off;

hold on;
figure(2);
plot(t,E, color,t,ex',color2);
TITLE('Moisture ratio from experiment and simulation');
XLABEL('time (min.)');
YLABEL('Moisture ratio');
text(100,1,info1);
text(100,0.9,info2);
text(100,0.8,info3);
hold off;
disp('Diffusivity residual correlation');
w=[x y corr(2)];
```

3. MathLab source code for file fickcylf.m

```
function ep=fickcylf(a1,a2,t,D,L)
%L=lenght(t);
R=bz(L);%call bessell zeros function
ep=0;
for n=1:L
  for m=1:L
    ep=ep+1/(2*m-1)^2*1/R(n)^2*exp(-(2*m-1)^2*(D*t)/a2^2*(pi/2)^2-R(n)^2*(D*t)/a1^2);

  end
 % disp(R(n));
end
  ep=32/pi^2*ep;
```

```
%ep=ep;
```

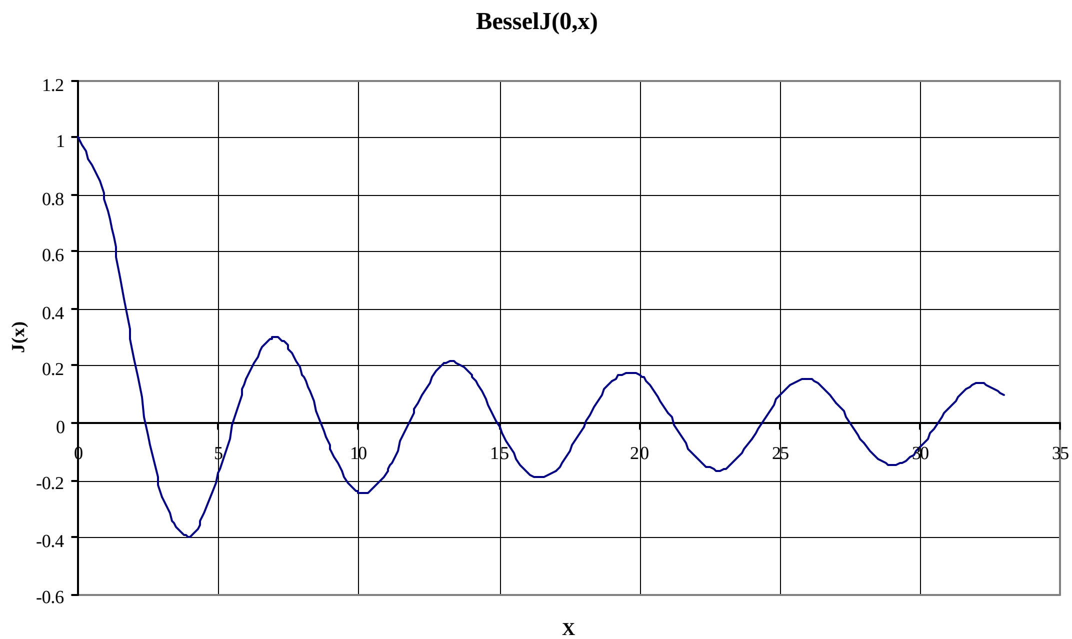
4. MathLab source code for file mr.m

```
function [t,E]=mr(data_tc)
%returm [time Moisture_ratio]
L=length(data_tc);
c0=data_tc(1,2);
ci=data_tc(L,2); % c at inf
t=data_tc(:,1);
E=(data_tc(:,2)-ci)/(c0-ci);
```

5. MathLab source code for file bz.m

```
function B=bc(t)
%retetum zeroes of Bessel function
%max term=40
z10=[2.4048 5.5201 8.6537 11.792 14.931 18.071 21.212 24.352 27.493 30.635];
z20=[33.776 36.917 40.058 43.199 46.341 49.482 52.624 55.766 58.907 62.048];
z30=[65.190 68.3315 71.473 74.615 77.756 80.8976 84.039 87.1807 90.3221 93.4637];
z40=[96.6052 99.7469 102.8883 106.03 109.1716 112.3131 115.4545 118.5962 121.7377 124.8794];

zt=[z10 z20 z30 z40];
B(1,:)=zt(1,1:t);
```



BesselJ's function for finding zeroes series.

APPENDIX C

UNITED STATE STANDARDS FOR RICE

United States Standards for Rough Rice

Effective September 11, 1995

Note: Compliance with the provisions of these standards does not excuse failure to comply with the provisions of the Federal Food, Drug, and Cosmetic Act, or other Federal laws. Source: 42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, unless otherwise noted.

Terms Defined

868.201 Definition of rough rice.

Rice (*Oryza sativa* L.) which consists of 50 percent or more of paddy kernels (see 868.202(i)) of rice.

868.202 Definition of other terms.

For the purposes of these standards, the following terms shall have the meanings stated below:

(a) **Broken kernels.** Kernels of rice which are less than three-fourths of whole kernels.

(b) **Chalky kernels.** Whole or large broken kernels of rice which are one-half or more chalky.

(c) **Classes.** The following four classes:

Long Grain Rough Rice
Medium Grain Rough Rice
Short Grain Rough Rice
Mixed Rough Rice

Classes shall be based on the percentage of whole kernels, large broken kernels, and types of rice.

(1) "Long grain rough rice" shall consist of rough rice which contains more than 25 percent of whole kernels and which after milling to a well-milled degree, contains not more than 10 percent of whole or broken kernels of medium or short grain rice.

(2) "Medium grain rough rice" shall consist of rough rice which contains more than 25 percent of whole kernels and which after milling to a well-milled degree, contains not more than 10 percent of whole or large broken kernels of long grain rice or whole kernels of short grain rice.

(3) "Short grain rough rice" shall consist of rough rice which contains more than 25 percent of whole kernels and which, after milling to a well-milled degree, contains not

more than 10 percent of whole or large broken kernels of long grain rice or whole kernels of medium grain rice.

(4) "Mixed rough rice" shall consist of rough rice which contains more than 25 percent of whole kernels and which, after milling to a well-milled degree, contains more than 10 percent of "other types" as defined in paragraph (h) of this section.

(d) **Damaged kernels.** Whole or broken kernels of rice which are distinctly discolored or damaged by water, insects, heat, or any other means, and whole or large broken kernels of parboiled rice in non-parboiled rice. "Heat-damaged kernels" (see paragraph (e) of this section) shall not function as damaged kernels.

(e) **Heat-damaged kernels.** Whole or large broken kernels of rice which are materially discolored and damaged as a result of heating, and whole or large broken kernels of parboiled rice in nonparboiled rice which are as dark as, or darker in color than, the interpretive line for heat-damaged kernels.

(f) **Milling yield.** An estimate of the quantity of whole kernels and total milled rice (whole and broken kernels combined) that are produced in the milling of rough rice to a well-milled degree.

(g) **Objectionable seeds.** Seeds other than rice, except seeds of Echinochloa crusgalli (commonly known as barnyard grass, watergrass, and Japanese millet).

(h) **Other types.** (1) Whole kernels of: (i) Long grain rice in medium or short grain rice, (ii) medium grain rice in long or short grain rice, (iii) short grain rice in long or medium grain rice, and (2) Large broken kernels of long grain rice in medium or short grain rice and large broken kernels of medium or short grain rice in long grain rice.

Note: Broken kernels of medium grain rice in short grain rice and large broken kernels of short grain rice in medium grain rice shall not be considered other types.

(i) **Paddy kernels.** Whole or broken unhulled kernels of rice.

(j) **Red rice.** Whole or large broken kernels of rice on which there is an appreciable amount of red bran.

(k) **Seeds.** Whole or broken seeds of any plant other than rice.

(l) **Smutty kernels.** Whole or broken kernels of rice which are distinctly infected by smut.

(m) **Types of rice.** The following three types:
Long grain
Medium grain
Short grain

Types shall be based on the length 09 width ratio of kernels of rice that are unbroken and the width, thickness, and shape of kernels of rice that are broken as prescribed in FGIS instructions.

(n) **Ungelatinized kernels.** Whole or large broken kernels of parboiled rice with distinct white or chalky areas due to incomplete gelatinization of the starch.

(o) **Whole and large broken kernels.** Rice (including seeds) that (1) passes over a 6 plate (for southern production), or (2) remains on top of a 6 sieve (for western production).

(p) **Whole kernels.** Unbroken kernels of rice and broken kernels of rice which are at least three-fourths of an unbroken kernel.

(q) **6 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.0938 (6/64) inch in diameter.

(r) **6 plate.** A laminated metal plate 0.142-inch thick, with a top lamina 0.051-inch thick, perforated with rows of round holes 0.0938 (6/64) inch in diameter, and a bottom lamina 0.091-inch thick, without perforations.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989; 54 FR 51344, Dec. 14, 1989]

Principles Governing Application of Standards

868.203 Basis of determination.

The determination of seeds, objectionable seeds, heat-damaged kernels, red rice and damaged kernels, chalky kernels, other types, color, and the special grade Parboiled rough rice shall be on the basis of the whole and large broken kernels of milled rice that are produced in the milling of rough rice to a well-milled degree. When determining class, the percentage of (a) whole kernels of rough rice shall be determined on the basis of the original sample, and (b) types of rice shall be determined on the basis of the whole and large broken kernels of milled rice that are produced in the milling of rough rice to a well-milled degree. Smutty kernels shall be determined on the basis of the rough rice after it has been cleaned and shelled as prescribed in FGIS instructions, or by any method that is approved by the Administrator as giving equivalent results. All other determinations shall be on the basis of the original sample. Mechanical sizing of kernels shall be adjusted by handpicking as prescribed in FGIS instructions, or by any method that is approved by the Administrator as giving equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989]

868.204 Interpretive line samples.

Interpretive line samples showing the official scoring line for factors that are determined by visual examinations shall be maintained by the Federal Grain Inspection Service, U.S. Department of Agriculture, and shall be available for reference in all inspection offices that inspect and grade rice.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982. Redesignated at 54 FR 21403, May 18, 1989]

868.205 Milling requirements.

In determining milling yield (see 868.202(f)) in rough rice, the degree of milling shall be equal to, or better than, that of the interpretive line sample for ``well-milled'' rice.

[42 FR 40869, Aug. 12, 1977. Redesignated at 54 FR 21413, May 18, 1989]

868.206 Milling yield determination.

Milling yield shall be determined by the use of an approved device in accordance with procedures prescribed in FGIS instructions. For the purpose of this paragraph, "approved device" shall include the McGill Miller No. 3 and any other equipment that is approved by the Administrator as giving equivalent results.

Note: Milling yield shall not be determined when the moisture content of the rough rice exceeds 18.0 percent.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; Redesignated and amended at 54 FR 21403, May 18, 1989]

868.207 Moisture.

Water content in rough rice as determined by an approved device in accordance with procedures prescribed in the FGIS instructions. For the purpose of this paragraph, "approved device" shall include the Motomco Moisture Meter and any other equipment that is approved by the Administrator as giving equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982. Redesignated at 54 FR 21403, May 18, 1989; 54 FR 51344, Dec. 14, 1989]

868.208 Percentages.

(a) **Rounding.** Percentages are determined on the basis of weight and are rounded as follows:

(1) When the figure to be rounded is followed by a figure greater than or equal to 5, round to the next higher figure; e.g., report 6.36 as 6.4, 0.35 as 0.4, and 2.45 as 2.5.

(2) When the figure to be rounded is followed by a figure less than 5, retain the figure; e.g., report 8.34 as 8.3 and 1.22 as 1.2.

(b) **Recording.** All percentages, except for milling yield, are stated in whole and tenth percent to the nearest tenth percent. Milling yield is stated to the nearest whole percent.

[54 FR 21403, May 18, 1989]

868.209 Information.

Requests for the Rice Inspection Handbook, Equipment Handbook, or for information concerning approved devices and procedures, criteria for approved devices, and requests for approval of devices should be directed to the U.S. Department of Agriculture, GIPSA Federal Grain Inspection Service, P.O. Box 96454, Washington, DC 20090-6454, or any field office or cooperator.

[54 FR 21404, May 18, 1989]

Grades, Grade Requirements, and Grade Designations

868.210 Grades and grade requirements for the classes of Rough Rice. (See also 868.212.)

	Maximum limits of–							
	Seeds and heat-damaged kernels				Chalky kernels[1][2]			
Grade	Total (singly or combined) (number in 500 grams)	Heat-damaged kernels and objectionable seeds (singly or combined) (number in 500 grams)	Heat-damaged kernels (number in 500 grams)	Red rice and damaged kernels (singly or combined) (percent)	In long grain rice (percent)	In medium or short grain rice (percent)	Other types [3] (percent)	Color requirements[1] (minimum)
U.S. No. 1	4	3	1	0.5	1	2	1	Shall be white or creamy
U.S. No. 2	7	5	2	1.5	2	4	2	May be slightly gray.
U.S. No. 3	10	8	5	2.5	4	6	3	May be light gray
U.S. No. 4	27	22	15	4	6	8	5	May be gray or slightly rosy
U.S. No. 5	37	32	25	6	10	10	10	May be dark gray or rosy
U.S. No. 6	75	75	75	15.0[4]	15	15	10	May be dark gray or rosy

U.S. Sample grade shall be rough rice which: (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 6, inclusive; (b) contains more than 14.0 percent of moisture; (c) is musty, or sour, or heating; (d) has any commercially objectionable foreign odor; or (e) is otherwise of distinctly low quality.

---

[1] For the special grade Parboiled rough rice, see 868.212(b).
[2] For the special grade Glutinous rough rice, see 868.212(d).
[3] These limits do not apply to the class Mixed Rough Rice.
[4] Rice in grade U.S. No. 6 shall contain not more than 6.0 percent of damaged kernels.

[56 FR 55978, Oct. 31, 1991]

868.211 Grade designation.

(a) The grade designation for all classes of rough rice, except Mixed Rough Rice, shall include in the following order: (1) The letters "U.S." (2) the number of the grade or the words "Sample grade", as warranted; (3) the words "or better"' when applicable and requested by the applicant prior to inspection; (4) the class; (5) each applicable special grade (see 868.213); and (6) a statement of the milling yield.

(b) The grade designation for the class Mixed Rough Rice shall include, in the following order: (1) The letters "U.S."; (2) the number of the grade or the words "Sample grade," as warranted; (3) the words "or better," when applicable and requested by the applicant prior to inspection; (4) the class; (5) each applicable special grade (see 868.213); (6) the percentage of whole kernels of each type in the order of predominance; (7) the percentage of large broken kernels of each type in the order of predominance; (8) the percent of material removed by the No. 6 sieve or the No. 6 sizing plate; (9) when applicable, the percentage of seeds; and (10) a statement of the milling yield.

Note: Large broken kernels other than long grain, in Mixed Rough Rice, shall be certificated as "medium or short grain."

[42 FR 40869, Aug. 12, 1977, as amended at 54 FR 51344, Dec. 14, 1989]

Special Grades, Grade Requirements, and Grade Designations

868.212 Special grades and requirements.

A special grade, when applicable, is supplemental to the grade assigned under 868.210. Such special grades for rough rice are established and determined as follows:

(a) **Infested rough rice.** Tolerances for live insects for infested rough rice are defined according to sampling designations as follows:

(1) Representative sample. The representative sample consists of the work portion, and the file sample if needed and when available. The rough rice (except when examined according to paragraph (a)(3) of this section will be considered infested if the representative sample contains two or more live weevils, or one live weevil and one or more other live insects injurious to stored rice or five or more other live insects injurious to stored rice.

(2) Lot as a whole (stationary). The lot as a whole is considered infested when two or more live weevils, or one live weevil and one or more other live insects injurious to stored rice, or five or more other live insects injurious to stored rice, or 15 or more live Angoumois moths or other live moths injurious to stored rice are found in, on, or about the lot.

(3) Sample as a whole during continuous loading/unloading. The minimum sample size for rice being sampled during continuous loading/unloading is 500 grams per each 100,000 pounds of rice. The sample as a whole is considered infested when a component (as defined in FGIS instructions) contains two or more live weevils, or one live weevil and one or more other live insects injurious to stored rice, or five or more other live insects injurious to stored rice.

(b) **Parboiled rough rice.** Parboiled rough rice shall be rough rice in which the starch has been gelatinized by soaking, steaming, and drying. Grades U.S. No. 1 to U.S. No. 6 inclusive, shall contain not more than 10.0 percent of ungelatinized kernels. Grades U.S. No. 1 and U.S. No. 2 shall contain not more than 0.1 percent, grades U.S. No. 3 and U.S. No. 4 not more than 0.2 percent, and grades U.S. No. 5 and U.S. No. 6 not more than 0.5 percent of nonparboiled rice. If the rice is: (1) Not distinctly colored by the parboiling process, it shall be considered "Parboiled Light"; (2) distinctly but not materially colored by the parboiling process, it shall be considered "Parboiled"; (3) materially colored by the parboiling process, it shall be considered "Parboiled Dark." The color levels for "Parboiled Light," "Parboiled," and "Parboiled Dark" rice shall be in accordance with the interpretive line samples for parboiled rice.

Note: The maximum limits for "Chalky kernels," "Heat-damaged kernels," "Kernels damaged by heat," and the "Color requirements" shown in 868.210 are not applicable to the special grade "Parboiled rough rice."

(c) **Smutty rough rice.** Smutty rough rice shall be rough rice which contains more than 3.0 percent of smutty kernels.

(d) **Glutinous rough rice.** Glutinous rough rice shall be special varieties of rice (Oryza sativa L. glutinosa) which contain more than 50 percent chalky kernels. Grade U.S. No. 1 shall contain not more than 1.0 percent of nonchalky kernels, grade U.S. No. 2 not more than 2.0 percent of nonchalky kernels, grade U.S. No. 3 not more than 4.0 percent of nonchalky kernels, grade U.S. No. 4 not more than 6.0 percent of nonchalky kernels, grade U.S. No. 5 not more than 10.0 percent of nonchalky kernels, and grade U.S. No. 6 not more than 15.0 percent of nonchalky kernels.

Note: The maximum limits for "Chalky kernels" in 868.210 are not applicable to the special grade "Glutinous rough rice."

(e) **Aromatic rough rice.** Aromatic rough rice shall be special varieties of rice (Oryza sativa L. scented) that have a distinctive and characteristic aroma; e.g., basmati and jasmine rice.

[42 FR 40869, Aug. 12, 1977, as amended at 54 FR 21406, May 18, 1989; 56 FR 55978, Oct. 31, 1991; 58 FR 68016, Dec. 23, 1993]

868.213 Special grade designation.

The grade designation for infested, parboiled, smutty, glutinous, or aromatic rough rice shall include, following the class, the word(s) "Infested," "Parboiled Light," "Parboiled," "Parboiled Dark," "Smutty," "Glutinous," or "Aromatic," as warranted, and all other information prescribed in 868.211.

[58 FR 68016, Dec. 23, 1993]

United States Standards for Brown Rice for Processing

Note to the Subpart: Compliance with the provisions of these standards does not excuse failure to comply with the provisions of the Federal Food, Drug, and Cosmetic Act, or other Federal laws.

Source: 42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, unless otherwise noted.

Terms Defined

868.251 Definition of brown rice for processing.

Rice (Oryza sativa L.) which consists of more than 50.0 percent of kernels of brown rice, and which is intended for processing to milled rice.

868.252 Definition of other terms.

For the purposes of these standards, the following terms shall have the meanings stated below:

(a) **Broken kernels.** Kernels of rice which are less than three-fourths of whole kernels.

(b) **Brown rice.** Whole or broken kernels of rice from which the hulls have been removed.

(c) **Chalky kernels.** Whole or broken kernels of rice which are one-half or more chalky.

(d) **Classes.** There are four classes of brown rice for processing.

Long Grain Brown Rice for Processing.
Medium Grain Brown Rice for Processing.
Short Grain Brown Rice for Processing.
Mixed Brown Rice for Processing.

Classes shall be based on the percentage of whole kernels, broken kernels, and types of rice.

(1) "Long-grain brown rice for processing" shall consist of brown rice for processing which contains more than 25.0 percent of whole kernels of brown rice and not more than 10.0 percent of whole or broken kernels of medium- or short-grain rice.

(2) "Medium-grain brown rice for processing" shall consist of brown rice for processing which contains more than 25.0 percent of whole kernels of brown rice and not more than 10.0 percent of whole or broken kernels of long-grain rice or whole kernels of short-grain rice.

(3) "Short-grain brown rice for processing" shall consist of brown rice for processing which contains more than 25.0 percent of whole kernels of brown rice and not more than 10.0 percent of whole or broken kernels of long-grain rice or whole kernels of medium-grain rice.

(4) "Mixed brown rice for processing" shall be brown rice for processing which contains more than 25.0 percent of whole kernels of brown rice and more than 10.0 percent of ``other types" as defined in paragraph (i) of this section.

(e) **Damaged kernels.** Whole or broken kernels of rice which are distinctly discolored or damaged by water, insects, heat, or any other means (including parboiled kernels in nonparboiled rice and smutty kernels). "Heat-damaged kernels" (see paragraph (f) of this section) shall not function as damaged kernels.

(f) **Heat-damaged kernels.** Whole or broken kernels of rice which are materially discolored and damaged as a result of heating and parboiled kernels in nonparboiled rice which are as dark as, or darker in color than, the interpretive line for heat-damaged kernels.

(g) **Milling yield.** An estimate of the quantity of whole kernels and total milled rice (whole and broken kernels combined) that is produced in the milling of brown rice for processing to a well-milled degree.

(h) **Objectionable seeds.** Whole or broken seeds other than rice, except seeds of Echinochloa crusgalli (commonly known as barnyard grass, watergrass, and Japanese millet).

(I) **Other types.** (1) Whole kernels of: (i) Long grain rice in medium or short grain rice and medium or short grain rice in long grain rice, (ii) medium grain rice in long or short grain rice, (iii) short grain rice in long or medium grain rice, (2) broken kernels of long grain rice in medium or short grain rice and broken kernels of medium or short grain rice in long grain rice.

Note: Broken kernels of medium grain rice in short grain rice and broken kernels of short grain rice in medium grain rice shall not be considered other types.

(j) **Paddy Kernels.** Whole or broken unhulled kernels and whole or broken kernels of rise having a portion or portions of the hull remaining which cover one-half (1/2) or more of the whole or broken kernel.

(k) **Red rice.** Whole or broken kernels of rice on which the bran is distinctly red in color.

(l) **Related material.** All by-products of a paddy kernel, such as the outer glumes, lemma, palea, awn, embryo, and bran layers.

(m) **Seeds.** Whole or broken seeds of any plant other than rice.

(n) **Smutty kernels.** Whole or broken kernels of rice which are distinctly infected by smut.

(o) **Types of rice.** There are three types of brown rice for processing:

Long grain
Medium grain
Short grain

Types shall be based on the length/width ratio of kernels of rice that are unbroken and the width, thickness, and shape of kernels of rice that are broken as prescribed in FGIS instructions.

(p) **Ungelantinized kernels.** Whole or broken kernels of parboiled rice with distinct white or chalky areas due to incomplete gelatization of the starch.

(q) **Unrelated material.** All matter other than rice, related material, and seeds.

(r) **Well-milled kernels.** Whole or broken kernels of rice from which the hulls and practically all of the embryos and the bran layers have been removed.

(s) **Whole kernels.** Unbroken kernels of rice and broken kernels of rice which are at least three-fourths of an unbroken kernel.

(t) **6 plate.** A laminated metal plate 0.142-inch thick, with a top lamina 0.051-inch thick, perforated with rows of round holes 0.0938 (6/64) inch in diameter, and a bottom lamina 0.091-inch thick, without perforations.

(u) **6 1/2 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.1016 (6 1/2 /64) inch in diameter.

[13 FR 9479, Dec. 31, 1948, as amended at 44 FR 73008, Dec. 17, 1979; 47 FR 34516, Aug. 10, 1982; 54 FR 21403, 21406, May 18, 1989; 54 FR 51344, Dec. 14, 1989]

Principles Governing Application of Standards

868.253 Basis of determination.

The determination of kernels damaged by heat, heat-damaged kernels, parboiled kernels in nonparboiled rice, and the special grade Parboiled brown rice for processing shall be on the basis of the brown rice for processing after it has been milled to a well-milled degree. All other determinations shall be on the basis of the original sample. Mechanical sizing of kernels shall be adjusted by handpicking as prescribed in FGIS instructions, or by any method which gives equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, 21406, May 18, 1989]

868.254 Broken kernels determination.

Broken kernels shall be determined by the use of equipment and procedures prescribed in FGIS instructions, 2/ or by any method which gives equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989. Redesignated at 54 FR 21406, May 18, 1989]

868.255 Interpretive line samples.

Interpretive line samples showing the official scoring line for factors that are determined by visual observation shall be maintained by the Federal Grain Inspection Service, U.S. Department of Agriculture, and shall be available for reference in all inspection offices that inspect and grade rice.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989. Redesignated at 54 FR 21406, May 18, 1989]

868.256 Milling requirements.

In determining milling yield (see 868.252(g)) in brown rice for processing, the degree of milling shall be equal to, or better than, that of the interpretive line sample for "well-milled" rice.

[42 FR 40869, Aug. 12, 1977. Redesignated at 21406, May 18, 1989]

868.257 Milling yield determination.

Milling yield shall be determined by the use of an approved device in accordance with procedures prescribed in FGIS instructions. For the purpose of this paragraph, "approved device" shall include the McGill Miller No. 3 and any other equipment that is approved by the Administrator as giving equivalent results.

Note: Milling yield shall not be determined when the moisture content of the brown rice for processing exceeds 18.0 percent.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989. Redesignated at 54 FR 21406, May 18, 1989]

868.258 Moisture.

Water content in brown rice for processing as determined by an approved device in accordance with procedures prescribed in FGIS instructions. For the purpose of this paragraph, "approved device" shall include the Motomco Moisture Meter and any other equipment that is approved by the Administrator as giving equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989. Redesignated at 54 FR 21406, May 18, 1989]

868.259 Percentages.

(a) **Rounding.** Percentages are determined on the basis of weight and are rounded as follows:

(1) When the figure to be rounded is followed by a figure greater than or equal to 5, round to the next higher figure; e.g., report 6.36 as 6.4, 0.35 as 0.4, and 2.45 as 2.5.

(2) When the figure to be rounded is followed by a figure less than 5, retain the figure, e.g., report 8.34 as 8.3 and 1.22 and 1.2.

(b) **Recording** All percentages, except for milling yield, are stated in whole and tenth percent to the nearest whole percent. Milling yield is stated to the nearest whole percent.

[54 FR 21406, May 18, 1989]

868.260 Information.

Requests for the Rice Inspection Handbook, Equipment Handbook, or for information concerning approved devices and procedures, criteria for approved devices, and requests for approval of devices should be directed to the U.S. Department of Agriculture, Federal Grain Inspection Service, P.O. Box 96454, Washington, DC 20090-96454, or any field office or cooperator.

[54 FR 21406, May 18, 1989]

Grades, Grade Requirements, and Grade Designations

868.261 Grade and grade requirements for the classes of brown rice for processing.

(See also 868.263.)

	Maximum limits of–									
	Paddy kernels		Seeds and heat damage kernels							
Grade U.S. No.	Percent	Number in 500 grams	Total (singly or combined) (number in grams)	Heat-damaged kernels (number in 500 grams)	Objectionable seeds (number in 500 grams)	Red rice and damaged kernels (singly or combined) (percent)	Chalky kernels [1], [2] (percent)	Broken kernels removed by a 6 plate or a 6 1/2 seive[3] (percent)	Other types [4]	Well-milled kernels (percent)
1	--	20	10	1	2	1.0	2.0	1.0	1.0	1.0
2	2.0	--	40	2	10	2.0	4.0	2.0	2.0	3.0
3	2.0	--	70	4	20	4.0	6.0	3.0	5.0	10.0
4	2.0	--	100	8	35	8.0	8.0	4.0	10.0	10.0
5	2.0	--	150	15	50	15.0	15.0	6.0	10.0	10.0

U.S. Sample grade shall be brown rice for processing which (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; (b) contains more than 14.5 percent of moisture; (c) is musty, or sour, or heating; (d) has any commercially objectionable foreign odor; (e) contains more than 0.2 percent of related material or more than 0.1 percent of unrelated material; (f) contains two or more live weevils or other live insects; or (g) is otherwise of distinctly low quality.

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[1] For the special grade Parboiled brown rice for processing, see 868.263(a).
[2] For the special grade Glutinous brown rice for processing, see 868.263(c).

[3] Plates should be used for southern production rice and sieves should be used for western production rice, but any device or method which gives equivalent results may be used.
[4] These limits do not apply to the class Mixed Brown Rice for Processing.

[56 FR 55979, Oct. 31, 1991]

868.262 Grade designation.

(a) The grade designation for all classes of brown rice for processing, except Mixed Brown Rice for Processing, shall include in the following order: (1) The letters "U.S."'; (2) the number of the grade or the words "Sample grade," as warranted; (3) the words "or better," when applicable and requested by the applicant prior to inspection; (4) the class; and (5) each applicable special grade (see 868.264).

(b) The grade designation for the class Mixed Brown Rice for Processing shall include in the following order: (1) The letters "U.S."; (2) the number of the grade or the words "Sample grade," as warranted; (3) the words "or better," when applicable and requested by the applicant prior to inspection; (4) the class; (5) each applicable special grade (see 868.264); (6) the percentage of whole kernels of each type in the order of predominance; and when applicable; (7) the percentage of broken kernels of each type in the order of predominance; and (8) the percentage of seeds, related material, and unrelated material.

Note: Broken kernels other than long grain, in Mixed Brown Rice for Processing, shall be certificated as "medium or short grain."

Special Grades, Grade Requirements, and Grade Designations

868.263 Special grades and special grade requirements.

A special grade, when applicable, is supplemental to the grade assigned under 868.262. Such special grades for brown rice for processing are established and determined as follows:

(a) **Parboiled brown rice for processing.** Parboiled brown rice for processing shall be rice in which the starch has been gelatinized by soaking, steaming, and drying. Grades U.S. Nos. 1 to 5, inclusive, shall contain not more than 10.0 percent of ungelatinized kernels. Grades U.S. No. 1 and U.S. No. 2 shall contain not more than 0.1 percent, grades U.S. No. 3 and U.S. No. 4 not more than 0.2 percent, and grade U.S. No. 5 not more than 0.5 percent of nonparboiled rice.

Note: The maximum limits for "Chalky kernels," "Heat-damaged kernels," and "Kernels damaged by heat" shown in 868.261 are not applicable to the special grade "Parboiled brown rice for processing."

(b) **Smutty brown rice for processing.** Smutty brown rice for processing shall be rice which contains more than 3.0 percent of smutty kernels.

(c) **Glutinous brown rice for processing.** Glutinous brown rice for processing shall be special varieties of rice (Oryza sativa L. glutinosa) which contain more than 50 percent chalky kernels. Grade U.S. No. 1 shall contain not more than 1.0 percent of nonchalky kernels, grade U.S. No. 2 not more than 2.0 percent of nonchalky kernels, grade U.S. No. 3 not more than 4.0 percent of nonchalky kernels, grade U.S. No. 4 not more than 6.0 percent of nonchalky kernels, and grade U.S. No. 5 not more than 10.0 percent of nonchalky kernels.

Note: The maximum limits for "Chalky kernels" in 868.261 are not applicable to the special grade "Glutinous brown rice for processing."

(d) **Aromatic brown rice for processing.** Aromatic brown rice for processing shall be special varieties of rice (Oryza sativa L. scented) that have a distinctive and characteristic aroma; e.g., basmati and jasmine rice.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 56 FR 55979, Oct. 31, 1991; 58 FR 68016, Dec. 23, 1993]

868.264 Special grade designation.

The grade designation for parboiled, smutty, glutinous, or aromatic brown rice for processing shall include, following the class, the word(s) "Parboiled," "Smutty," "Glutinous," or "Aromatic," as warranted, and all other information prescribed in 1A68.262.

[58 FR 68016, Dec. 23, 1993]

United States Standards for Milled Rice

Note to the Subpart: Compliance with the provisions of these standards does not excuse failure to comply with the provisions of the Federal Food, Drug, and Cosmetic Act, or other Federal laws.

Source: 42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, unless otherwise noted.

Terms Defined

868.301 Definition of milled rice.

Whole or broken kernels of rice (Oryza sativa L.) from which the hulls and at least the outer bran layers have been removed and which contain not more than 10.0 percent of seeds, paddy kernels, or foreign material, either singly or combined.

[48 FR 24859, June 3, 1983]

868.302 Definition of other terms.

For the purposes of these standards, the following terms shall have the meanings stated below:

(a) **Broken kernels.** Kernels of rice which are less than three-fourths of whole kernels.

(b) **Brown rice.** Whole or broken kernels of rice from which the hulls have been removed.

(c) **Chalky kernels.** Whole or broken kernels of rice which are one-half or more chalky.

(d) **Classes.** There are seven classes of milled rice. The following four classes shall be based on the percentage of whole kernels, and types of rice:

Long Grain Milled Rice
Medium Grain Milled Rice
Short Grain Milled Rice
Mixed Milled Rice

The following three classes shall be based on the percentage of whole kernels and of broken kernels of different size:

Second Head Milled Rice
Screenings Milled Rice
Brewers Milled Rice

(1) "Long grain milled rice" shall consist of milled rice which contains more than 25.0 percent of whole kernels of milled rice and in U.S. Nos. 1 through 4 not more than 10.0 percent of whole or broken kernels of medium or short grain rice. U.S. No. 5 and U.S. No. 6 long grain milled rice shall contain not more than 10.0 percent of whole kernels of medium or short grain milled rice (broken kernels do not apply).

(2) "Medium grain milled rice"' shall consist of milled rice which contains more than 25.0 percent of whole kernels of milled rice and in U.S. Nos. 1 through 4 not more than 10.0 percent of whole or broken kernels of long grain rice or whole kernels of short grain rice. U.S. No. 5 and U.S. No. 6 medium grain milled rice shall contain not more than 10.0 percent of whole kernels of long or short grain milled rice (broken kernels do not apply).

(3) "Short grain milled rice" shall consist of milled rice which contains more than 25.0 percent of whole kernels of milled rice and in U.S. Nos. 1 through 4 not more than 10.0 percent of whole or broken kernels of long grain rice or whole kernels of medium grain rice. U.S. No. 5 and U.S. No. 6 short grain milled rice shall contain not more than 10.0 percent of whole kernels of long or medium grain milled rice (broken kernels do not apply).

(4) "Mixed milled rice" shall consist of milled rice which contains more than 25.0 percent of whole kernels of milled rice and more than 10.0 percent of "other types" as defined in paragraph (i) of this section. U.S. No. 5 and U.S. No. 6 mixed milled rice shall contain more than 10.0 percent of whole kernels of "other type" (broken kernels do not apply).

(5) "Second head milled rice" shall consist of milled rice which, when determined in accordance with 868.303, contains:

(i) Not more than (a) 25.0 percent of whole kernels, (b) 7.0 percent of broken kernels removed by a 6 plate, (c) 0.4 percent of broken kernels removed by a 5 plate, and (d) 0.05 percent of broken kernels passing through a 4 sieve (southern production); or

(ii) Not more than (a) 25.0 percent of whole kernels, (b) 50.0 percent of broken kernels passing through a 6 1/2 sieve, and (c) 10.0 percent of broken kernels passing through a 6 sieve (western production).

(6) "Screenings milled rice" shall consist of milled rice which, when determined in accordance with 868.303, contains:

(i) Not more than (a) 25.0 percent of whole kernels, (b) 10.0 percent of broken kernels removed by a 5 plate, and (c) 0.2 percent of broken kernels passing through a 4 sieve (southern production); or

(ii) Not more than (a) 25.0 percent of whole kernels and (b) 15.0 percent of broken kernels passing through a 5 1/2 sieve; and more than (c) 50.0 percent of broken kernels passing through a 6 1/2 sieve and (d) 10.0 percent of broken kernels passing through a 6 sieve (western production).

(7) "Brewers milled rice" shall consist of milled rice which, when determined in accordance with 868.303, contains not more than 25.0 percent of whole kernels and which does not meet the kernel-size requirements for the class Second Head Milled Rice or Screenings Milled Rice.

(e) **Damaged kernels.** Whole or broken kernels of rice which are distinctly discolored or damaged by water, insects, heat, or any other means, and parboiled kernels in nonparboiled rice. "Heat-damaged kernels" (see paragraph (g) of this section) shall not function as damaged kernels.

(f) **Foreign material.** All matter other than rice and seeds. Hulls, germs, and bran which have separated from the kernels of rice shall be considered foreign material.

(g) **Heat-damaged kernels.** Whole or broken kernels of rice which are materially discolored and damaged as a result of heating and parboiled kernels in nonparboiled rice which are as dark as, or darker in color than, the interpretive line for heat-damaged kernels.

(h) **Objectionable seeds.** Seeds other than rice, except seeds of Echinochloa crusgalli (commonly known as barnyard grass, watergrass, and Japanese millet).

(i) **Other types.** (1) Whole kernels of: (i) Long grain rice in medium or short grain rice, (ii) medium grain rice in long or short grain rice, (iii) Short grain rice in long or medium grain rice, and (2) broken kernels of long grain rice in medium or short grain rice and broken kernels of medium or short grain rice in long grain rice, except in U.S. No. 5 and

U.S. No. 6 milled rice. In U.S. No. 5 and U.S. No. 6 milled rice, only whole kernels will apply.

Note: Broken kernels of medium grain rice in short grain rice and broken kernels of short grain rice in medium grain rice shall not be considered other types.

(j) **Paddy Kernels.** Whole or broken unhulled kernels of rice; whole or broken kernels of brown rice, and whole or broken kernels of milled rice having a portion or portions of the hull remaining which cover one-eighth (1/8) or more of the whole or broken kernel.

(k) **Red rice.** Whole or broken kernels of rice on which there is an appreciable amount of red bran.

(l) **Seeds.** Whole or broken seeds of any plant other than rice.

(m) **Types of rice.** There are three types of milled rice as follows:

Long grain
Medium grain
Short grain

Types shall be based on the length-width ratio of kernels of rice that are unbroken and the width, thickness, and shape of kernels that are broken, prescribed in FGIS instructions.

(n) **Ungelatinized kernels.** Whole or broken kernels of parboiled rice with distinct white or chalky areas due to incomplete gelatinization of the starch.

(o) **Well-milled kernels.** Whole or broken kernels of rice from which the hulls and practically all of the germs and the bran layers have been removed.

Note: This factor is determined on an individual kernel basis and applies to the special grade Undermilled milled rice only.

(p) **Whole kernels.** Unbroken kernels of rice and broken kernels of rice which are at least three-fourths of an unbroken kernel.

(q) **5 plate.** A laminated metal plate 0.14209inch thick, with a top lamina, 0.05109-inch thick, perforated with rows of round holes 0.0781 (5/64) inch in diameter, 5/32 inch from center to center, with each row staggered in relation to the adjacent rows, and a bottom lamina 0.091-inch thick, without perforations.

(r) **6 plate.** A laminated metal plate 0.142-inch thick, with a top lamina 0.051-inch thick, perforated with rows of round holes 0.0938 (6/64) inch in diameter, 5/32 inch from center to center, with each row staggered in relation to the adjacent rows, and a bottom lamina 0.09109inch thick, without perforations.

(s) **2 1/2 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.0391 (2 1/2/64) inch in diameter, 0.075-inch from center to center, with each row staggered in relation to the adjacent rows.

(t) **4 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.0625 (4/64) inch in diameter, 1/8 inch from center to center, with each row staggered in relation to the adjacent rows.

(u) **5 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.0781 (5/64) inch in diameter, 5/32 inch from center to center, with each row staggered in relation to the adjacent rows.

(v) **5 1/2 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.0859 (5 1/2/64) inch in diameter, 9/64 inch from center to center, with each row staggered in relation to the adjacent rows.

(w) **6 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.0938 (6/64) inch in diameter, 5/32 inch from center to center, with each row staggered in relation to the adjacent rows.

(x) **6 1/2 sieve.** A metal sieve 0.032-inch thick, perforated with rows of round holes 0.1016 (6 1/2/64) inch in diameter, 5/32 inch from center to center, with each row staggered in relation to the adjacent rows.

(y) **30 sieve.** A woven wire cloth sieve having 0.0234-inch openings, with a wire diameter of 0.0153 inch, and meeting the specifications of American Society for Testing and Materials Designation E-11-61, prescribed in FGIS instructions.

[13 FR 9479, Dec. 31, 1948, as amended at 44 FR 73008, Dec. 17, 1979; 47 FR 34516, Aug. 10, 1982; 54 FR 21403, 21406, May 18, 1989; 54 FR 51345, Dec. 14, 1989]

Principles Governing Application of Standards

868.303 Basis of determination.

All determinations shall be on the basis of the original sample. Mechanical sizing of kernels shall be adjusted by handpicking, as prescribed in FGIS instructions, or by any method which gives equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, 21406, May 18, 1989]

868.304 Broken kernels determination.

Broken kernels shall be determined by the use of equipment and procedures prescribed in FGIS instructions or by any method which gives equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989. Redesignated at 54 FR 21406, May 18, 1989]

868.305 Interpretive line samples.

Interpretive line samples showing the official scoring line for factors that are determined by visual observation shall be maintained by the Federal Grain Inspection Service, U.S. Department of Agriculture, and shall be available for reference in all inspection offices that inspect and grade rice.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982. Redesignated at 54 FR 21406, May 18, 1989]

868.306 Milling requirements.

The degree of milling for milled rice; i.e., "well milled," "reasonably well milled," and "lightly milled" shall be equal to, or better than, that of the interpretive line samples for such rice.

[42 FR 40869, Aug. 12, 1977. Redesignated at 54 FR 21406, May 18, 1989]

868.307 Moisture.

Water content in milled rice as determined by an approved device in accordance with procedures prescribed in FGIS instructions. For the purpose of this paragraph, "approved device" shall include the Motomco Moisture Meter and any other equipment that is approved by the Administrator as giving equivalent results.

[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 47 FR 34516, Aug. 10, 1982; 54 FR 21403, May 18, 1989. Redesignated at 54 FR 21406, May 18, 1989]

868.308 Percentages.

(a) **Rounding.** Percentages are determined on the basis of weight and are rounded as follows:

(1) When the figure to be rounded is followed by a figure greater than or equal to 5, round to the next higher figure; e.g., report 6.36 as 6.4, 0.35 as 0.4, and 2.45 as 2.5.

(2) When the figure to be rounded is followed by a figure less than 5, retain the figure, e.g., report 8.34 as 8.3 and 1.22 and 1.2.

(b) **Recording.** The percentage of broken kernels removed by a 5 plate in U.S. Nos. 1 and 2 Milled Rice and the percentage of objectionable seeds in U.S. No. 1 Brewers Milled Rice is reported to the nearest hundredth percent. The percentages of all other factors are recorded to the nearest tenth of a percent.

[54 FR 21406, May 18, 1989]

868.309 Information.

Requests for the Rice Inspection Handbook, Equipment Handbook, or for information concerning approved devices and procedures, criteria for approved devices, and requests for approval of devices should be directed to the U.S. Department of Agriculture, Federal Grain Inspection Service, P.O. Box 96454, Washington, DC 20090-96454, or any field office or cooperator.

[54 FR 21407, May 18, 1989]

Grades, Grade Requirements, and Grade Designations

868.310 Grades and grade requirements for the classes Long Grain Milled Rice, Medium Grain Milled Rice, Short Grain Milled Rice, and Mixed Milled Rice. (See also 868.315.)

Grade	Maximum limits of-- Seeds, heat-damaged, and paddy kernels (singly or combined): Total (number in 500 grams)	Seeds, heat-damaged, and paddy kernels (singly or combined): Heat-damaged kernels and objectionable seeds (number in 500 grams)	Red rice and damaged kernels (singly or combined) (%)	Chalky kernels [1][2]: In long grain rice (%)	Chalky kernels [1][2]: In medium or short grain rice (%)	Broken kernels: Total (%)	Broken kernels: Removed by a 5 plate [3] (%)	Broken kernels: Removed by a 6 plate [3] (%)	Broken kernels: Through a 6 sieve [3] (%)	Other types [4]: Whole kernels (%)	Other types [4]: Whole and broken kernels (%)	Color requirements [1]	Minimum milling requirements [5]
1	2	1	0.5	1	2	4	0.04	0.1	0.1	--	1	Shall be white or creamy	Well milled
2	4	2	1.5	2	4	7	0.06	0.2	0.2	--	2	May be slightly gray	Well milled
3	7	5	2.5	4	6	15	0.1	0.8	0.5	--	3	May be light gray	Reason-ably well milled
4	20	15	4	6	8	25	0.4	2	0.7	--	5	May be gray or slightly rosy	Reason-ably well milled
5	30	25	6 [5]	10	10	35	0.7	3	1	10	--	May be dark or rosy	Lightly milled
6	75	75	15 [6]	15	15	50	1	4	2	10	--	May be dark gray or rosy	Lightly milled

U.S. Sample grade shall be milled rice of any of these classes which: (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 6, inclusive; (b) contains more than 15.0 percent of moisture; (c) is musty or sour, or heating; (d) has any commercially objectionable foreign odor; (e) contains more than 0.1 percent of foreign material; (f) contains two or more live or dead weevils or other insects, insect webbing, or insect-refuse; or (g) is *otherwise of distinctly low quality.*

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[1] For the special grade Parboiled milled rice, see 868.315(c).
[2] For the special grade Glutinous milled rice, see 868.315(e).
[3] Plates should be used for southern production rice; and sieves should be used for western production rice, but any device or method which gives equivalent results may be used.
[4] These limits do not apply to the class Mixed Milled Rice.
[5] For the special grade Undermilled milled rice, see 868.315(d).
[6] Grade U.S. No. 6 shall contain not more than 6.0 percent of damaged kernels. *[56 FR 55979, Oct. 31, 1991]*

868.311 Grades and grade requirements for the class Second Head Milled Rice. (See also 868.315)

	Maximum limits of--					
	Seeds, heat-damaged, and paddy kernels (single or combined)					
Grade U.S. No.	Total (number in 500 grams)	Heat-damaged kernels and objectionable seeds (number in 500 grams)	Red rice and damaged kernels (singly or combined) (percent)	Chalky kernels [1][3] (percent)	Color requirements [1]	Minimum milling requirements
1	15	5	1	4	Shall be white or creamy	Well milled
2	20	10	2	6	May be slightly gray	Well milled
3	35	15	3	10	May be light gray	Reasonably well milled
4	50	25	5	15	May be gray or slightly rose	Reasonably well milled
5	75	40	10	20	May be dark gray or rosy	Lightly milled

U.S. Sample grade shall be milled rice of this class which: (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; (b) contains more than 15.0 percent of moisture; (c) is musty or sour, or heating; (d) has any commercially objectionable foreign odor; (e) contains more than 0.1 percent of foreign material; (f) contains two or more live or dead weevils or other insects, insect webbing, or insect refuse; or (g) is otherwise of distinctly low quality.

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[1] For the special grade Parboiled milled rice, see 868.315(c).
[2] For the special grade Undermilled milled rice, see 868.315(d).
[3] For the special grade Glutinous milled rice, see 868.315(e).
[56 FR 55980, Oct. 31, 1991]

868.312 Grades and grade requirements for the class Screenings Milled Rice. (See also 868.315.)

Grade U.S. No.	Maximum limits of– Paddy kernels and seeds Total (singly or combined) (number in 500 grams)	Objectionable seeds (number in 500 grams)	Chalky kernels [1][3] (percent)	Color requirements [1]	Minimum milling requirements [2]
1 [4][5]	30	20	5.0	May be white or creamy	Well milled
2 [4][5]	75	50	8.0	May be slightly gray	Well milled
3 [4][5]	125	90	12.0	May be light gray or slightly gray	Reasonably well milled
4 [4][5]	175	140	20.0	May be gray or rosy	Reasonably well milled
5	250	200	30.0	May be dark gray or very rosy	Lightly milled

U.S. Sample grade shall be milled rice of this class which: (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5, inclusive; (b) contains more than 15.0 percent of moisture; (c) is musty, or sour, or heating; (d) has any commercially objectionable foreign odor; (e) has a badly damaged or extremely red appearance; (f) contains more than 0.1 percent of foreign material; (g) contains two or more live or dead weevils or other insects, insect webbing, or insect refuse; or (h) is otherwise of distinctly low quality.

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[1] For the special grade Parboiled milled rice, see 868.315(c).
[2] For the special grade Undermilled milled rice, see 868.315(d).
[3] For the special grade Glutinous milled rice, see 868.315(e).
[4] Grades U.S. No. 1 to U.S. No. 4, inclusive, shall contain not more than 3.0 percent of heat-damaged kernels, kernels damaged by heat and/or parboiled kernels in nonparboiled rice.
[5] Grades U.S. No. 1 to U.S. No. 4, inclusive, shall contain not more than 1.0 percent of material passing through a 30 sieve.
[56 FR 55981, Oct. 31, 1991]

868.313 Grades and grade requirements for the class Brewers Milled Rice. (See also 868.315.)

Grade U.S. No.	Maximum limits of– Paddy kernels and seeds: Total (singly or combined) (percent)	Maximum limits of– Paddy kernels and seeds: Objectionable seeds (percent)	Color requirements [1]	Minimum milling requirements [2]
1 [3][4]	0.5	0.05	Shall be white or creamy	Well milled
2 [3][4]	1.0	0.1	May be slightly gray	Well milled
3 [3][4]	1.5	0.2	May be light gray or slightly rosy	Reasonably well milled
4 [3][4]	3.0	0.4	May be gray or rosy	Reasonably well milled
5	5.0	1.5	May be dark gray or rosy	Lightly milled

U.S. Sample Grade shall be milled rice of this class which: (a) does not meet the requirements for any of the grades from U.S. No. 1 to U.S. No. 5 inclusive; (b) contains more than 15.0 percent of moisture; (c) is musty, or sour, or heating; (d) has any commercially objectionable foreign odor; (e) has a badly damaged or extremely red appearance; (f) contains more than 0.1 percent of foreign material; (g) contains more than 15.0 percent of broken kernels that will pass through a 2 1/2 sieve; (h) contains two or more live or dead weevils or other insects, insect webbing or insect refuse; or (i) is otherwise of distinctly low quality.

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[1] For the special grade Parboiled milled rice, see 868.315(c).
[2] For the special grade Undermilled milled rice, see 868.315(d).
[3] Grades U.S. No. 1 to U.S. No. 4, inclusive, shall contain not more than 3.0 percent of heat-damaged kernels, kernels damaged by heat and/or parboiled kernels in nonparboiled rice.
[4] Grades U.S. No. 1 to U.S. No. 4, inclusive, shall contain not more than 1.0 percent of material passing through a 30 sieve. This limit does not apply to the special grade Granulated brewers milled rice.
[42 FR 40869, Aug. 12, 1977, as amended at 54 FR 21407, May 18, 1989]

868.314 Grade designations.

(a) The grade designation for all classes of milled rice, except Mixed Milled Rice, shall include in the following order: (1) The letters "U.S."; (2) the number of the grade or the words "Sample grade", as warranted; (3) the words "or better," when applicable and requested by the applicant prior to inspections; (4) the class; and (5) each applicable special grade (see 868.316).

(b) The grade designation for the class Mixed Milled Rice shall include, in the following order: (1) The letters "U.S."; (2) the number of the grade or the words "Sample grade", as warranted; (3) the words "or better," when applicable and requested by the applicant prior to inspection; (4) the class; (5) each applicable special grade (see 868.316); (6) the percentage of whole kernels of each type in the order of predominance and when applicable; (7) the percentage of broken kernels of each type in the order of predominance; and (8) the percentage of seeds and foreign material.

Note: Broken kernels other than long grain, in Mixed Milled Rice, shall be certificated as "medium or short grain.'"

Special Grades, Grade Requirements, and Grade Designations

868.315 Special grades and special grade requirements.

A special grade, when applicable, is supplemental to the grade assigned under 868.314. Such special grades for milled rice are established and determined as follows:

(a) **Coated Milled Rice.** Coated milled rice shall be rice which is coated, in whole or in part, with substances that are safe and suitable as defined in the regulation issued pursuant to the Federal Food, Drug, and Cosmetic Act at 21 CFR 130.3(d).

(b) **Granulated brewers milled rice.** Granulated brewers milled rice shall be milled rice which has been crushed or granulated so that 95.0 percent or more will pass through a 5 sieve, 70.0 percent or more will pass through a 4 sieve, and not more than 15.0 percent will pass through a 2 1/2 sieve.

(c) **Parboiled milled rice.** Parboiled milled rice shall be milled rice in which the starch has been gelatinized by soaking, steaming, and drying. Grades U.S. No. 1 to U.S. No. 6, inclusive, shall contain not more than 10.0 percent of ungelatinized kernels. Grades U.S. No. 1 and U.S. No. 2 shall contain not more than 0.1 percent, grades U.S. No. 3 and U.S. No. 4 not more than 0.2 percent, and grades U.S. No. 5 and U.S. No. 6 not more than 0.5 percent of nonparboiled rice. If the rice is: (1) Not distinctly colored by the parboiling process, it shall be considered "Parboiled Light"; (2) distinctly but not materially colored by the parboiling process, it shall be considered "Parboiled"; (3) materially colored by the parboiling process, it shall be considered "Parboiled Dark." The color levels for "Parboiled Light," "Parboiled," and "Parboiled Dark" shall be in accordance with the interpretive line samples for parboiled rice.

Note: The maximum limits for "Chalky kernels," "Heat-damaged kernels," "Kernels damaged by heat", and the "Color requirements" in 868.310, 868.311, 868.312, and 868.313 are not applicable to the special grade "Parboiled milled rice."

(d) **Undermilled milled rice.** Undermilled milled rice shall be milled rice which is not equal to the milling requirements for "well milled," "reasonably well milled," and "lightly milled" rice (see 868.306). Grades U.S. No. 1 and U.S. No. 2 shall contain not more than 2.0 percent, grades U.S. No. 3 and U.S. No. 4 not more than 5.0 percent, grade U.S. No. 5 not more than 10.0 percent, and grade U.S. No. 6 not more than 15.0 percent of well-milled kernels. Grade U.S. No. 5 shall contain not more than 10.0 percent of red rice and damaged kernels (singly or combined) and in no case more than 6.0 percent of damaged kernels.

Note: The "Color and milling requirements" in 868.310, 868.311, 868.312, and 868.313 are not applicable to the special grade "Undermilled milled rice."

(e) **Glutinous milled rice.** Glutinous milled rice shall be special varieties of rice (Oryza sativa L. glutinosa) which contain more than 50 percent chalky kernels. For long grain, medium grain, and short grain milled rice, grade U.S. No. 1 shall contain not more than 1.0 percent of nonchalky kernels, grade U.S. No. 2 not more than 2.0 percent of nonchalky kernels, grade U.S. No. 3 not more than 4.0 percent of nonchalky kernels, grade U.S. No. 4 not more than 6.0 percent of nonchalky kernels, grade U.S. No. 5 not more than 10.0 percent of nonchalky kernels, and grade U.S. No. 6 not more than 15.0 percent of nonchalky kernels. For second head milled rice, grade U.S. No. 1 shall contain not more than 4.0 percent of nonchalky kernels, grade U.S. No. 2 not more than 6.0 percent of nonchalky kernels, grade U.S. No. 3 not more than 10.0 percent of nonchalky kernels, grade U.S. No. 4 not more than 15.0 percent of nonchalky kernels, and grade U.S. No. 5 not more than 20.0 percent of nonchalky kernels. For screenings milled rice, there are no grade limits for percent of nonchalky kernels. For brewers milled rice, the special grade "Glutinous milled rice" is not applicable.

Note: The maximum limits for "Chalky kernels," shown in 868.310, 868.311, and 868.312 are not applicable to the special grade "Glutinous milled rice."

(f) **Aromatic milled rice.** Aromatic milled rice shall be special varieties of rice (Oryza sativa L. scented) that have a distinctive and characteristic aroma; e.g., basmati and jasmine rice.

(Secs. 203, 205, 60 Stat. 1087, 1090 as amended; 7 U.S.C. 1622, 1624)
[42 FR 40869, Aug. 12, 1977; 42 FR 64356, Dec. 23, 1977, as amended at 48 FR 24859, June 3, 1983; 54 FR 21403, 21407, May 18, 1989; 56 FR 55981, Oct. 31, 1991; 58 FR 68016, Dec. 23, 1993]

868.316 Special grade designation.

The grade designation for coated, granulated brewers, parboiled, undermilled, glutinous, or aromatic milled rice shall include, following the class, the word(s) "Coated," "Granulated," "Parboiled Light," "Parboiled," "Parboiled Dark," "Undermilled," "Glutinous," or "Aromatic," as warranted, and all other information prescribed in 868.314.

[58 FR 68016, Dec. 23, 1993]