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# Effect of Heat Treatments on the Properties of Two Long-grain Rice Cultivars During Storage

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# EFFECT OF HEAT TREATMENTS ON THE PROPERTIES OF TWO LONG-GRAIN RICE CULTIVARS DURING STORAGE

# EFFECT OF HEAT TREATMENTS ON THE PROPERTIES OF TWO LONG-GRAIN RICE CULTIVARS DURING STORAGE

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**ABSTRACT**

During storage, the milling and physicochemical properties and eating quality of rice change, which is generally termed óagingô. Aged rice is preferred by processors, and there are attempts to develop accelerated aging process using various heat sources. In this study, the effects of various heat treatments and their influence on the milling, pasting, thermal, and cooking properties of two long-grain rice cultivars during storage were investigated using a full-factorial experimental design. Two long-grain rice cultivars, Wells and XP723, was treated with 8 different heat treatments including one control and stored at room temperature for 180 days. Heat treatments included 2 levels of UV irradiation, 2 levels of autoclaving and 3 levels of convection oven. The heat treatments significantly influenced head rice yield and thermal properties. The surface lipid content and cooked rice hardness and stickiness were impacted by cultivars, heat treatments and storage with different extent showing 3-way interactions. Severe autoclaving resulted in different protein composition from the other treatments. Peak pasting viscosity significantly increased at the first 3 months and gradually leveled off regardless of cultivar and heat treatments. Leached solid contents were decreased gradually during storage. Autoclaving (especially severe autoclaving) samples showed more distinct characteristics on HRY, leached solids and cooking properties. Although different heat treatments had different impacts on their properties, the results show that the various heat treatments employed in this study slightly accelerated rice aging by stabilizing rice properties during storage.

This thesis is approved for recommendation
to the Graduate Council.

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# CHAPTER 1

# INTRODUCTION

Rice is typically consumed as whole rice kernel, therefore the quality of whole rice grain is important to consumers. During storage, the physicochemical properties of rice change, which is generally termed ñagingò. Aged rice is preferred by processors because of its better cooking characteristics and eases of processing, such as lower viscosity and decreased leached materials. The mechanism of aging process has been studied, but is not yet fully understood. Studies have shown positive relationship between storage temperature and aging when rice stored at higher temperatures with significant changes in pasting and thermal properties. Because of the positive impact of higher storage temperatures on aging, there are attempts to develop accelerated aging processes using various heat sources.

This research attempted to get a better understanding of rice aging through the determination of physicochemical properties of rice subjected to various heat treatments. It was hypothesized that different heat treatments may have different impacts on the physicochemical properties of rice during storage. In this study, three different heat sources, UV irradiation, high moisture and high pressure, and oven heating, were used to treat two long-grain rice cultivars, which were selected to represent the old traditional drying method, the parboiling process, and the conventional drying method in the U.S., respectively. By employing three different heat sources and charactering the physicochemical properties of the treated rice, it was anticipated to have a better understanding of the components involved in aging, thus providing information on the approaches to accelerate the aging process.

The objectives of this study were:

To determine the milling quality and physicochemical properties of two long-grain rice cultivars subjected to various heat treatments during storage for 6 months, and their interactions.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction of rice

Almost all cultivated rice belong to the grass family of *Oryza sativa L.* Rice is the most important staple food to sustain over half of the worldôs population, and the United States is the top 5 largest rice exporting country (Childs 2012). In the U.S., rice is grown in flooded fields, such as Mississippi delta area and Sacramento valley area. Arkansas is the leading rice-producing state in the U.S, followed by California, Louisiana, Mississippi, Texas and Missouri. The U.S. rice varieties are classified into long-, medium- and short-grain types based on the length of grains. Long-grain rice, mostly indica type, accounts for nearly 75% of U.S. rice production (Childs 2001) and is mainly grown in Arkansas, Louisiana and Texas. Medium- and short-grain rices, classified as japonica type, are grown primarily in California. Functionally rice grain type is associated with specific cooking and processing characteristics. Cooked kernels of long-grain varieties are dry, fluffy and separate, whereas those of medium- and short-grain varieties are moist, chewy and sticky. Besides the common types, there are other varieties such as waxy/glutinous type and aromatic/scented type based on the starch characteristics and grain aroma, respectively (Webb 1985).

## 2.2 Rice composition

A rice grain consists of the hull, including the awn, lemma and palea, and the caryopsis, which is the edible part of the rice grain and also known as brown rice (Fig. 2.1). Milled rice is produced when the bran layer is removed from brown rice by milling. The degree of milling determines the remaining amount of nutrients and affects the functional properties of milled rice. Milled rice is composed of approximately 77% starch, 7% protein, 0.4% lipid, 0.4% ash, and 0.4% fiber and other components such as free sugars, lignin and pentosans at 14% moisture content (Juliano and Bechtel 1985).

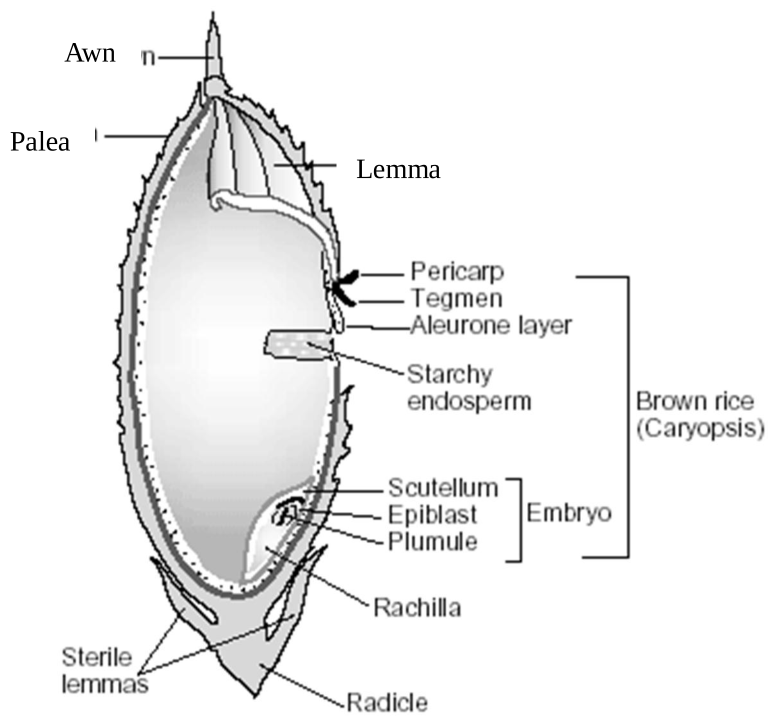


Fig. 2.1. Cross-section of a rice grain (Juliano and Bechtel 1985).

### 2.2.1 Starch

Starch is the main component (approximately 90% dry basis) in milled rice and composed of three types of polymers, amylose, amylopectin and intermediate component that has properties between amylose and amylopectin. Starch is synthesized in amyloplast as discrete particles called granules. Two or more rice granules can form larger and denser compound granules in one amyloplast. Rice starch has a very small granule size ranging from 3 to 8 µm and an irregular, polygonal shape. By light microscopy and scanning electron microscopy a radial ring structure can be seen in hydrated starch granules, which is called growth ring that consists of repeating semi-crystalline and amorphous regions with a length between 120 and 400 nm (Yamaguchi et al 1979). The ordered semi-crystalline structure arranged in a radial direction is capable of rotating polarized light and displays birefringence. Starch also displays a distinct X-ray diffraction pattern depending on its botanical source. Cereal starches such as rice starch display A-pattern; tuber and fruit starches are of B-pattern; C-pattern is a mixture of A- and B-patterns as in bean starches; V-pattern arises from complexes formed by amylose and alcohols, fatty acids or phospholipids.

Starch swells irreversibly and loses its crystalline structure during heating in excess water, which is known as gelatinization. Gelatinization is an endothermic process, and both amylose and amylopectin leach out from the starch granules during gelatinization.

***Amylose***

Amylose is an essentially linear molecule linked of Ŭ-1,4 anhydro-D-glucose units with limited branching. Amylose content (AC) in rice varies with varieties and has been classified into waxy (0-2%), very low (2-10%), low (10-20%), intermediate (20-25%), and high (25-32%) as determined by iodine colorimetry (Juliano 1985). Long-grain rices usually have higher amylose contents (high or intermediate AC) than medium- and short-grain rices (low or very low

AC).

Amylose has been considered as the primary factor determining rice cooking quality (Juliano 1985). As amylose content increases, rice grains become less sticky and firmer. Nevertheless, the textural properties of cooked rice could not be fully explained solely by the apparent amylose content, which can be measured spectrophotometrically from the formation of iodine-amylose complex. Bhattacharya et al (1978) reported that an increase in insoluble amylose content in cooked rice was associated with a decrease in stickiness among 32 rice varieties, and gelatinization temperatures (GTs) were not correlated with textural properties of cooked rice. Merca and Juliano (1981) studied rice varieties of intermediate AC and observed higher GT for softer cooked rices compared with rices with lower GTs.

***Amylopectin***

Amylopectin is the major component of most rice starch (70~80%) and a highly branched macromolecule, which is the largest molecules in nature with a molecular size of degree of polymerization (DP) 10,000 to 100,000 Ŭ-D-(1Ÿ 4)-glucose units with 5~6% branched points of Ŭ-D-(1Ÿ 6) linkages (Manners 1989). Takeda et al (1986) reported that japonica (low AC varieties) amylopectins had higher DP of 8,200 ï 12,800 but lower average chain length of DP 19 ï 20 compared with indica (high AC varieties) amylopectins of DP 4,700 ï 5,800 and average chain lengths of DP 21 - 22.

Amylopectin chains can be classified into A, B, and C chains (Peat et al 1952). The A chain is linear and links to the B and C chains by its reducing end with no other chains attached.

The B chain carries the A or other B chains. The C chain is the only chain of the amylopectin molecule with a free reducing end. The B chains can be classified into four types, B1 to B4, by high-performance gel permeation chromatography (Hizukuri 1986) (Fig. 2.2).

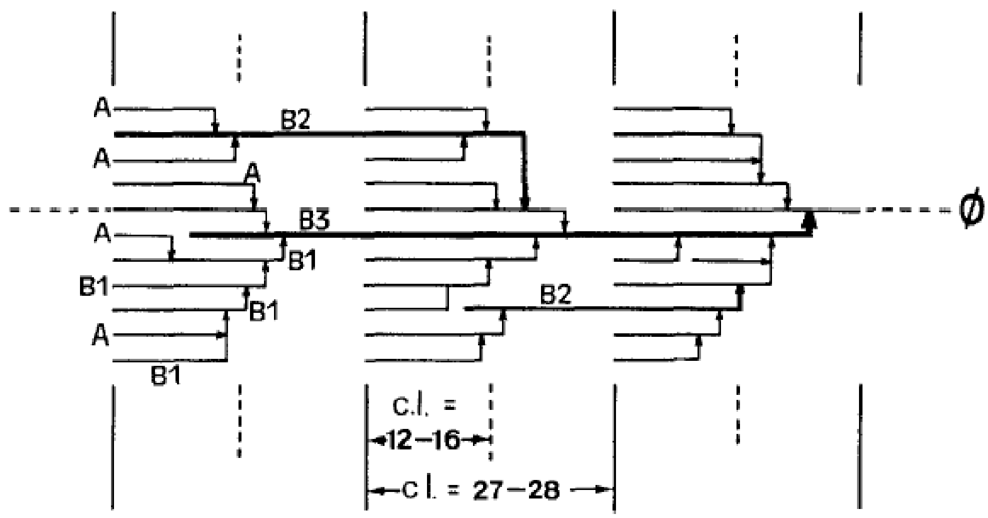


Fig. 2.2. A cluster model for amylopectin. Ø, reducing chain end; ð , (1Ÿ 4) Ŭ-D-glucan chain; Ÿ , Ŭ(1Ÿ 6) linkages (Hizukuri 1986)

Reddy et al (1993) correlated the starch fraction by gel permeation chromatography with the texture of cooked rice and proposed that the texture of cooked rice was affected by the fine structure of amylopectin. Ong and Blanshard (1995) reported that rice with longer amylopectin chains and higher amylose content tended to have higher values of hardness in 11 cooked rice cultivars. More recently, Cameron and Wang (2005) demonstrated that both amylose and amylopectin leached out, and the insoluble amylose content had a stronger correlation with the cooked rice hardness than did the apparent amylose or leached amylose content in eight U.S.

long-grain rice cultivars. Cuevas and Fitzgerald (2007) found a negative correlation between the hot water-soluble amylopectin and peak viscosity in waxy rice.

***Intermediate component***

Starch components cannot be clearly separated into linear amylose and highly branched amylopectin. Lansky et al (1949) suggested that 5~7% of intermediate components was present in corn starch based on pentasol precipitation. Intermediate component is considered as molecules similar to amylopectin but with long branches or similar to amylose but with more branches.

### 2.2.2 Protein

Protein accounts for ~8% (w/w) of brown rice at 14% moisture and is the second dominant component in rice (Juliano et al 1965). Rice consists of two major proteins, glutelin (alkali-soluble ~80%) and globulin (salt-soluble ~12%), and two minor ones, albumin (water-soluble ~5%) and prolamin (alcohol-soluble ~3%). Rice proteins are unique among cereals because its major protein is glutelin compared with prolamin in the others. The glutelin is called óOryzeninô- rice storage protein. The denaturation temperatures of albumin, globulin and glutelin have been reported as 73.3°C, 78.9°C and 82.2°C, respectively (Ju et al 2001). Non-protein nitrogen of 2~4% is mainly from free amino acids (Juliano 1985). Hayakawa et al (1980) observed protein body to tightly bind to starch granules in rice endosperm by scanning electron microscopy (SEM).

Proteins affect the surface hardness and stickiness of cooked rice (Chrastil 1994). Rice with higher protein content requires a longer cooking time and shows lower water absorption (Juliano et al 1965). Removal or disruption of protein in rice flour affects rice viscoelastic properties. Hamaker and Griffin (1990) observed an increase in stickiness in cooked rice and a decrease in rice flour peak pasting viscosity with the addition of a reducing agent (dithiothreitol) and suggested that the presence of disulfide-bound protein complexes may improve the rigidity of swollen starch granules.

### 2.2.3 Lipids

Rice is low in lipids relative to other cereals with 1-4% (in dry basis) in brown rice and less than 1% in milled rice. The majority of rice lipids are triacylglycerides accumulated in the spherosomes or lipid droplets that exist in the aleurone layer and the embryo. The degradation of rice lipids is strongly related to quality deterioration of rice during storage (Champagne 1994). During storage, lipids are hydrolyzed to free fatty acids and/or further oxidized to peroxides, which result in deterioration of taste and flavor.

Rice lipids are generally classified into nonstarch lipids and starch lipids. Nonstarch lipids are mostly triglycerides and from the embryo and the aleurone layer. Starch lipids, which are located in starch granules, are tightly bound to starch granules to form amylose-lipid complexes and include monoacyl lipids, free fatty acids and lysophospholipids (Juliano 1985). Non-starch lipids can be extracted by non-polar solvents such as ether, and starch lipids can be extracted with water-saturated butanol (Choudhury and Juliano 1980).

The deterioration of lipids in brown and milled rice produces rancid off-odors and is detrimental to oil and brewing applications (Champagne 1994). Because lipids in rice are mainly located on surface such as aleurone layer, the surface lipid content, which is closely related to degree of milling, has a great impact on cooked rice properties. Milled rice with lower surface lipid content is softer and more sticky when cooked (Saleh and Meullenet 2005). The peak viscosity was also influenced by lipid content. Yasumatsu et al (1964) showed that defatted rice had a lower peak viscosity and a different pasting profile compared with undefatted one.

#### 2.2.4 Minor components

A higher concentration of minerals is present in the bran layer. Phosphorus is the most dominant mineral in milled rice with 0.8-1.5 g in 100 g milled rice (Juliano 1985). Potassium and magnesium are also abundant in brown and milled rice. Several minor organic components such as non-starch polysaccharides, phenolics, and aroma constituents are also present in rice.

### 2.3 Effect of storage temperature and storage period

Rice experiences a variety of physical, chemical, and biological changes during storage, which are termed aging. Rice aging is a complicated, long process of approximately 4-6 months, and its detailed mechanism is not yet fully understood. Aging commences before harvest, continues during storage, and is temperature- and humidity-dependent. Aging imparts both desirable and undesirable characteristics on stored rice, for example, an increase in the tensile strength for milling, an increase in water absorption and volume expansion during cooking, and a decrease in extractable solids in cooking water. Little change in rice gross composition is noticed during storage, but some hydrolysis or degradation of the components probably occurs (Juliano 1985). Attempts to explain the changes in rice aging process mainly focus on the rice main components and their interactions.

### 2.3.1 Milling quality

The milling qualities, such as tensile strength and head rice yield, change during storage. Head rice yield, the weight percentage of whole rice (three-fourth kernel or greater) over rough rice after milling, is one of the most important traits for rice because it is used to determine the price that the farmers are paid for their crop. It is reported that aging results in improved tensile strength and increased head rice yield after 3 to 6 months of storage (Juliano 1985), which is related to moisture absorption condition (Kunze and Choudhury 1972). A thermal drying process of high temperature resulted in a lower head rice yield than a gentle drying condition (Soponronnarit et al 2008). The color of milled rice also affects its value, which decreases in whiteness during storage as a result of the browning reaction or drying process.

### 2.3.2 Cooking characteristics

Changes in cooking quality during storage have been observed. The volume expansion and water absorption of rice increase during cooking as aging progresses. Cooking time increases during storage, and cooked aged rice is harder and less sticky than freshly harvested cooked rice (Juliano 1985). The rice aged at a higher temperature (37°C) for 16 months had harder and less adhesive textures, increased water absorption, and decreased leached solids and amylose than the one aged at lower temperature (4°C) after cooking (Zhou et al 2007). Indudhara Swamy et al (1978) observed that the aging parameters such as water uptake occurred much faster and to a greater extent in high-amylose (indica-class) than in low-amylose (japonica-class) rice varieties. The elongation property and aroma score of Basmati-type rice improved during storage (Archana et al 2007).

### 2.3.3 Pasting properties

One of the most common indicators of rice aging is the change in pasting properties as measured by amylography, such as Brabender ViscoAmylography and Rapid ViscoAnalyser (RVA) with programmed heating and cooling cycle.

The peak viscosity of rice flour increased 35-50% at a high storage temperature (37°C) in the first 3 months and then plateaued (Perdon et al 1997). The changes in viscosity were affected by storage temperature and moisture content. The increase in viscosity occurred immediately when rice was stored at a higher temperature but was gradual when stored at a lower temperature (Teo et al 2000).

Indudhara Swamy et al (1978) observed an initial increase followed by a steady decrease in paste and setback viscosities of rice stored at three temperature conditions (cold 1~3°C, room temperature 23~35°C, and hot 37~40°C) for three years. Aging rendered rice more organized and resistant to swelling. The viscosity change was not halted even after 4 years of storage (Sowbhagya and Bhattacharya 2001).

### 2.3.4 Thermal properties

The gelatinization temperature (GT) of starch, commonly measured by differential scanning calorimetry (DSC), is an important quality determinant of raw rice grain because of its relevance to many properties. Zhou et al (2003a) reported that rice stored at a higher temperature (37°C) for 16 months had higher peak gelatinization temperature and broader peak width than the one stored at a lower (4°C) temperature. Brown rice stored at a higher temperature (38°C) showed increased gelatinization temperature and enthalpy than those stored at a lower temperature (4°C) (Patindol et al 2005), but this increase was not observed for starch isolated from the same rice samples.

### 2.3.5 Enzyme activity

Dhaliwal et al (1991) reported that the activities of Ŭ- and ɓ-amylase in rough rice significantly decreased while the activities of proteases, lipases and lipoxygenase increased during storage for 1 year. Chrastil (1990) reported that the apparent initial velocities of protease and Ŭ-amylase significantly decreased especially at higher storage temperature (37°C), but the specific rate constant of these enzymes did not change at higher storage temperatures or longer storage times. This means these enzymes in rice were not destroyed but partially deactivated by substrate-binding proteins (reversible substrate-receptor inhibitor).

### 2.3.6 Starch content

Although the amylose content in rice did not change significantly at any storage temperature, the leached amylose content decreased when rice stored at a higher temperature (37°C) than at a lower temperature (4°C) after 16 months of storage (Zhou et al 2007). The average molecular-weight of amylopectin slightly increased during storage, whereas that of amylose slightly decreased after storage for 1 year (Chrastil 1994). Pantindol et al (2005) reported that aged rice stored at 21°C and 37°C showed a decrease in amylose, amylose:amylopection ratio, and decreased amylopectin average chain length after 9 months of storage.

### 2.3.7 Carbohydrates

Reducing sugars (such as maltose or glucose) increase and non-reducing sugars (sucrose) decrease after storage for 5 months (Pushpamma and Reddy 1979). Cao et al (2004) reported a decrease in disaccharides (maltose and sucrose) and an increase in monosaccharides (glucose and fructose) during aging. These studies indicate the occurrence of hydrolysis of carbohydrates during rice aging.

### 2.3.8 Protein

The crude protein content in rice remained unchanged during storage (Indudhara Swamy et al 1978) but the molecular weight and the number of disulfide bonds of oryzenin increased significantly (Chrastil 1992). After 12 months of storage, it was found that the binding of oryzenin to starch was strongly related to cooked rice stickiness (Chrastil 1990), particularly at a high (40°C) storage temperature. As the ratio of oryzenin to starch decreased during storage, the cooked rice stickiness also decreased. The amount of extracted protein fraction from rice stored at 37°C after 16 months was less compared with that from rice stored at 4°C (Zhou et al 2003b). These results suggest decreased solubility of protein after aging. The pasting properties such as peak viscosity of rice starch did not change in relation to storage temperature (Teo et al 2000). Removal of protein, such as dithiothretol (DTT) or protease, from aged rice stored at 37°C for 16 months resulted in an increase in pasting viscosity compared with fresh rice (Zhou et al 2003a). Martin and Fitzgerald (2002) observed similar effects on fresh and aged rice in 6 different rice varieties. They removed protein using protease or DTT on fresh and aged rice, and the resultant treated sample showed decreased peak viscosities in fresh rice but increased peak viscosities in stored rice except one variety, Basmati.

### 2.3.9 Lipids

Rice lipids can be hydrolyzed or oxidized to free fatty acids (FFA) or peroxides to result in increased free fatty acids, acidity, and rancid odor within the first 2 days of storage. According to Lam and Proctor (2003), the formation of FFA in milled rice within 48 hr of storage was rapid, especially at 37°C, and the FFA increase was positively correlated with increasing storage temperature between 12 to 50 days of storage. Nishiba et al (2000) also observed an increase in FFA in milled rice and rice bran from 7 to 69 days of storage using convenient TLC-FID (thin-layer chromatography flame ionization detection) method. Zhou et al (2003c) reported a significant decrease of fatty acids in free lipids (mainly nonstarch lipid), but no change in bound lipids (starch lipids) in rice when stored at 37°C after 4 or 7 months of storage.

## 2.4 Heat treatment effect on rice

It has been shown that higher storage temperatures result in more rapid changes of pasting properties and molecular-weight distribution of protein or starch in stored rice. The conventional rice aging process takes a long time, therefore it is of commercial interest to develop processes that may accelerate the aging process. The process that induces the aging changes within a short time to produce rice with similar properties to those of naturally aged rice is called accelerated aging (Gujral and Kumar 2003).

In the U.S., the commercial rice drying facility use ambient or convective heated air (up to 54°C), normally with multiple passes, to minimize moisture gradient occurring during drying (Kunze and Calderwood 1985). The purpose of drying is to prevent fungal or microbial damage when storing rough rice. Convective drying process is not efficient to remove fungus or insects at low temperatures, e.g. 23~35°C, whereas moisture gradients may cause rice fissuring at the kernel surface under rapid desorption as a result of internal hygroscopic stress (Kunze and Choudhury 1972).

Parboiling, which is a precooking process of rough rice with water and heat prior to drying, can reduce breakage during milling and promote retention of minerals and water-soluble vitamins. During parboiling, starch is partially gelatinized, protein bodies in rice are ruptured, enzymes in the grain are largely inactivated, especially lipase, and grain discoloration occurs (Bhattacharya 1985). Commercial parboiling process involves three steps: soaking, steaming, and drying. Gujral and Kumar (2003) obtained accelerated aged rice using modified parboiling process at different moisture levels of rice. The physicochemical properties such as elongation, water absorption, and cooking time increased whereas solid loss decreased after accelerated aging. At higher moisture contents, the extent of changes from parboiling increased.

Rice drying with solar radiation is the traditional method of reducing moisture content in rice for controlling microbial growth purpose. Recently Sung (2005) used irradiation on indica rice and found that the pasting properties and cooked rice texture of gamma-irradiated rice were similar to those of aged rice for one year. The mechanisms of natural aging and irradiation treatment seemed different but both showed similar impacts on pasting and cooked properties. Nguyen and Goto (2008) suggested that the microwave radiation using high frequency generator may retard rice aging as a heat-shock treatment, i.e. short time exposure at high temperature, 60, 70 and 80°C for 6 months at 40°C storage temperature. The treated sample had delayed volume expansion and decreased titratable acidity compared with the control. However, the relationship between exposed dosage and delayed effects was not clear.

# CHAPTER 3

# EFFECT OF HEAT TREATMENTS ON THE MILLING, PHYSICOCHEMICAL AND COOKING PROPERTIES OF TWO LONG-GRAIN RICE CULTIVARS DURING STORAGE

## 3.1 Abstract

During storage, the milling, physicochemical properties, and eating quality of rice change, which is generally termed óagingô. Aged rice is preferred by processors because of better processing characteristics, and therefore there are attempts to develop accelerated aging process. In this study, the effect of heat treatments and its influence on the milling, physicochemical, and cooking properties of two long-grain rice cultivars during storage were investigated using a full-factorial design. Two long-grain rice cultivars, Wells and XP723, were treated with 8 different heat treatments, including 2 levels of UV irradiation, 2 levels of autoclaving, 3 levels of convection oven, and one control, and then stored for 180 days at room temperature. The heat treatments significantly influenced HRY (head rice yield) and thermal properties. The surface lipid content, cooking hardness and stickiness differed by cultivars, heat treatments, and storage with different extent showing 3-way interactions. The severe autoclaving treatment resulted in rice of different protein composition when compared with other treatments. Storage influenced the pasting properties and leached solids content. Autoclaving (especially severe autoclaving) produced samples with more distinct aging characteristics on HRY, leached solids and cooking properties.

## 3.2 Introduction

Rice is harvested once a year, stored as rough rice until further process, and typically consumed as whole kernel. Therefore the quality of whole rice grain is important to consumers. After harvest and during storage, the physicochemical properties of rice gradually change, which is called aging. Milling properties are also affected during storage (Daniels et al 1998). The rice obtained from freshly harvested paddy is less suitable for processing and culinary use. Aged rice is preferred by processors because of its better cooking characteristics and ease of processing, such as reduced viscosity (Perdon et al 1997) and decreased leaching materials (Indudhara Swamy et al 1978).

The mechanism of aging has been researched, but is not yet fully understood. Studies have shown positive relationship between storage temperature and aging when rice is stored at higher temperatures with significant changes in cooking, pasting and thermal properties (Indudhara Swamy et al 1978, Zhou et al 2002, 2003). Higher storage temperatures result in more rapid changes of pasting properties (Teo et al 2000) and molecular-weight distribution of protein and starch in stored rice (Chrastil 1992; Teo et al 2000). Although little change in rice gross composition is noticed, some hydrolysis or degradation of the components probably occurs during storage (Juliano 1985). Because of the long aging process of 4 to 6 months and the effect of higher storage temperatures on aging, there have been attempts to develop accelerated aging process using various heat sources, such as autoclaving (Archana et al 2007), infrared (Pan et al 2008), hot air (Jaisut et al 2009, Soponronnarit et al 2008), and microwave radiation (Nguyen and Goto 2008).

After harvest, rice may experience different heat treatments, such as drying and parboiling, prior to storage. The commercial drying facilities in the U.S. use ambient or heated air (up to 54°C) with multiple passes to minimize moisture gradient occurring during drying (Kunze and Calderwood 1985). Although rapid drying may cause rice fissuring at the kernel surface under rapid desorption as a result of internal hygroscopic stress (Kunze and Choudhury 1972), it is not clear if high drying temperatures would impact rice aging. More recently, Siebenmorgen et al (2004) applied the glass transition theory and demonstrated that rough rice can be dried at a higher air temperature (60°C) in a rubbery state without reducing head rice yield. Parboiling is a hydrothermal treatment of rough rice prior to milling, and parboiled rice accounts for about 15% of the worldôs milled rice (Bhattacharya 2004). The impact of parboiling on rice aging has not been studied. Rice drying with solar radiation is the traditional method of reducing moisture content, and recently irradiation has been evaluated for controlling the aging process. Gamma-irradiated indica rice had similar pasting properties and cooked texture to those of aged rice after for one year (Sung 2005), whereas microwave radiation slowed the changes in rice associated with aging.

It was hypothesized that rice aging could be accelerated by heat treatments, and different heat treatments may have different impacts on the rice properties during storage. Three heat sources, including UV irradiation, autoclaving, and high temperature convective heating, were studied for their impacts on the milling, physicochemical and cooking properties of two rice cultivars during storage for 6 months.

## 3.3 Materials and Methods

### Rice samples

Two long-grain rice cultivars, Wells, a pureline, and XP723, a hybrid, from the 2008 crop were used in this study. They were provided by the University of Arkansas Rice Processing Program in Fayetteville, Arkansas, and stored at 4°C until use.

### Heat treatments

Immediately after harvest, fresh rough rice of Wells at 18% moisture content and XP723 at 16% moisture content, approximately 1000 g of each, was treated with 3 different heat sources of 7 heat treatments along with a control (untreated): UV irradiation (750W) for 15 hr (UV15) and 25 hr (UV25); autoclaving without pre-soaking at mild (100°C, 0 kPa, A100) and severe (121°C, 98 kPa, A121) conditions for 20 min using an autoclave (8816A, AMSCO, Erie, PA); convective heating at 80 (O80), 90 (O90), and 100°C (O100) for 10 min in a convection oven. After each heat treatment, the rice sample was spread evenly on wooden meshed trays and dried in an EMC (equilibrium moisture content) chamber (AA60-PF, RSP Industries Inc. Brooklyn, NY) at 25°C and 40% relative humidity until ~12% moisture content. The control was dried under the same condition without prior heat treatment. The treated rough rice was equally divided and packed into 5 tightly sealed plastic bags in a closed container and stored under ambient conditions. One bag from each heat treatment was removed every 45 days for evaluation.

**Milling properties**

One hundred and fifty gram of each rough rice samples was dehulled with a dehuller (THU-35, Satake Corp., Hiroshima, Japan). The recovered brown rice was milled for 30 sec in a friction mill (McGill Miller #2, Rapsco, Brookshire, TX). The milled rice was separated into head rice and broken kernels using a double-tray shaker table (GrainMan Machinery, Miami, FL) to calculate head rice yield (HRY), % whole kernel . The whiteness of the milled head rice was measured with a Kett C-300-3 whiteness meter (Kett Electric Lab., Tokyo, Japan) calibrated with a magnesium oxide standard plate. A portion of the milled rice was ground into flour with a UDY cyclone sample mill (UDY Corp., Ft. Collins, CO) fitted with a 0.50-mm screen. The head rice and rice flour were stored at 4°C until analysis.

**Chemical composition of rice**

Moisture content of rough rice was determined using Approved AACC Method 44-15A (AACC International, 2000) by placing 15-20 g sample in an aluminum dish in a convection oven at 130°C for 24 hr. Moisture content of rice flour was determined by drying 0.5 g of samples in a convection oven at 130°C for 2 hr. Crude protein was measured with a micro-Kjedahl apparatus according to Approved Method 46-13 (AACC International, 2000) using a 0.5 g flour and a factor of 5.95 for converting nitrogen content to crude protein content. Surface lipid content was determined by extracting flour with isopropyl alcohol according to the method of Lam and Proctor (2001). The apparent amylose content was determined by iodine colorimetry (Juliano 1979).

**Protein analysis**

The protein composition of treated sample was analyzed using sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) (15% running gel and 4% stacking gel) using a vertical gel system Mini-Protean 3 (Minigel, Bio-Rad Laboratories, Hercules, CA) . Approximately 21 mg of rice flour was added into 0.3 mL of buffer (0.01% bromophenol blue, 10% glycerol, 0.625 M Tris-HCl, 10% SDS) and reduced with 4% 2-mercaptoehtanol to obtain a final concentration of 3.75 mg protein per mL. Under the reducing conditions, samples were placed in a boiling water bath for 5 min, and 20 µL of the supernatant was loaded into sample wells along with 5 µL of standards with molecular mass ranging 10-250 kDa. Gels were stained with Coomassie Brilliant Blue R-250 staining solution (BioRad, Hercules, CA) and then distained with 40% methanol and 10% glacial acetic acid before drying.

**Thermal and pasting properties**

Thermal properties were assessed by a differential scanning calorimeter (Pyris Diamond model, Perkin-Elmer Co., Norwalk, CT). Approximately 4 mg of rice flour was weighed into an aluminum DSC pan, and 8 µL deionized water was added by a microsyringe. The mixture was hermetically sealed and equilibrated at room temperature for at least 1 hr prior to heating from 25°C to 120°C at 10°C/min. An empty pan was used as the reference. The onset, peak and end gelatinization temperatures and enthalpy ($\Delta Hg$) was calculated from the endotherm.

The pasting properties of rice flour were determined using a Rapid ViscoAnalyser (Newport Scientific Pty. Ltd, Warriewood NSW, Australia) according to Approved Method

61-02 (AACC International 2000) with modifications. Rice flour slurry was prepared by mixing 3.0 g of rice flour (12% moisture content basis) with 25 mL of deinoized water in a canister. The slurry was heated from 50°C to 95°C at a rate of 3°C/min. The initial speed was 960 rpm for the first 10 sec to thoroughly mix the slurry and the test speed was 160 rpm. The pasting properties including pasting temperature, peak viscosity, peak time, trough viscosity, final viscosity, breakdown, and setback were recorded.

**Leaching and cooking characteristics**

Twenty gram of head rice was cooked in 100 g of boiling deionized water in a 250-mL Pyrex glass vessel with a lid at 98.5°C for 20 min. Immediately after cooking, cooking water was drained through a strainer into a pre-weighed beaker and dried at 40°C for 48 hr. Percent leached soilds was calculated by dividing the dried residue weight with initial rice weight (as is).

The cooked rice texture was analyzed following the method of Sesmat and Meullenet (2001) with modification. Ten intact cooked kernels were used for compression test to determine the hardness and stickiness using a texture analyzer (Model TA-XT2*Plus*, Texture Technologies, Scarsdale, NY). Rice kernels were placed in a single layer on a clean flat aluminum base, and a 5-kg maximum load cell was used. The compression plate traveled to compress the kernels to 90% of their original height. The crosshead pretest speed was 2 mm/s, and test speed and post-test speed was 0.5 mm/s. Data were collected and analyzed by the Texture Expert (1.17 Stable Macro System, England). Cooked rice was kept at a constant temperature (25°C) in the rice cooker, and 5 replications were performed. The remaining cooked rice was placed in a weighing dish and dried at 40°C for 48 hr. The water content of cooked rice was calculated by the percentage of weight loss.

### Data analysis

This experiment was analyzed as a completely randomized experiment with a 8×5×2 complete factorial treatment design containing three factors of 8 heat treatments, 5 storage periods and 2 cultivars. All analyses were done with 2 replicates. The data was analyzed with JMP 10 and least squared means (LSM) differences to determine the significance of the main factors and their interactions using Tukey HSD test. A significance level of 0.05 was used to report the significant differences.

## 3.4 Results and Discussion

### Head rice yield

Table 3.1 presents the head rice yield (HRY) of Wells and XP723 cultivars from 7 heat treatments and the control when stored at ambient conditions for 180 days. The HRY ranged 54.1-63.1% immediately after the treatments and 50.9-66.6% after 180 days of storage. Autoclaving at 121°C (A121) for 20 min resulted in higher HRY, but severe UV (UV25) and oven-heating (O100) treatments decreased HRY when compared with the control. In general, Wells had similar or slightly higher HRY than XP723 for the same treatment. It is known that parboiling of rice results in increased HRY because the gelatinized starch and disrupted protein bodies fill the gaps of fissured kernels (Bhattacharya 2004). Although the rice was not soaked in excess water and had only 16-18% moisture content prior to autoclaving, autoclaving at 121°C still significantly increased the HRY, implying some changes occurred in the starch and/or protein components of this autoclaved rice. The HRY of Wells remained unchanged or increased after the treatment, and slightly increased during storage, whereas that of XP723 unchanged or decreased after treatment and unchanged during storage. Wells cultivar (60.5%) had higher mean of HRY than XP723 (56.8%) but the effect of cultivars on HRY was not significant ($P<0.05$) in this experiment. Nevertheless, the interaction of storage period and cultivars significantly affected HRY. These results indicate that the impacts of the heat treatment on HRY were affected by the type and extent of the heat treatment.

**Surface lipid content**

The surface lipid content of heat-treated Wells and XP723 samples ranged from mean values of 0.25 to 0.76% during storage (Table 3.2). Autoclaved samples (A100 and A121) had higher surface lipid contents than the others, which was attributed to outward migration of oil bodies in the bran layer during the steam treatment (Mukherjee and Bhattacharjee, 1978). In general, the surface lipid content of treated samples increased at 45 days of storage and then remained unchanged or slightly decreased (Fig. 3.1). The initial increase in rice surface lipid content might be due to hydrolysis and/or oxidation of lipids in the first 50 days of storage as reported by Lam and Proctor (2003). These hydrolyzed and oxidized lipid products may be easier to extract.

Only the 3-way interaction among individual factors, including cultivar, treatment and storage, was found to have significant impacts on surface lipid content. Enzymes were probably deactivated in the severe autoclaving process (A121) (Dhaliwal et al. 1991) but not affected by other heat treatments, therefore the surface lipid content of A121 decreased at the beginning of the storage. Different rice cultivars are known to be milled differently (Bhattacharya KR. 2004), and the storage could also impact rice cultivars differently to result in different degrees of milling among treated samples, consequently different surface lipid contents.

**Protein content and composition**

The crude protein content by the micro-Kjedahl method did not change by the heat treatments and during storage (data not shown). The protein compositions of treated rice samples at 0 day as analyzed by SDS-PAGE are shown in Fig 3.2. The soluble protein compositions in the treated rice samples were similar except that the severe autoclaving (A121) samples of both cultivars had diminished bands between 50-75 kDa which was previously reported by Reza et al (2005). They attributed the decrease to reduced solubility and extractability of protein, particularly the high molecular weight ones, after parboiling. These protein bands could be internal granule associated protein of higher molecular weights of around 52 kDa (Baldwin 2001) or starch granule-bound starch synthase (55 to 61 kDa) (Han and Hamaker, 2002).

There was little change in total protein during storage (data not shown), and the control samples stored at room temperature for 180 days did not show any notable change of protein composition based on their SDS-PAGE of native protein without the 2-mercaptoethanol reduction (Fig. 3.3). Chrastil (1992) reported that soluble (extractable) protein significantly decreased and average molecular-weight of oryzenin, the major rice protein, increased for one-year storage at 40°C, which was however not observed in the present study. The protein composition results show that only autoclaving at 121°C affected the protein composition of rice, while storage had little impact.

**Thermal properties**

Tables 3.3 and 3.4 summarize the peak gelatinization temperatures and enthalpy of the treated rice samples. The onset, peak, and conclusion temperatures of treated rice flour samples were in range of 70.3-75.3, 75.3-80.1 and 80.6-90.4, respectively, and gelatinization enthalpy ($\varphi H$) was in range of 10.2 to 12.9. XP723 had significantly higher gelatinization temperatures and enthalpies than Wells. Among the treatments, A121 resulted in samples with significantly higher gelatinization temperatures and slightly lower enthalpies, which was attributed to the annealing conditions from its heat-moisture conditions during autoclaving. The thermal properties of all samples did not change during storage for all treatments. Fan and Marks (1999) and Patintdol et al (2005) also reported that the gelatinization properties of rice grains remained unchanged when stored at ambient temperature but significantly increased when stored at high temperatures. Therefore, gelatinization temperatures were significantly influenced by rice cultivar and heat treatment, but not by storage in this study.

**Pasting properties**

The peak viscosity of the rice flour samples ranged from 3342 to 4735 cp, and gradually yet significantly increased during storage (Fig 3.4). XP723 had higher peak and breakdown viscosities and lower setback and final viscosity than Wells (Tables 3.5-3.8) because of its lower apparent amylose content of 19.5% compared with 22.8% of Wells as measured by iodine colorimetry. The most distinctive change for all treatments during storage was the increase in peak viscosity in the first 3 months before it subsequently leveled off, which was also noted by Perdon et al (1997). This increase was also observed for breakdown, final, and setback viscosities during the first 3 months of storage. These results suggest that the heat treatments used in this study did not accelerate rice aging based on the changes in pasting viscosities of the control. Even though the severe autoclaving (A121) caused significantly lower peak and breakdown and higher final and setback viscosities, these viscosities still gradually changed during storage as did the control.

**Leached solids**

The leached solid in cooking water of treated rice samples ranged from 4.30 to 6.70 (g/100 g rice) and gradually decreased during storage in all heat treatments (Table 3.9). Villareal et al (1976) reported that the percentage of extractable solids in cooking water decreased more when rice stored at 29°C than at 2°C for 6 months regardless of rice type. Zhou et al (2007) also reported higher water uptakes and lower solids in cooking water of rice stored at a higher storage temperature (37°C vs. 4°C) after 16 months of storage, which are considered as characteristics of aged rice. The effects of heat treatment and cultivar on leached solid were not clear, probably because of variability in sample and method, whereas A121 sample of Wells showed lower leached solid content. Again, similar to pasting properties, the leached solids results demonstrate that the heat treatments used in this study did not effectively accelerate rice aging.

**Cooked rice texture**

The hardness of cooked rice samples ranged from 56.7 to 96.7 N (Newton) for various heat treatments and storage periods (Table 3.10). Cooked rice hardness slightly decreased for the controls, unchanged or slightly decreased for the autoclaved- and oven-treated samples, and slightly increased for the UV-treated samples. The UV treatments resulted in less hard texture in Wells, whereas O80 yielded harder texture in XP723. In general, cooked rice hardness gradually decreased during storage until 90 days, and then gradually increased.

Cooked rice stickiness ranged from 6.7 to 16.2 N (Table 3.11) among various heat treatments and during storage. All heat-treated Wells samples had lower stickiness than the control at 0 day, which, however, was not observed for XP723. Furthermore, the samples treated with UV and autoclaving had a stickiness value similar to the aged controlled samples at 180 days. The stickiness of cooked rice had a similar trend as the hardness values, which were higher at 0 day, decreased during storage for 90 days, and then increased thereafter. Similar to hardness, the extent of change in stickiness varied with treatments and cultivars. A decrease in stickiness is usually associated with aging of rice (Juliano 1985), which was noted in this study.

Chrastil (1990) found that the binding of oryzenin on amylopectin and/or amylose decreased during storage, and the binding of oryzenin to starch was directly related to the cooked rice stickiness. Therefore he proposed that oryzenin-starch binding as one of the most important factors influencing cooked rice stickiness, among factors including molecular weights of oryzenin, amylose and amylopectin, amylose content, and disulfide bonds. The heat treatments in the present study might decrease oryzenin solubility that resulted in decreased stickiness, whereas its impact on cooked rice hardness was not clear. The cooked rice hardness might be more related to amylose/amylopectin ratio and insoluble amylose, not amylose alone (Juliano, 1979) in cooking, and may be more strongly influenced by cultivar and storage.

**Statistical analysis**

In order to identify the significance of the experimental main factors and their interactions, a least squared means (LSM) differences analysis for complete factorial design was performed for all response properties. Statistically, heat treatments influenced head rice yield and storage affected pasting properties and leached solids content (Table 3.12). The interactions of cultivar * heat treatments had significance on pasting and thermal properties. There were three-way interactions on surface lipid content, cooking hardness and stickiness among heat treatment * storage * cultivar, which is the highest interactions.

Autoclaved samples showed significant difference when compared with the other treatments in terms of higher HRY, higher surface lipid content, different protein composition, higher gelatinization temperature and harder cooked rice. Some UV and oven treatments presented differences from control on HRY.

### 3.5 Conclusion

The seven heat treatments used in this study produced changes in the associated milling, physicochemical, and cooking properties with gradual changes observed in these properties during storage. These heat treatments did accelerate the aging process by stabilizing the properties by 90 days for both rice cultivars. Nevertheless variations were observed among heat treatments and cultivars. More studies are needed to confirm these findings and to understand the mechanism underlying the accelerated aging by different heat sources.

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**Tab 3.1.** Changes in HRY of treated rice as influenced by heat treatments, storage periods and cultivars[1]

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 60.9 | 57.5 | 54.2 | 58.6 | 63.1 | 62.1 | 59.5 | 54.1 |
| | 45 | 62.1 | 60.1 | 56.8 | 62.9 | 67.1 | 59.3 | 58.3 | 56.9 |
| | 90 | 60.0 | 60.4 | 57.5 | 62.9 | 66.8 | 61.2 | 60.8 | 57.9 |
| | 135 | 63.1 | 59.8 | 56.1 | 63.2 | 67.9 | 61.0 | 60.6 | 58.1 |
| | 180 | 64.3 | 60.6 | 56.5 | 62.5 | 66.6 | 61.7 | 60.2 | 56.7 |
| XP723 | 0 | 59.5 | 55.8 | 55.2 | 62.4 | 62.8 | 58.0 | 55.1 | 55.2 |
| | 45 | 60.1 | 55.1 | 55.4 | 57.2 | 60.6 | 56.0 | 53.7 | 52.4 |
| | 90 | 57.5 | 55.9 | 54.5 | 59.0 | 62.3 | 57.1 | 52.0 | 50.9 |
| | 135 | 57.6 | 57.8 | 55.3 | 59.4 | 63.0 | 58.2 | 55.0 | 54.0 |
| | 180 | 58.9 | 55.2 | 52.7 | 57.4 | 62.1 | 58.2 | 54.1 | 50.9 |
| HSD[2] ï 3.05 | | 60.2 | 56.7 | 54.7 | 60.5 | 63.0 | 60.1 | 57.3 | 54.7 |

[1]UV15: UV irradiation for 15 hr; UV25: UV irradiation for 25 hr; A100: autoclaving at 100°C for 20 min; A121: autoclaving at 121°C for 20 min; O80: oven heating at 80°C for 10 min; O90: oven heating at 90°C for 10 min; O100: oven heating at 100°C for 10 min.

[2]In a row, levels of heat treatments with smaller mean differences from HSD value are not significantly different at $p<0.05$ based on LSMeans Differences Tukeyôs HSD test.

**Table 3.2.** Changes in surface lipid content (%) of treated rice as influenced by cultivars, storage period and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 0.31 | 0.29 | 0.28 | 0.60 | 0.74 | 0.40 | 0.38 | 0.31 |
| | 45 | 0.37 | 0.44 | 0.35 | 0.63 | 0.68 | 0.45 | 0.36 | 0.40 |
| | 90 | 0.28 | 0.32 | 0.36 | 0.34 | 0.51 | 0.37 | 0.33 | 0.29 |
| | 135 | 0.48 | 0.27 | 0.33 | 0.41 | 0.59 | 0.35 | 0.29 | 0.25 |
| | 180 | 0.35 | 0.32 | 0.27 | 0.39 | 0.64 | 0.27 | 0.28 | 0.32 |
| XP723 | 0 | 0.36 | 0.41 | 0.36 | 0.41 | 0.76 | 0.40 | 0.35 | 0.37 |
| | 45 | 0.52 | 0.52 | 0.47 | 0.43 | 0.68 | 0.37 | 0.36 | 0.43 |
| | 90 | 0.35 | 0.29 | 0.31 | 0.34 | 0.49 | 0.33 | 0.30 | 0.28 |
| | 135 | 0.33 | 0.35 | 0.29 | 0.35 | 0.56 | 0.31 | 0.36 | 0.30 |
| | 180 | 0.34 | 0.34 | 0.34 | 0.33 | 0.56 | 0.36 | 0.35 | 0.35 |

[1] Abbreviations see Table 3.1.

**Table 3.3.** Changes in peak temperature on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 | HSD[2] ï 0.95 |
| Wells | 0 | 75.5 | 75.6 | 75.4 | 76.4 | 79.3 | 75.3 | 75.6 | 75.3 | |
| | 45 | 75.8 | 75.8 | 75.5 | 76.4 | 78.8 | 76.1 | 75.6 | 75.6 | |
| | 90 | 75.6 | 76.5 | 75.9 | 76.3 | 78.9 | 75.7 | 75.5 | 75.8 | |
| | 135 | 75.8 | 76.1 | 76.1 | 76.7 | 79.3 | 76.1 | 76.0 | 75.8 | |
| | 180 | 75.9 | 75.9 | 75.9 | 75.9 | 79.3 | 75.9 | 76.2 | 76.4 | 75.5 |
| XP723 | 0 | 77.0 | 77.1 | 77.1 | 78.2 | 80.1 | 77.3 | 77.4 | 77.8 | |
| | 45 | 78.2 | 77.5 | 78.3 | 77.4 | 79.3 | 77.0 | 76.6 | 77.0 | |
| | 90 | 77.7 | 77.5 | 78.2 | 78.1 | 79.6 | 77.8 | 77.6 | 77.2 | |
| | 135 | 77.3 | 77.4 | 78.2 | 77.7 | 79.5 | 77.1 | 77.4 | 77.3 | |
| | 180 | 76.9 | 76.9 | 77.0 | 76.9 | 79.6 | 77.2 | 77.4 | 77.1 | 77.0 |
| HSD[3] ï 0.6 | | 76.2 | 76.3 | 76.2 | 77.3 | 79.7 | 76.3 | 76.5 | 76.5 | |

[1] Abbreviations see Table 3.1.

[2] In a column, levels of cultivars with smaller mean differences from HSD value are not significantly different at $p<0.05$ based on LSMeans Differences Studentôs t-test.

[3] In a row, levels of heat treatments with smaller mean differences from HSD value are not significantly different at $p<0.05$ based on LSMeans Differences Tukeyôs HSD test.

**Table 3.4.** Changes in enthalpy on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 10.5 | 11.1 | 11.5 | 11.9 | 10.5 | 11.3 | 10.9 | 11.4 |
| | 45 | 11.7 | 10.9 | 11.0 | 11.0 | 10.3 | 10.6 | 11.1 | 11.5 |
| | 90 | 11.9 | 11.5 | 11.4 | 10.8 | 10.3 | 10.4 | 10.9 | 11.0 |
| | 135 | 11.5 | 11.0 | 11.2 | 11.2 | 10.4 | 11.5 | 11.4 | 11.4 |
| | 180 | 10.9 | 10.7 | 11.5 | 10.9 | 10.2 | 10.7 | 10.8 | 10.4 |
| XP723 | 0 | 11.7 | 12.9 | 12.3 | 12.6 | 12.0 | 12.9 | 12.0 | 12.3 |
| | 45 | 12.4 | 12.8 | 12.3 | 13.3 | 12.7 | 12.8 | 12.3 | 12.6 |
| | 90 | 11.9 | 12.3 | 11.7 | 12.0 | 12.0 | 11.2 | 11.3 | 11.8 |
| | 135 | 12.0 | 12.1 | 11.6 | 12.1 | 11.8 | 12.7 | 12.1 | 11.8 |
| | 180 | 11.8 | 11.4 | 11.4 | 11.7 | 11.6 | 11.4 | 11.5 | 11.2 |

[1] Abbreviations see Table 3.1.

**Table 3.5.** Changes in peak viscosity on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 3840 | 3898 | 3942 | 3853 | 3462 | 3784 | 3720 | 3786 |
| | 45 | 4159 | 3938 | 4226 | 3952 | 3563 | 4003 | 4153 | 4078 |
| | 90 | 4157 | 4276 | 4325 | 4141 | 3778 | 4278 | 4303 | 4256 |
| | 135 | 4088 | 4242 | 4310 | 4269 | 3609 | 4149 | 4122 | 4261 |
| | 180 | 4163 | 4204 | 4339 | 4089 | 3342 | 4301 | 4318 | 4305 |
| XP723 | 0 | 4141 | 4360 | 4291 | 4086 | 4401 | 4230 | 4167 | 4357 |
| | 45 | 4348 | 4516 | 4364 | 4505 | 4453 | 4398 | 4429 | 4420 |
| | 90 | 4482 | 4615 | 4657 | 4735 | 4735 | 4512 | 4565 | 4594 |
| | 135 | 4531 | 4574 | 4675 | 4725 | 4391 | 4445 | 4527 | 4602 |
| | 180 | 4619 | 4553 | 4684 | 4724 | 4382 | 4660 | 4538 | 4594 |

[1]Abbreviations see Table 3.1.

**Table 3.6.** Changes in breakdown viscosity on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 2365 | 2510 | 2407 | 2226 | 1633 | 2366 | 2270 | 2354 |
| | 45 | 2634 | 2492 | 2642 | 2445 | 1665 | 2644 | 2672 | 2591 |
| | 90 | 2704 | 2790 | 2770 | 2560 | 1915 | 2732 | 2817 | 2744 |
| | 135 | 2688 | 2897 | 2909 | 2716 | 1758 | 2740 | 2736 | 2814 |
| | 180 | 2752 | 2810 | 2938 | 2625 | 1624 | 2842 | 2857 | 2897 |
| XP723 | 0 | 2869 | 2991 | 2881 | 2723 | 2682 | 2814 | 2767 | 2925 |
| | 45 | 2980 | 3146 | 2951 | 3068 | 2769 | 3058 | 3060 | 3047 |
| | 90 | 3146 | 3233 | 3225 | 3151 | 2735 | 3107 | 3171 | 3195 |
| | 135 | 3184 | 3228 | 3281 | 3277 | 2588 | 3115 | 3198 | 3261 |
| | 180 | 3246 | 3199 | 3312 | 3259 | 2493 | 3279 | 3184 | 3232 |

[1]Abbreviations see Table 3.1.

**Table 3.7.** Changes in final viscosity on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 3192 | 3167 | 3287 | 3422 | 3702 | 3162 | 3166 | 3171 |
| | 45 | 3304 | 3214 | 3369 | 3277 | 3769 | 3154 | 3263 | 3280 |
| | 90 | 3290 | 3292 | 3391 | 3389 | 3841 | 3364 | 3331 | 3362 |
| | 135 | 3160 | 3124 | 3199 | 3336 | 3679 | 3218 | 3201 | 3235 |
| | 180 | 3199 | 3197 | 3209 | 3227 | 3582 | 3308 | 3248 | 3232 |
| XP723 | 0 | 2732 | 2924 | 2947 | 2929 | 3448 | 2978 | 2990 | 2958 |
| | 45 | 2911 | 2943 | 2961 | 3045 | 3495 | 2878 | 2935 | 2947 |
| | 90 | 2898 | 2997 | 3033 | 3247 | 3760 | 3008 | 2991 | 2998 |
| | 135 | 2894 | 2941 | 3000 | 3073 | 3571 | 2903 | 2907 | 2941 |
| | 180 | 2929 | 2948 | 2973 | 3093 | 3630 | 2996 | 2963 | 2973 |

[1]Abbreviations see Table 3.1.

**Table 3.8.** Changes in setback viscosity on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 1717 | 1778 | 1752 | 1794 | 1873 | 1744 | 1715 | 1739 |
| | 45 | 1780 | 1768 | 1785 | 1770 | 1870 | 1795 | 1782 | 1793 |
| | 90 | 1836 | 1806 | 1836 | 1808 | 1978 | 1817 | 1846 | 1850 |
| | 135 | 1760 | 1779 | 1798 | 1782 | 1828 | 1809 | 1816 | 1789 |
| | 180 | 1788 | 1804 | 1809 | 1763 | 1864 | 1849 | 1786 | 1823 |
| XP723 | 0 | 1460 | 1555 | 1536 | 1565 | 1729 | 1563 | 1590 | 1526 |
| | 45 | 1543 | 1574 | 1548 | 1607 | 1810 | 1538 | 1567 | 1574 |
| | 90 | 1562 | 1615 | 1601 | 1663 | 1760 | 1602 | 1580 | 1599 |
| | 135 | 1547 | 1596 | 1606 | 1625 | 1769 | 1573 | 1578 | 1600 |
| | 180 | 1557 | 1594 | 1601 | 1628 | 1741 | 1615 | 1608 | 1612 |

[1]Abbreviations see Table 3.1.

**Table 3.9.** Changes in leached solids (g/100g) on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 6.05 | 5.98 | 6.53 | 6.40 | 5.03 | 6.63 | 6.03 | 6.70 |
| | 45 | 6.30 | 5.78 | 6.13 | 6.25 | 5.03 | 5.93 | 6.00 | 5.65 |
| | 90 | 6.10 | 5.78 | 5.93 | 6.40 | 4.90 | 5.58 | 5.95 | 5.88 |
| | 135 | 5.43 | 5.55 | 6.15 | 6.55 | 4.85 | 5.85 | 6.45 | 5.60 |
| | 180 | 5.75 | 5.25 | 5.60 | 5.90 | 5.15 | 5.75 | 5.05 | 5.80 |
| XP723 | 0 | 5.95 | 5.93 | 5.83 | 5.40 | 5.70 | 5.75 | 6.45 | 5.88 |
| | 45 | 5.40 | 5.95 | 6.53 | 6.20 | 5.58 | 6.18 | 6.68 | 6.43 |
| | 90 | 4.30 | 5.63 | 5.70 | 6.03 | 5.15 | 5.58 | 5.73 | 5.33 |
| | 135 | 5.95 | 6.20 | 5.55 | 6.05 | 5.35 | 5.80 | 6.05 | 5.85 |
| | 180 | 5.30 | 5.25 | 5.55 | 5.30 | 5.35 | 5.15 | 5.50 | 5.40 |

[1]Abbreviations see Table 3.1.

**Table 3.10.** Changes in cooked rice hardness (N) on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 81.3 | 66.6 | 75.0 | 77.3 | 83.6 | 80.6 | 80.1 | 78.1 |
| | 45 | 78.4 | 73.6 | 73.2 | 80.7 | 88.4 | 83.6 | 81.8 | 85.2 |
| | 90 | 76.9 | 73.6 | 63.5 | 71.4 | 74.8 | 73.6 | 70.7 | 72.9 |
| | 135 | 74.5 | 73.6 | 71.7 | 69.1 | 96.7 | 94.9 | 77.5 | 79.5 |
| | 180 | 79.2 | 80.7 | 80.3 | 75.8 | 82.1 | 75.8 | 81.8 | 75.2 |
| XP723 | 0 | 83.8 | 78.7 | 79.5 | 76.6 | 83.2 | 90.3 | 79.9 | 78.2 |
| | 45 | 65.0 | 75.3 | 71.1 | 73.5 | 76.0 | 80.6 | 68.9 | 78.6 |
| | 90 | 56.7 | 67.3 | 68.6 | 70.0 | 86.2 | 76.3 | 72.9 | 75.7 |
| | 135 | 71.1 | 69.8 | 73.6 | 76.2 | 77.4 | 76.9 | 70.0 | 78.4 |
| | 180 | 79.2 | 81.4 | 82.1 | 79.5 | 75.6 | 78.9 | 70.5 | 78.2 |

[1]Abbreviations see Table 3.1.

**Table 3.11.** Changes in cooked rice stickiness (N) on treated rice as affected by cultivars and heat treatments

| Cultivar | Storage (days) | Heat treatments[1] | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Control | UV15 | UV25 | A100 | A121 | O80 | O90 | O100 |
| Wells | 0 | 16.0 | 9.7 | 9.9 | 9.6 | 10.9 | 11.8 | 13.0 | 10.6 |
| | 45 | 13.2 | 10.7 | 8.2 | 11.1 | 11.7 | 11.8 | 13.7 | 13.3 |
| | 90 | 8.6 | 8.6 | 7.7 | 8.1 | 6.7 | 9.6 | 8.5 | 8.3 |
| | 135 | 10.3 | 11.4 | 11.0 | 12.3 | 15.7 | 15.1 | 12.2 | 12.0 |
| | 180 | 9.7 | 12.0 | 10.5 | 9.5 | 7.8 | 9.1 | 10.2 | 8.5 |
| XP723 | 0 | 13.2 | 14.0 | 13.9 | 13.0 | 11.5 | 16.2 | 12.8 | 13.7 |
| | 45 | 11.0 | 12.3 | 13.3 | 11.9 | 10.2 | 11.9 | 14.5 | 14.8 |
| | 90 | 8.8 | 9.6 | 11.7 | 10.1 | 10.4 | 10.0 | 11.1 | 11.7 |
| | 135 | 8.3 | 8.2 | 8.6 | 8.7 | 7.0 | 8.9 | 8.3 | 9.9 |
| | 180 | 11.0 | 11.1 | 10.1 | 10.8 | 7.4 | 12.2 | 10.8 | 11.3 |

[1]Abbreviations see Table 3.1.

**Table 3.12.** Statistical analysis of factors and interactions using Tukeyôs method

| | Analysis variance of p-values[1] | | | | | | |
|---|---|---|---|---|---|---|---|
| | Cultivar | Storage | Cultivar *Storage | Heat treatment | Cultivar*Heat treatment | Storage*Heat treatment | Cultivar *Storage*Heat treatment |
| HRY | <0.0001 | [2]NS | 0.0552 | <0.0001 | NS | NS | NS |
| surface lipid | NS | <0.0001 | NS | <0.0001 | <0.0001 | <0.0001 | 0.0007 |
| Peak vis. | <0.0001 | <0.0001 | NS | <0.0001 | <0.0001 | NS | NS |
| Breakdown | <0.0001 | <0.0001 | NS | <0.0001 | <0.0001 | NS | NS |
| Final vis. | <0.0001 | <0.0001 | 0.0421 | <0.0001 | 0.0013 | NS | NS |
| Setback | <0.0001 | <0.0001 | NS | <0.0001 | <0.0001 | NS | NS |
| Gel Onset | <0.0001 | 0.0017 | 0.0040 | <0.0001 | 0.0002 | NS | NS |
| Gel Peak | <0.0001 | NS | NS | <0.0001 | 0.0204 | NS | NS |
| Gel end | <0.0001 | NS | NS | <0.0001 | NS | NS | NS |
| Gel enthalpy | <0.0001 | 0.0007 | 0.0394 | NS | NS | NS | NS |
| Leached% | NS | 0.0337 | NS | 0.0733 | NS | NS | NS |
| Hardiness | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Stickiness | NS | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |

[1] p-values of effect test for complete factorial analysis

[2]Statistically significant at 0.05 level. NS = not significant

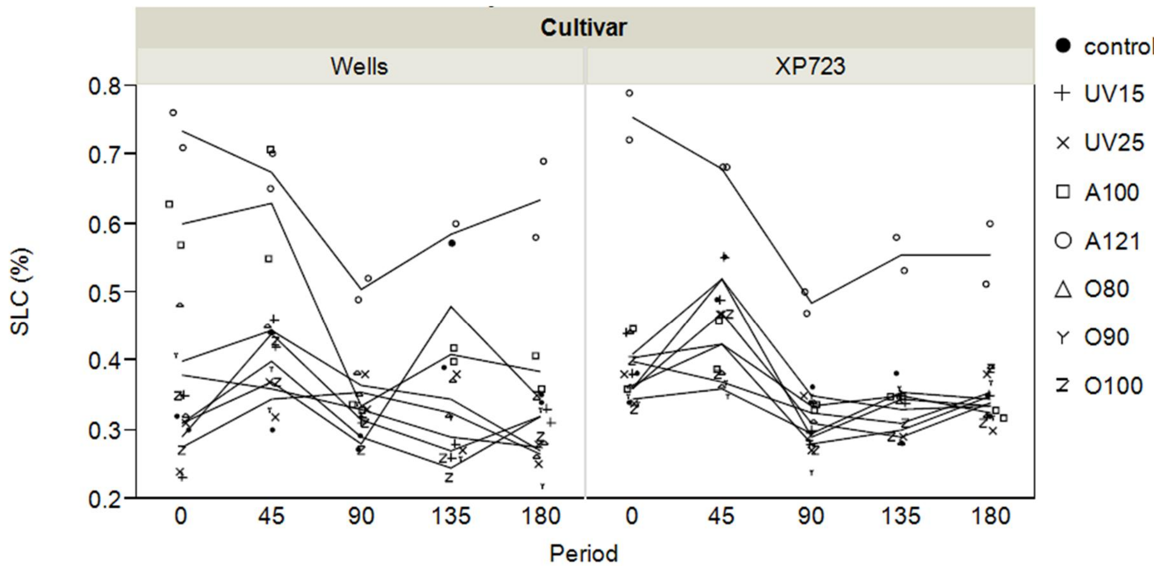


**Figure 3.1.** Surface Lipid content of two U.S. long-grain rice cultivars showing 3-way interaction among cultivar, treatment and storage.

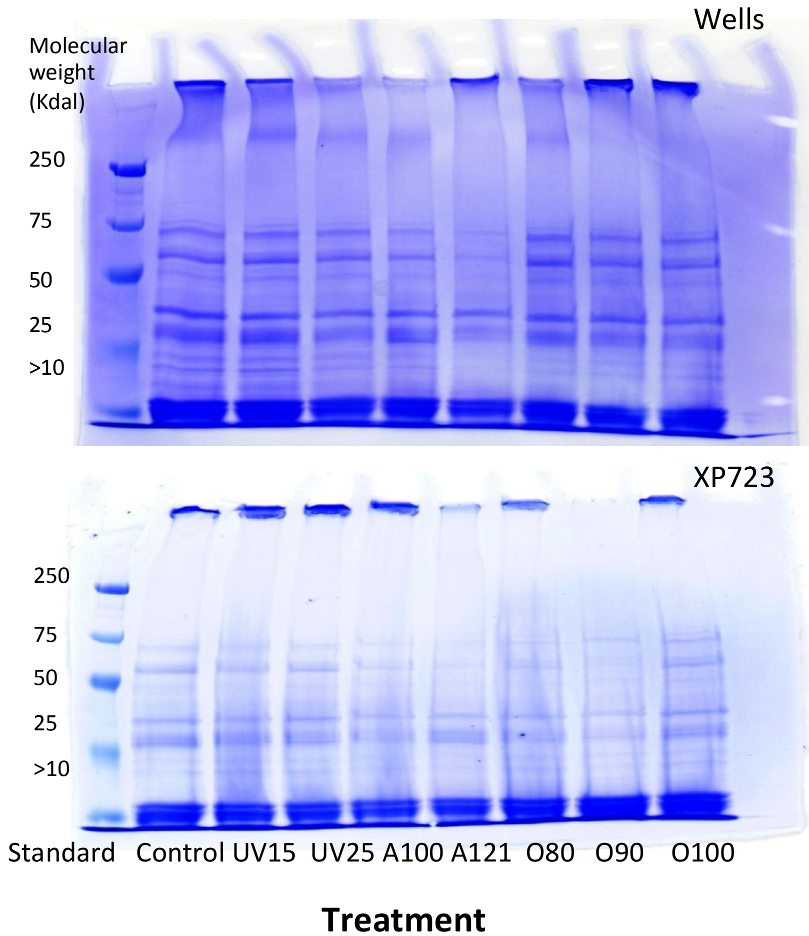


**Figure 3.2.** SDS-PAGE of reduced protein of Wells and XP723 after various heat treatments at 0 day. Abbreviations see Table 3.1.

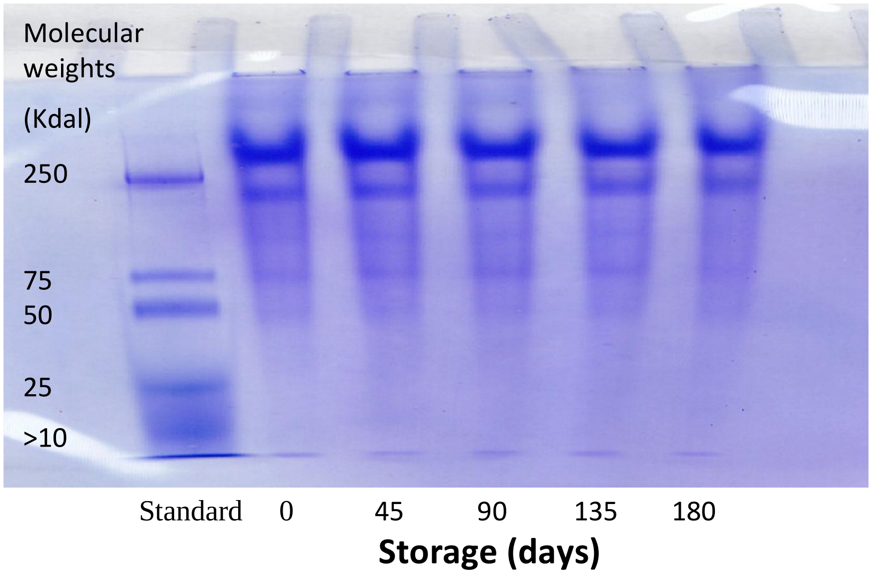


**Figure 3.3.** SDS-PAGE of native protein of Wells control sample during storage.

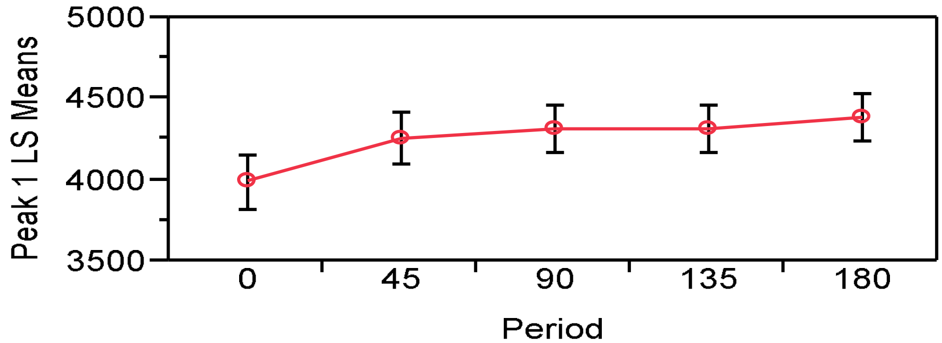


**Figure 3.4.** Peak viscosity LS means of treated rice as significantly affected by storage period