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Effects of Harvest Conditions and Thickness Fractionation on Physicochemical Properties, and Cooking and Sensory Characteristics of Long Grain Rice

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Food Science

by

Sara Esther Jarma Arroyo
Universidad de Córdoba
Bachelor of Science in Food Engineering, 2014

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This thesis is approved for recommendation to the Graduate Council.

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Abstract

Previous research has demonstrated the extensive impacts of various environmental and processing conditions on rice milling and processing characteristics. Nevertheless, little is known about the influences of these conditions on cooking and sensory qualities of rice. The present study aimed to determine the impact of cultivating location, harvest moisture content (HMC), and thickness fractionation on the physicochemical properties, and cooking and sensory characteristics of long-grain rice. Four long-grain rice cultivars (purelines: Cheniere and V3501, and hybrids: XP760 and XL753) were cultivated at Harrisburg, AR and Alvin, TX, and harvested at three HMC. Rough rice lots were conditioned and a portion was fractionated according to thickness into thin (<1.9 mm) and thick (≥1.9 mm) fractions. Unfractioned rice and thick kernels were used for further comparison. Overall, rice samples cultivated in TX showed higher amount of broken kernels, chalkiness as well as lower amylose contents compared to those cultivated in AR regardless of the cultivar, possibly due to the greater nighttime air temperatures reported in Alvin, TX. Additionally, textural characteristics and flavor attributes were affected by the cultivating location. Increases in broken kernels, lipid content, and protein content were observed with increasing of HMC. However, cooking qualities were mostly unaffected by HMC. Finally, the addition of thickness fractionation in the process stream showed to improve rice physical quality. However, fractioned rice showed longer cooking duration and a greater width kernel expansion than did unfractioned rice. This study demonstrated that cultivating location and HMC affect rice final attributes and that thickness fractionation may have impacts on cooking and textural characteristics of long-grain rice.

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Abbreviations

GT – Gelatinization Temperature

HMC – Harvest Moisture Content

HRY – Head Rice Yield

LER – Length Expansion Ratio

MC – Moisture Content

NIR – Near Infrared Reflectance

NTAT- Nighttime Air Temperatures

OCD- Optimum Cooking Duration

RVA – Rapid Visco Analyser

SLC – Surface Lipid Content

WER – Width Expansion Ratio

Chapter 1.

General Introduction

Rice (*Oryza sativa* L.) is the second most economically important cereal in the world after wheat. This cereal is the predominant staple food for 34 countries in Asia, Latin America, and Africa, and it is the main source of calorie for about two-thirds of the world population (FAO, 2014). Even though it has a relatively low protein content (7-9 % weight on average) compared to other cereals, rice is the biggest source of protein in the rice-consuming countries contributing up to 60 % of the total protein in the Asian diet (Shih, 2013). Moreover, rice provides a great source of calories due to its high content of carbohydrates in form of starch and offers a number of benefits, such as higher yields per cultivated hectare, to the agriculture over other cereals (Pathak, 1979).

In recent years, worldwide concerns about the assurance of food security policies and the initiative to promote the generation of employment and incomes in the rural sector have raised serious questions about the long-term sustainability of modern agricultural production systems in the rice sector (FAO, 2004). Therefore, the development of new rice varieties with improved nutritional characteristics and the initiative to plant more hybrid cultivars has emerged as a viable option as they can offer higher yields, increase disease resistance, provide better grain quality, and increase production (Deliberto and Salassi, 2011). Rice varieties are usually characterized according to their grain features and physicochemical traits that impact the eating quality of the cooked rice. However, in the United States rice is classified for marketing purposes only according to the length-width ratio of the grain into three main categories: short-, medium-, and long-grain. Depending on this classification rice, cooking behavior and overall quality of the cooked rice may vary. Short- and medium-grain varieties typically cook moist, chewy, and clingy and are preferred for such products as dry breakfast cereals and baby foods, and for brewing uses. On the other hand, long-grain rice varieties cook dry, fluffy, and remain separate when cooked and are preferred for use in such prepared products as parboiled rice, quick-cooking rice, canned rice, canned soups, dry soup mixes, frozen dishes, and other convenience-type rice-containing foods (Lee, 1987).

Some other classifications of rice are made based on rice's milling, processing, and physicochemical characteristics. Currently, due to the increment of rice consumption in the world, cooking quality has become a key factor for rice producers and consumers. Cooking quality of rice is mostly influenced by its predominant constituent starch, which accounts for about 90% of the dry weight of milled rice. Therefore, it is not surprising that the estimation of starch two main fractions, amylose and amylopectin, constitutes the major quality indicator. Amylopectin is the highly branched component of starch and it has been reported that cooked rice hardness is positively correlated with the amount of long-B chains in the exterior region of amylopectin (Radhika-Reddy et al., 1993). Additionally, since insoluble amylose reflects the amount of long-B chains in the starch structure, its estimation has been set as a sensitive indicator of rice quality. To a lesser extent, components such as protein and lipids also influence the cooking properties of rice. Martin and Fitzgerald (2002) reported that protein affected textural characteristics of cooked rice by competing with starch for water and the formation of disulfide bonds, and lipid restrains the moisture uptake of rice during cooking through amylose-lipid complexes, impeding the leaching of amylose and swelling of starch.

Rice quality traits are influenced by numerous elements that include pre-harvest and post-harvest drying and storage treatments (Lanning and Siebenmorgen, 2011). Pre-harvest factors depend almost exclusively on rice farmer and allow expressing the potential of the rice grain delivered to the mill. However, the influence of other environmental factors that can be hardly controlled during the pre-harvest stage, have also been demonstrated. The effect of air temperature during the grain development stages on cooking and milling quality is perhaps the most studied issue on rice. Higher night air temperature during grain development has a significant impact on starch accumulation, more specifically a decrease in total starch amylose content which, in turn, will have an influence on cooked rice texture. Cultivar selection is another factor of great importance on the cooking and processing behavior of rice. Genotypic interactions on amylose content and cooking quality of different cultivars have been previously demonstrated. Bao et al. (2004) reported that amylose content, breakdown viscosity, setback viscosity, and gel hardness were primarily affected by genotype of rice cultivar. Furthermore, other pre-harvest factors that influence rice quality include time of planting, planting location, irrigation and nitrogen rates, panicle characteristics and kernel maturation, and harvest moisture content (Siebenmorgen, 2013). Siebenmorgen et al. (2013) found that the growing location and HMC affect kernel thickness distributions, green kernel content, fissured kernel content, and head rice yield (HRY). Environmental conditions across different locations, such as different temperatures and soil compositions may explain these results.

Unlike other cereal crops, which are milled into flours, rice is mostly cooked and consumed as an intact grain form (Crowhurst and Creed, 2001). Del Mundo (1979) reported that characteristics such as grain size, color, brittleness, and wholeness of the grain are the most relevant aspects in consumers buying criteria. Likewise, post-harvest processing conditions such as degree of milling can affect rice appearance-related characteristics, thereby influencing consumers' willingness to purchase (Rodriguez-Arzuaga et al., 2015). The rice industry is constantly seeking for new methods that help to improve the quality of rice after harvesting. Among these innovative approaches, many studies have shown that thickness grading on rice may signify an important step in the right direction of enhancing rice overall quality. Building on previous research, this thesis aims to determine whether thickness fractionation, harvest moisture content and cultivating location can affect physical properties, chemical composition, and sensory and cooking qualities of rice.

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Chapter 2.

Literature Review

1.1 Rice History

Rice (*Oryza sativa*, L.) is the most widely consumed cereal in the world and its importance is growing every day due to industrialization and increasing world population. The origins of rice domestication have long been debated on the literature. Currently the varieties grown in most countries belong to the *Oryza sativa* species, commonly known as Asian rice, which in turn contains two major subspecies, *indica* and *japonica*. The vast majority of the varieties grown belong to these species, which are characterized by their plasticity and their taste quality (Nayar, 2014).

Genetic evidence shows that all forms of Asian rice, both *indica* and *japonica*, spring from a single domestication that occurred 8,200–13,500 years ago in the Yangtze Valley of China (Molina et al., 2011) and then spread gradually both northwards and southwards (Bellwood and Glover, 2004). This practice spread to the Huai River by 6,000-5,000 years BP, and over the next millennium, its cultivation also spread to both south and west china (Tang and Xuan, 2010). Moreover, further evidence showed that the oldest evidence of rice cultivation in India date to 2500 BC, in Thailand to 3500 BCE, in the Philippines to 1400 BCE, in Pakistan to 2500 BCE, and in Japan between 1000 to 3000 BCE (Chang, 2000).

It is believed that rice came into the America continent through the “Grand Exchange”, a widespread transfer of animals, plants technology and ideas between the American and Afro-Eurasian hemispheres. The “Black Rice Theory”, proposed by Carney (2001), assumes that rice and the technology for growing it were first brought to the Americas by West African slaves. In the 1670’s, South Carolina became the first state in the United States that was able to grow rice after several fail attempts in other regions such as Florida and Virginia. However, these first crops were only grown for personal use and not for marketing. It was not until the early 18th century that rice cultivation, production and merchandizing became established as a commercial activity in the U.S. (Coclanis, 2011). In the 19th century, after the end of the American civil war, several changes occurred in rice production in the U.S. A reduction of rice production on the Atlantic coast and an increment of cultivation in the southern states such as Louisiana, Texas, and Arkansas began to take place. Rice cultivation in the south became increasingly mechanized with the implementation of irrigation and culture technologies that were commonly used on wheat fields and it is estimated that currently six states account for over 99% of all rice grown in the United States, with the state of Arkansas on the top of this list (Nayar, 2014).

1.2 Nutritional importance of rice

Rice is the predominant staple food for 17 countries in Asia and the Pacific, 9 countries in North and South America, and 8 countries in Africa. This cereal provides 20% of dietary energy supply in the world, while wheat supplies 19% and maize 5% (FAO, 2004). Rice is comprised of 77 to 89% of carbohydrate (milled rice at 14% moisture**)** (Juliano, 1985), which is the major source of energy of the human body. Like other cereals, the carbohydrate in rice is mainly in the form of starch – a complex carbohydrate that exists as either amylose or amylopectin and comprises units of glucose (a simple sugar) linked together in very large numbers. Additionally, rice is a nutritionally important cereal because it has the highest digestibility, biological value, and protein efficiency ratio (PER) among all the cereals (Kaul, 1973). Even though this cereal contains a relative small proportion of protein as compared to other cereals, rice contains more lysine than do wheat, corn and sorghum. Likewise, rice usually provides less dietary fiber than other cereals and thus is more digestible.

1.3. Rice production and consumption

Rice is cultivated in more than 100 countries around the world and is a primary food for about a half of the world's population. The global production of rice reached more than 715 million tons of paddy rice (480 million tons of milled rice) in 2015 (USDA, 2016). Asian countries account for the 90% of the world's total rice production where China and India alone account for around 50% of the rice grown (USDA, 2016). Other major non-Asian rice producing countries include Brazil, the United States, Egypt, Madagascar, and Nigeria, which together account for 5% of the rice produced globally (USDA, 2016). In the U.S., specifically, rice production has been mainly concentrated in the states of Arkansas, California, Louisiana, Mississippi, Missouri, and Texas, using different cultural production practices (Snyder and Slaton, 2001).

Current global milled rice consumption is at 480 million metric tons (MMT) yearly (USDA, 2016), with over 85% (408 MMT) for human consumption (Muthayya et al., 2014). Since China and India which are the two major rice producers also account for ~50% of the world's rice consumption, the rice global trade market reports only 7% over the total production (Muthayya et al., 2014). This export market is, in fact, concentrated in mainly 12 countries, namely, Thailand, Vietnam, Pakistan, the U.S., India, Italy, Uruguay, China, the United Arab Emirates, Benin, Argentina, and Brazil, which explains for more than 90% of the global rice traded (FAO, 2014). By world standards, per capita rice consumption in the U.S. is not large, although it has increased during the past several decades, reaching a level of 30.0 lb per capita annually today (FAO, 2014).

1.4. Rice grain morphology

Rice grain freshly harvested, commonly known as “paddy” or “rough rice”, consists of an outer protective cover, the hull and caryopsis (Figure 1). Integral or brown rice consists of the outer layers of pericarp, seed coat and nucellus, the germ or embryo, and the endosperm (Juliano and Betchel, 1985). The composition and properties of the rice grain and its fractions depend on the genotype, the environment, and the type of processing to which rice is subjected.

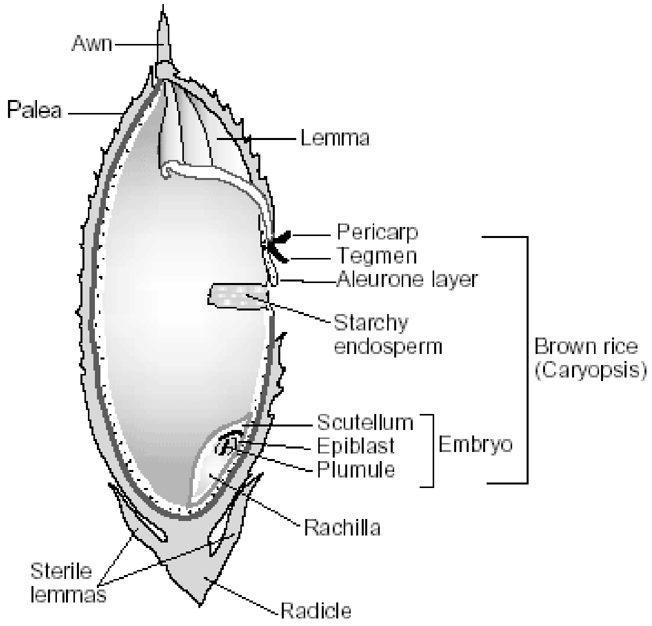

Figure 1. Cross-section of a rice kernel (Juliano and Betchel, 1985)

1.5. Classification of rice grain

Since rice paddy has a husked caryopsis, most rough rice is dry-milled into white polished rice (also named “milled” rice) for further human consumption. USDA (2009) defines milled rice as “*Intact 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 no more than 10.0 percent of* *seeds, paddy kernels, or foreign material, either singly or combined*". In the U.S., milled rice is marketed according to size, form, and condition. These properties are directly related to milling performance, cooking quality, and organoleptic properties of the cooked rice (USDA, 2009).

According to the length-width ratio of the kernel rice is generally classified into short, medium, and long-grain (Table 1) (USDA, 2009). Furthermore, other classifications are based on the physicochemical characteristics of rice such as the amylose content and gelatinization temperature. According to the amylose content rice varieties can be classified into waxy (0-2%), very low (2- 9%), low (10-20%), intermediate (20-25%), and high (25 or greater) (Juliano, 1979). Waxy or glutinous rice which lacks in amylose, has a glossy appearance, slightly expands or absorbs water during cooking and remains wet and sticky after cooking. On the other hand, rice with high amylose content cooks dry and fluffy, whereas rice with intermediate or low amylose content cooks moist, softer, and stickier (Luh and Mickus, 1991).

Table 1. Grain type classification according to the dimensions of the rice kernel for each rice form.

	Length/width ratio (mm)		
Rice form	**Long-grain**	**Medium-grain**	**Short-grain**
Paddy or rough rice	≥ 3.4 to 1	≥ 2.3 to 1	≥ 2.2 to 1
Brown rice	≥ 3.1 to 1	≥ 2.1 to 1	≥ 2.0 to 1
Milled rice	≥ 3.0 to 1	≥ 2.0 to 1	≥ 1.9 to 1

Source: United States Standards for Rice (USDA, 2009)

1.6. Pure-line and hybrid rice varieties

Prior success with the genetic improvements of other cereals such as maize, sorghum and cotton based on the exploitation of the heterosis phenomenon, encouraged researchers to explore these procedures on rice. The term "heterosis" in rice usually refers to the phenomenon whereby a population (hybrid) obtained by crossing two genetically different parents-mind shows superiority to them in growth vigor, vitality, reproductive ability, stress resistance, adaptability , yield, quality of grain and other features (Deliberto and Salassi, 2011). The development of hybrid crops is considered as an important achievement in crop breeding, since compared to other cultivars hybrids usually show superiority in terms of yield (15% to 30% over other cultivars) and disease resistance (Virmani, 1994).

Pureline and hybrid cultivars have also shown differences in their physical and milling characteristics. The degree of milling (DOM), defined as the extent of bran removal from brown rice, is usually an established quality parameter on rice (Puri et al., 2014; Siebenmorgen and Lanning, 2014) since it influences rice characteristics such as color and cooking behavior. Total lipid content (TLC) and surface lipid content (SLC) are commonly used methods employed to estimate the DOM on rice since bran is approximately 20% lipids, hence the surface lipid content of milled rice is directly related to the amount of bran remaining on milled kernels (Siebenmorgen, 2013). Siebenmorgen et al. (2006) demonstrated that hybrid (XL7 and XL8) and pure-line cultivars (Cocodrie, Cypress, and Lemont) differed in their total lipid content and in their surface lipid content; in particular, the SLC levels of hybrids were lower than those of pureline cultivars, suggesting that different cultivars have unique physical or chemical properties that affect their milling characteristics. Moreover, Lanning and Siebenmorgen (2011) evaluated the differences on milling characteristics between two long-grain pure-line cultivars (Wells and Francis) and four long-grain hybrid cultivars (XL723, XL729, CL XL730, and CL). Results showed that hybrids generally reached the target surface lipid content in a shorter duration than did purelines, which is evidenced in shorter milling durations to achieve the same degree of milling (Siebenmorgen and Grigg, 2013a).

2. Rice quality

The concept of rice quality varies from region to region depending on local preferences and requirements set by the international market. The quality of the rice demanded by a particular community may be completely unacceptable. Similarly, within each sector that is part of the rice industry, the term “quality” may have different connotations. For instance, the farmer or producer correlates the term quality with good germination and vigor in the field that guarantees a good yield. On the other hand, from a consumer standpoint quality is determined by rice external appearance when purchased, and/or flavor and texture of the rice after cooked. However, the definition of quality in rice should be defined as the integration and fulfillment of the vast majority of these requirements that each sector demands as separately.

2.1 Rice physical qualities

2.1.1 Milling and head rice yields

From strictly a milling quality perspective, the primary indices used to assess rice quality are milled-rice yield (MRY) and head-rice yield (HRY). Milling is an important processing step of rough rice which is usually done to produce white and polished grain. A commercial rice milling system is a multi-stages process where the rough rice is first subjected to de-husking and then to the removal of brownish outer bran layer, known as whitening. Finally, polishing is carried out to remove the bran particles and provide surface gloss to the edible white portion. Milled-rice yield constitutes the mass fraction of unprocessed, rough rice that remains as milled rice, including both head rice and broken kernels. On the other hand, head rice yield refers the mass fraction of rough rice that remains as head rice, synonymous with “intact kernels” and defined as well-milled rice kernels three-fourths or more of the original kernel length (Siebenmorgen, 2013).

Milling and head rice yields can be highly affected by environmental and processing conditions. Head rice yield typically varies with the moisture content (MC) at which rice is harvested. The harvest MC at which HRY is maximum, under Arkansas weather conditions, is approximately 19% to 21% for long-grain cultivars and 22% to 24% for medium-grains (Siebenmorgen et al., 2007). Fan et al. (2000) also reported significant differences on the HRY of rough rice are subjected to heated-air drying under the variation of several conditions such as variety, harvest moisture content, drying condition and drying duration. Additionally, nighttime air temperature (NTAT) was found to influence the HRY of five cultivars (Cypress, LaGrue, XP710, XL8, M204, and Bengal). As nighttime temperature increased, head rice yields significantly decreased for all cultivars except Cypress and Bengal, for which HRY did not vary among nighttime temperature treatments (Cooper et al., 2008).

2.1.2 Chalkiness

Chalky rice is characterized by a brittle texture due to loose packing of starch granules in the grain, resulting in weaker grain that is more susceptible to breaking (Lanning et al., 2011). Evidently, this characteristic is undesirable in almost every market since it will directly affect the appearance of rice and diminish the rice grade and consumer acceptance. Depending on the localization of the chalky area on or in the endosperm, chalky rice can be classified into four types: white center (core), white belly, milky white, and opaque (Figure 2). White centers are characterized by chalky spots in the center of grain, while white belly refers to chalkiness on the dorsal side of the grain (Suzuki et al., 1979). Furthermore, milky white grains have a chalky texture except in the peripheral part of the grain and opaque or dead grains have an overall chalky texture caused by the interruption of final filling of the grain (Ikehashi and Khush, 1979).

White belly

White core or white center

Milky white

Opaque grain

Figure 2. Types of chalkiness in rice grain (Suzuki et al., 1979)

Air temperature is considered as the major environmental factor that directly causes chalkiness in rice (Lanning et al., 2011). Lisle et al. (2000) reported significant differences among three cultivars that were grown in a glasshouse at either 38/21°C or 26/15°C (day/night temperatures). Rice grown at the higher temperature contained more chalky kernels. Similarly, Fitzgerald and Resurreccion (2009) found similar results on two *indica* varieties of rice. The authors suggested that the formation of chalky kernels is presumably explained due to the decreased substrate supply in high temperatures during critical developmental stages of rice growth. Ambardekar et al. (2011) showed that elevated nighttime air temperatures may contribute to increased chalk and reduced milling quality. However, they suggested that the relationship between temperature and chalkiness was not strictly lineal but rather a quadratic association in which elevated chalk levels were observed at NTATs below and above 18 ºC. Ambardekar et al. (2011) explained this behavior as the possibility of optimum temperature for enzyme activities responsible for packing of starch granules in the endosperm during the grain-filling stages of different rice cultivars.

Along with the environmental conditions such as air temperature, previous studies have found that genetic traits also play an important role in determining the amount of chalkiness in rice. Fitzgerald (2012) identified important genetic information on what makes rice chalky. The discovery of these genetic regions together with well controlled crop conditions could lead to the development of higher quality, chalk-free rice varieties.

2.1.3 Grain fissures

Fissures are cracks in the rice kernel. During milling, kernels with fissures tend to break, causing lower head rice yields, reducing the economic value down to a half (Kunze, 1985). The rice grain is highly hygroscopic, which may make it very susceptible to moisture and temperature changes in the environment (Lan and Kunze, 1996a). Thus, rice is subject to fissuring as it dries below a critical moisture level, either in the field or after harvest (Buggenhout et al., 2013). Mukhopadhyay and Siebenmorgen (2013) observed that fissuring on rice kernels is induced when low moisture content kernels are exposed to rapid moisture-adsorption environments or high moisture content kernels are exposed to rapid moisture-desorption environments. When head rice kernels are exposed to different conditions of air temperatures (10 °C and 30 °C), relative humidity (10%, 20%, 50%, 80%, and 90%), and exposing duration (4, 8, 16, 32, 60, and 120 min), fissured kernel percentages were found to be greater at an air temperature of 30 °C and at extreme relative humidity (10%, 20%, or 90%). Moreover, the authors observed that the pattern of the fissures differed among the different environmental exposures, causing “zig-zag/jagged” surface fissures when the rice was exposed to a rapid-moisture desorption and “cross-wise” fissures when exposed to a rapid-moisture adsorption (Figure 3).

Rice varieties have also shown some differences in their genetic resistance to fissuring. Lan and Kunze (1996b) evaluated these genetic differences among fourteen varieties of rice and encountered that medium grain varieties fissured between 91.6 and 100%, while only 28.6 to 91% of the grains fissured in the long-grain varieties after a controlled environmental condition (30 h at 24 °C and 100% RH). Siebenmorgen (2013) also reported significant differences between a medium grain cultivar and two long-grain varieties (one hybrid and one pure line); more specifically, the medium-grain cultivar group was fissured less than either of the pureline or hybrid long-grain groups.

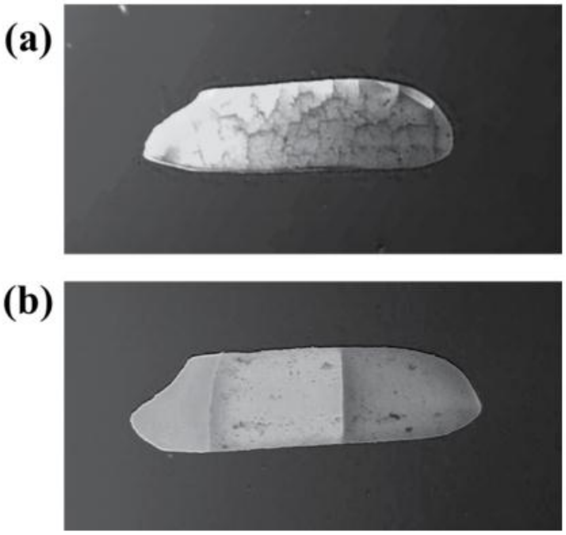

Figure 3. a) Fissured head rice after expose to a rapid moisture-desorption environment (10% RH) and **b)** to a rapid moisture-adsorption environment (90% RH). Both images were taken after the head rice was exposed to air at 30 °C for 90 min (Source: Mukhopadhyay and Siebenmorgen, 2013).

2.1.4 Rice size grading

Rough rice comprises kernels of various sizes. Many studies have shown the importance of size grading on rice in order to enhance milling operations and to reduce kernel breakage during milling of rough rice. Matthews and Spadaro (1976) demonstrated the variability of size of rice kernels within lots after classifying six lots of rough rice into four fractions according to the thickness of the kernels. They found that the distribution of rice among the four thickness fractions differed considerably in the various lots of rice and further reported that breakage in the milled rice was greater for the thinner fractions (0.064 to 0.070 inches). Moreover, Jindal and Siebenmorgen (1994) showed that thicker kernels of rice produced dramatically greater HRY when compared to thinner kernels due to a higher susceptibility of moisture absorption. This behavior was also observed by Chen et al. (1998) where the thinnest fractions of the rice kernel (<1.49 mm) showed a higher SLC than the other kernel fractions. These results implied that during the milling procedure the pressure or duration causes the thinnest kernel fraction to be milled at a greater bran removal rate than the other kernel fractions. Thinner kernels would thus possibly require a shorter milling duration, which will result in a reduction of breakage and an increased milling yield, if milled as a separate process stream.

Physicochemical differences have also been found to be linked with different kernel size fractions. Thinner kernel fractions are associated with higher contents of protein and lipid compared to thick kernels (Mathews et al., 1982; Chen et al., 1998). Siebenmorgen and Grigg (2013b) claimed that the high values of protein are likely to be due to an incompletely filled thin kernel, explained under the light that the development of the bran layer (major protein source in the grain) occurs prior to the endosperm formation during the kernel development. Matthews and Spadaro (1976) showed that bran milled from the thickest (2.0-2.4 mm) fraction was 11% of brown rice mass on average, while bran milled from the thinnest (1.6-1.8 mm) fraction was greater, an average of 17.8% of brown rice mass, considering that the composition of the bran indicates a higher proportion of protein and lipid.

Since size-grading rice would imply an extra process in the rice industry, Siebenmorgen and Grigg (2013a) proposed to split bulk rice into only two thickness fractions, “Thick” (>2 mm) and “Thin” (<2 mm) in order to increase MRY and HRY and decrease variability among lots.

2.2. Cooking quality of rice

2.2.1. Definition of cooking quality in rice

Cooking and processing characteristics of rice are elements of major relevance in countries where rice is a staple food. These characteristics are the fundamental components that determine and establish the economic value of the rice grain. Cooking quality in rice refers to the behavior of milled rice during cooking that involves rice grain volume expansion, water absorption, solids in cooking water, and sensory characteristics including appearance, whiteness, hardness, stickiness, aroma, and taste (Juliano, 1982). These characteristics are mostly influenced by the main constituent of rice, starch. Thus, the measurements of the physicochemical properties of rice starch and its components are set as the major quality standard on cooking quality.

2.3 Physicochemical properties of rice

2.3.1 Amylose content

Starch is formed mainly by two fractions called amylose and amylopectin. The relationship between these two fractions is considered to be one of the most important constitutional indices of rice cooking and processing behavior since it determines a great proportion of the final characteristics of cooked rice (Lee, 1987). Chinnaswamy and Bhattacharya (1986) suggested that the proportion of long-B chains in the amylopectin fraction was a major determinant of rice texture due to an intermolecular association that strengthened the starch molecule conferring to the rice a firm texture. Furthermore, it has been shown that the amount of insoluble amylose in the starch molecule is directly proportional to the presence of long-B chains of amylopectin (Radhika-Reddy, 1993). Thus, the determination of insoluble amylose was proposed as a successful indicator of rice quality.

Varietal selection and differences in processing methods are two of the most important factors that influence amylose content of rice and rice products. Overall, long-grain varieties generally have higher amylose content than short grain varieties (Williams et al., 1958; Hettiarachchy et al., 1997). However, differences on the amylose content have been observed within the same rice varieties, which indicates that environmental factors are highly influential in composition and, consequently, cooking characteristics of rice. For instance, one of the primary environmental factors that can directly affect the amylose content of the rice starch is the ambient temperature during grain development (Juliano, 1985). Elevated temperatures generally cause the amylose content of the rice endosperm to decrease. Ahmed et al. (2014) evaluated the effect of high temperature (32 °C) during the grain filling period on the amylose content of Basmati rice. Higher temperature caused a reduction in total starch (3.1%) and amylose content (22%). They suggested that these changes in amylose/amylopectin ratio observed in plants grown at high temperatures were attributable to a reduction in activity of GBSS, the sole enzyme responsible for amylose biosynthesis. The temperature impact is greater in low-amylose cultivars and lesser in intermediate- and high-amylose cultivars (Cameron et al., 2005).

The traditional method for quantitation of amylose in rice is based on the starch-iodine-blue value protocol of Williams et al. (1958) amylose complexes with iodine produce a brilliant blue color. Thus, this characteristic has been used as an analytical tool for measuring amylose content based on the absorbance of the blue color measured with a spectrophotometer. Additionally, other studies have suggested the use of other technologies such as Near-Infrared Reflectance Spectrophotometry to measure the apparent amylose content of milled rice, in order to overcome some of the issues that chemical methods could offer (Delwiche et al., 1995; Meullenet et al., 2002; Ibrahim and Rahim, 2012).

2.3.2. Gelatinization temperature

Starch granules in their native form are insoluble in water but can reversibly absorb water and swell slightly. However, at higher temperatures, starch molecules vibrate more energetically, provoking the breakage of intermolecular bonds and allowing the penetration of water, which subsequently induces an irreversible swelling and a significantly altered structure of the grain. This process is called gelatinization and the temperature at which it occurs is called gelatinization temperature (GT) (Lee, 1987). Gelatinization temperature of rice starch varies widely among rice varieties and is classified as low (58°- 69.5°C), intermediate (70°-74°C), and high (74.5°-79°C) (Juliano, 1979).

Although rice lines with higher gelatinization temperature have been found to contain lower amylose content (Juliano, 1985), gelatinization temperature is not directly related with the texture of cooked rice. Gelatinization temperature is positively correlated with cooking duration; rice with higher GT needs more water and a longer cooking duration than rice with low or intermediate GT. Temperature during grain ripening has been shown to affect gelatinization temperature of rice starch. Villareal et al. (1976) demonstrated that a high ambient temperature results in higher gelatinization temperature of the rice starch. Similarly, studies have found that starch in the different portions of the rice grain is affected at different moments when rice is treated at higher temperatures in different stages of the grain ripening phase. Generally, starch in the inner portions of the rice grain was more affected by the temperature in the early ripening stage, whereas in the outer layer it was more affected in the late ripening stage (He et al., 1990).

There are several methods that are currently used to estimate gelatinization temperature of milled rice. The alkali spreading value (ASV) is one of these approaches and it is based on the extent of grain dispersion when soaked in potassium hydroxide solution (Little et al., 1958). The ASV is inversely related to the gelatinization temperature; thus rice with low GT disintegrates completely, whereas rice with intermediate GT shows only partial disintegration. Rice with high GT, on the other hand, remains largely unaffected in the alkali solution. Additionally, gelatinization properties can be assessed by differential scanning calorimetry (DSC) as well. DSC is a thermal analysis technique to measure the temperature and heat flows associated with phase transitions in materials as a function of time and temperature. Such measurements can provide both quantitative and qualitative information concerning physical and chemical changes that involve endothermic (energy consuming) and exothermic (energy producing) processes, or changes in heat capacity (Roos, 1995).

3. Sensory aspects of rice

3.1. Sensory aspects of raw rice

Sensory qualities of food are widely considered as the main factors in food choice and food consumption (Clark, 1998; Meiselman and MacFie, 1996). Regarding rice consumption, the appearance of the rice grain is the principal attribute that is established by the consumer as determinant in their selection standards. More specifically, appearance-related characteristics such as grain size, color, brittleness, and wholeness of the grain are highly relevant in consumers’ buying criteria (Del Mundo, 1979). However, consumer preferences for grain size and shape vary from one group of consumers to the other. Short grain rice, which has a nearly spherical shape, is preferred by people in the countries like Japan, China, and Korea. Medium grain rice is the most used in the Spanish cuisine and is widely used in Latin America where the largest producers and consumers are Brazil, Colombia, Peru, Ecuador, Argentina, Chile, Cuba, Puerto Rico, and Dominican Republic. Moreover, lon- grain rice is widely used in the Chinese and Indian cuisine and is the most sold popular in the United States (FAOSTAT, 2014).

Grain appearance is also largely determined by endosperm opacity, the amount of chalkiness, and the condition of the eye (pit left by the embryo). In some varieties the grain tends to be broken more frequently at the eye when it is milled (Khush et al., 1979). Rice samples with damaged eyes have poor appearance and low market value. Similarly, as rice has greater chalkiness, its market acceptability decreases. The starch granules in the chalky areas are less densely packed when compared to translucent areas. Therefore, the chalky areas are not as hard as the translucent areas and the grains with chalkiness are more prone to breakage during milling (DeLa Cruz and Khush, 2000). Additionally, surface color is an important measure of the quality of rice grains, which directly reflects the preservation phase, maturity degree, grade, and growth defect of rice grains, so that it can show the quality of rice grains (Liu, 2010).

Aroma in rice is an issue of particular importance as it is not only a factor determining market price, but also a trait with clear local and national identity. There are some specific varieties that are characterized by their strong aroma and commonly named aromatic rices. Some examples of aromatic rice varieties are Basmati, Jasmine, Texmati, Tulaipanji, Wehani, and Wild Pecan. Typically, varieties of Jasmine rice are consumed in countries of South East of Asia and many Basmati styles of rice are consumed in countries of South and Central Asia (Fitzgerald, 2004). However, for consumers in Europe, a trace of aroma in rice is an unpleasant trait because for them any scents in rice signal spoilage and contamination (Efferson, 1985).

Processing and environmental conditions such as degree of milling and amylose content have shown to affect the appearance and aroma of uncooked rice. Rodríguez-Arzuaga et al. (2015) demonstrated that sensory impacts of DOM on raw rice were present between brown rice and milled rice samples, but not among the milled rice samples varying in SLC level from 0.64% to 0.25%. These results indicated that consumers may not detect appearance- or aroma-related differences among raw rice samples ranging in SLC from 0.64% to 0.25% which could be used as a nutritional benefit in the market without affecting the sensory quality. Moreover, amylose content has been negatively correlated with the whiteness of rice and positively correlated with the aroma (Juliano, 1979).

3.2. Sensory aspects of cooked rice

Sensory characteristics of the cooked rice include appearance, as well as flavor, taste, aroma, mouth-feel, and textural features (Juliano et al., 1981; Meullenet et al., 2001; Yau and Huang, 1996). Texture is perhaps the most studied parameter of rice sensory quality. Szczesniak (2002) defined texture as "*the sensory and functional manifestation of the structural, mechanical and surface properties of foods detected through the senses of vision, hearing, touch and kinesthetic*". Rice texture has been found to be affected by several factors such as rice variety, amylose content, and processing conditions (Meullenet et al., 1998). The amylose content was found to show a positive correlation with the sensory hardness and stickiness of the cooked rice (Champagne et al., 1999; Lu et al., 2013). Mohapatra and Bal (2007) reported that amylose content had a negative impact on the adhesiveness of the rice and a positive impact on the cohesiveness and hardness. Moreover, Mestres et al. (2011) reported that the protein content of rice was negatively correlated with the adhesion of the grains, defined as the degree to which the grains stick together in a mass. These results were supported by previous studies that suggested that protein affects the amount of water that the rice absorbs through an interaction of a protein network linked by disulfide bonds. Thus, higher protein content and higher disulfide bonds limit starch/water interaction and consequently adhesion (Martin and Fitzgerald, 2002),

Instrumental analysis for assessing rice texture has been widely used in order to overcome some of the drawbacks, such as the impracticality and the high costs, of the descriptive sensory analysis. Lyon et al. (1999) showed instrumental texture profile of cooked rice on 1 g aliquots using a texture analyzer. They found that the texture profile analysis (TPA) was sufficiently sensitive to find distinct differences in textural characteristics among the rice samples. However, the sensitivity of the descriptive panel was higher and the correlation between the instrumental analysis and the sensory attributes was weak. Furthermore, Meullenet et al. (1999) predicted the sensory textural characteristics of rice using a miniature extrusion cell. They found that this method had a high correlation with sensory textural characteristics and was less demanding of sample quantities than other methods such as the Ottawa cell.

Aroma and flavor of rice have been regarded as one of the main buying criteria for consumers (Del Mundo and Juliano 1981). Instrumental analyses (gas chromatography or mass spectrometer) have found over 200 volatile compounds present in rice. However, only a few compounds have shown to affect aroma and flavor of rice. Overall, there is a general agreement on the influence of 2-acetyl-1-pyrroline (2-AP) (popcorn aroma) as the main influencer on rice flavor (Champagne, 2008). Additionally, many researchers have attempted to link other volatiles with specific rice descriptors (Jezussek et al., 2002; Lam and Proctor 2003). Lam and Proctor (2003), determined that lipid oxidation products are the most likely contributors to rice off flavors. They concluded that hexanal (grassy flavor) and 2-pentylfuran (beany) probably contributed more to flavor change in milled rice early in storage rather than later. 2- Nonenal (rancid flavor) and octanal (fatty flavor) contributed more to the overall flavor of milled rice during long-term storage. These results could indicate that perceived aroma of rice may result from interactions of several volatiles.

Different techniques of descriptive analysis have been used to determine cooked rice aroma, flavor, and texture attributes. Yau and Hang (1996) evaluated the sensory characteristics of four rice varieties (TNu 67, TNu 70, TC 189, and TC Sen 10) using a modified quantitative descriptive analysis with 20 trained assessors. They identified 13 attributes that described cooked rice appearance, texture, aroma, and flavor characteristics. The study was based on some lexicons for cooked rice texture (Lyon et al., 1999; Stikalin and Meullenet, 2000) and flavor attributes (Meilgaard et al., 2007) previously developed. Meullenet et al. (2000) evaluated the effect of post-harvest conditions (rough rice moisture content, storage temperature, and storage duration) on sensory quality of one long-grain rice cultivar grown in Arkansas (Cypress) using nine professional descriptive panel according to a Spectrum methodology (Sensory Spectrum, Chatham, NJ). The Spectrum methodology is a sensory profiling method designed to provide universal sensory intensities, especially adequate to provide reliable results for shelf life studies. The method relies on common commercial food references used as anchors for each of the specific sensory attributes studied and provides absolute sensory intensities that can be compared even if testing dates are spread throughout long periods of time. Temperature at which the samples are evaluated on either instrumental or descriptive analysis highly affects cooked rice attributes (Okabe, 1979). Yau and Hang (1996) evaluated the effects of two temperatures (18-60 °C) on the descriptive sensory analysis of four rice cultivars. Their results showed that the samples served at either 18 °C or 60 °C significantly differed with respect to nine attributes. It was found that the rice served at 60 °C were rated higher in looseness, hot-rice aroma, brown-rice aroma, and sweetness, but it was rated lower in cold-rice aroma, hardness, cohesiveness, chewiness and roughness when compared to the rice served at 18 °C. Meullenet et al. (1998) stated that repeatability of instrumental measurements was poor when conducted on warm rice. Due to that point, they proposed that rice samples should be sifted immediately after cooking and rinsed for 5 min. under cold water. Then, spread on plastic trays covered with aluminum foil and stored at 4 °C until testing (2–3 hr). Before the instrumental analysis, rice samples may be allowed to equilibrate to room temperature for 30 min. For descriptive analysis, on the other hand, samples were served at 71 ± 1 °C. Panelists were asked to monitor the temperature during the test and to complete the evaluation before the temperature of the reached 60 ± 2 °C.

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Chapter 3.

Evaluation of thickness fractionation as a process to potentially impact cooking qualities and sensory characteristics of long-grain rice (*Oryza sativa* L.)

Abstract

Thickness fractionation has been proposed as a method to improve kernel uniformity and increase milling yields in the rice industry. This process consists in the exclusion of thinner kernels that have shown to decrease rice milling and physical properties. However, little is known about how this process can impact cooking and sensory qualities of rice. This study aimed to determine whether physicochemical properties, cooking qualities, and sensory characteristics can vary by the application of thickness fractionation in the rice process stream. Two long-grain pureline cultivars (Cheniere and V3501) and two hybrid cultivars (XL753 and XP760) were used in this study. After conditioning, rough rice lots were thickness-graded into two fractions: thin (<1.9 mm) and thick (≥1.9 mm) kernels. Thin kernels were discarded and physicochemical properties in addition to cooking and sensory qualities of unfractionated and fractionated (thick fraction) rice were determined. Overall, removal of thin kernels decreased the percentage of broken and chalky kernels as well as increased head rice yield (HRY). Thickness-graded rice exhibited higher amylose content, crude protein content, and peak viscosities than non-fractioned rice, but lower gelatinization temperatures. Similarly, cooking qualities such as a longer cooking duration and greater width kernel expansion were shown by rice samples after thickness fractionation. However, there were little impacts of the thickness grading on sensory and textural characteristics of long-grain rice. This study provides an overview about how the implementation of an extra step such as thickness fraction in the process flow may affect qualities of uncooked and cooked long-grain rice. The findings may be useful for rice processors to better understand the impacts of thickness fractionation on rice qualities.

1. Introduction

Previous studies have demonstrated the importance of thickness grading on rice as a process to improve milling operation and to reduce kernel breakage during milling of rough rice (Siebenmorgen et al., 2006). Thickness grading or fractionation of rice refers to the process in which rough rice is first screened according to size into different thickness fractions and then the thinner kernels are removed for other applications such as flour or parboiling (Mathews, 1982). Jindal and Siebenmorgen (1994) showed that thicker kernels of rice produced dramatically greater head rice yield (HRY) when compared to thinner kernels due to a higher susceptibility of moisture absorption of thinner kernels that consequently increase the breakage rate during milling. Additionally, Chen et al. (1998) observed that thinnest fraction (<1.49 mm) of the rice kernel showed a higher surface lipid content than the other kernel fractions after milling under the same condition. These results proved that the pressure to which rice is subjected during milling or the duration of the milling procedure causes the thinnest kernel fraction to be milled at a greater bran removal rate than the other kernel fractions. Thus, since thinner kernels will require a shorter milling duration, if these are milled in a separate process breakage could be reduced and higher milling yields be obtain.

Physicochemical properties of rice have been found to vary depending on the kernel thickness (Mathews et al., 1982; Chen et al., 1998). Thinner kernel fraction shows greater amounts of crude protein and lipid and lower amount of starch than thick kernel fraction (Mathews et al., 1982; Chen et al., 1998). Such differences in physicochemical properties can be linked to cooking and sensory qualities of rice (Singh et al., 2005). Rice with a high amylose content (25-30%) tends to cook firm and non-sticky, while rice with an intermediate amylose content (20-25%) tends to be softer and stickier and rice with a low amylose content (<20%) is generally quite soft and sticky (Bhattacharya, 2011). To a lesser extent, components such as protein and lipid also influence cooking properties of rice (Martin and Fitzgerald, 2002). More specifically, protein content of rice was found to affect textural characteristics of cooked rice by competing with starch for water and the formation of disulfide bonds, and lipid restrains the moisture uptake of rice during cooking through amylose-lipid complexes, impeding the leaching of amylose and swelling of starch (Martin and Fitzgerald, 2002).

Since rice is usually consumed as a intact grain, rice industries determine the economic value of rice depending on its cooking and eating qualities, which can be measured in terms of water uptake ratio, kernel elongation during cooking, solids in cooking water, cooking duration, and sensory aspects. In addition, the steady increment of rice consumption is accompanied by more strict consumers who demand rice products with premium qualities. Appearance of the grain, with respect to shape, size, or color, is considered as the major attribute that determines quality of rice by consumers. For example, rice products including many broken and /or chalky kernels (opaque regions of the grain) are considered as a low grade quality, which may in turn decrease overall market value (Juliano, 1990; Wrigley and Batey, 2010). Color of polished grain is another perceptible quality that influences consumers' purchase decision. After milling, color of rice varies from white to yellow based on variety, pre-processing, and storage conditions. Overall, consumers are more likely to favour white uncooked rice than yellowish rice (Bhattacharya, 2011). Furthermore, for cooked rice, appearance, aroma, flavor, and texture are all sensory characteristics that play a crucial role in consumer acceptance (Champagne, 2004; Suwannaporn and Linnemann, 2008). Meullenet et al. (2001) indicated that the most important sensory characteristics influencing Asian consumers' acceptance were appearance (degree of whiteness and visual stickiness) and aroma/flavor (starchy, cooked grain, nutty, sulfur, heated oil, and metallic). High cohesiveness, high softness, and low stickiness were found to be textural characteristics that Asian consumers preferred. However, non-sensory characteristics such as price, location where the rice was grown, and nutritional value are also considered as factors that influence consumers' preference and purchase decision (Meullenet et al., 2001).

Even though the benefits of including thickness fraction process in milling quality of rice has been widely explored, little attention has been paid to the influences of thickness fraction process on cooking and sensory qualities of rice. Therefore, the objectives of this study were to determine whether cooking qualities and sensory characteristics, in addition to the physicochemical properties, can vary with the implementation of the thickness fraction step in the rice processing flow.

2. Materials and Methods

2.1 Rice samples conditioning

Two long-grain pureline cultivars (Cheniere and V3501) and two hybrid cultivars (XL753 and XP760) grown in Harrisburg, AR were used in this study. Each cultivar was harvested at a moisture content level (18.5-20.5%, wet basis) in fall 2015. Rough rice samples were cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, MN, U.S.A.). The cleaned lots were then conditioned to12.0 ± 0.5% (wet basis) moisture content using a climate controlled chamber (26°C and 56% relative humidity), regulated by a stand-alone conditioner (Model 5580A, Parameter Generation & Control, Black Mountain, N.C.).

A preliminary study was conducted with the purpose of determining if consumers were able to discriminate the appearance of milled rice that was included in the thickness grading process (thickness-graded rice) compared to when it was not applied (unfractioned rice). Two long-grain rice cultivars (pureline: V3501 and hybrid: XL753) were thickness-graded into four thickness fractions: 1.6 mm, 1.7 mm, 1.80 mm 1.9 mm and 2.0 mm. Participants were asked to compare the difference of the four thickness fractions with a control (unfractioned rice) on a 10-point scale (0= *no difference*, 10 = *Extreme difference*) for both cultivars. The study was conducted across three different cultural backgrounds (Asian, Hispanic, and Caucasian) in order to assess the influence of cultural background on the appearance discrimination of the various thickness fractions. Based on the result of the preliminary study, the cutoff level of thickness grading would be determined for the rest of this study. However, as shown in Table 1 consumers were not able to detect any significant differences among any of the thickness fractions in the two cultivars, regardless of the cultural background ($P > 0.05$ for all). Thus, a standard thickness cutoff of 1.9 mm was chosen based on previous research and realistic occurrence in rice industry (Siebenmorgen et al., 2016).

2.2 Thickness fractionation of rough rice and milling properties

In addition to bulk, unfractioned rice, a portion of each bulk rice lot was thickness graded at a 12.0 ± 0.5% (wet basis) moisture content using a precision sizer (Model ABF2, Carter-Day, Minneapolis, MN) equipped with rotary screens (30-cm diameter). Bulk rice was screened only once, and split into two thickness fractions, thin (<1.9 mm) and thick (≥1.9 mm), in order to mimic what could occur in a realistic setting in rice industry. For the purposes of this study, the thin fraction was discarded, and the thick (fractioned) and the unfractioned rice portions were used for further analysis.

Rough rice of each cultivar was dehulled using a dehusker (THU-35, Satake, Hiroshima, Japan), and the resultant brown rice was milled using a laboratory miller (McGill number 2, RAPSCO, Brookshire, TX, U.S.A.). Rice was milled for durations of 10, 20, 30 and 40 in order to develop relationships between degree of milling (DOM) and milling duration; allowing determination of the milling duration required to achieve the desired DOM for each lot and fraction, as indicated by 0.4 ± 0.05% surface lipid content (SLC). Each rice sample was stored in a sealed container at 4 °C. The containers were placed at room temperature (22 °C) for 24 h prior to sample preparation and further analysis. Head rice yield was determined, with head rice being separated from broken kernels using a sizing device (Model 61, Grain Machinery Manuf. Corp., Miami, FL) and maintained for determination of quality properties.

2.3 Physical properties

To determine the effects of thickness fractionation on physical properties of rice, approximately 100 kernels of head rice were weighted and placed in a 32 mm-thick tray (152 mm x 100 mm x 20 mm); in a manner that no two kernels were in contact with each other. Physical properties, i.e., kernel dimensions, broken kernels, chalky kernels, and discoloration of head rice samples, were measured using an image analysis system (SeedCount SC 5000, Next Instruments, Condell Park, Australia). From a preload profile, discoloration of kernels were defined as the discolored area percentage with yellow, red, brown, black, green, and light pink shades. Chalky area of milled rice (100 kernels of each cultivar/fraction/replicate) was determined by the procedure of Ambardekar et al. (2011). Upon scanning the kernels, the software determined number of color pixels associated with both non-chalky and chalky tissue, as previously identified through a calibration procedure, and calculated the percentage of the total-kernel area that was chalky. The measurements were done by triplicate and averaged.

Furthermore, degree of whiteness (*L**) was determined by scanning approximately 60-g of head-rice kernels using near-infrared reflectance (NIR) spectroscopy (NIR-DA 7200, Perten Instruments, Huddinge, Sweden). All the analyses were evaluated in triplicate.

2.4 Chemical composition

A 60-g portion from one head rice sub-sample was ground into flour with a cyclone mill (3010-30, UDY, Fort Collins, CO, U.S.A.) with a 0.5 mm screen to determine the effects of thickness fractionation on moisture content, amylose content, pasting property, thermal property, and crude protein content of rice samples.

The moisture content of the rice flour was measured according to AACCI method (44 15.02), i.e., by drying a 2.5-g portion at 130°C oven for 2 h. Amylose content was determined by the simplified iodine assay method (Juliano, 1971). Approximately 100 mg of rice flour were transferred into a 50 ml test tube where 1 ml of 95% ethanol and 9 ml of 1 N NaOH were added. The sample was then heated for 20 minutes in boiling water bath. After cooling, the content was transferred into a 100 mL col flask and the volume made up to 100 mL. A 5 mL aliquot was pipetted from the 100 mL solution into a disposable test tube, and 0.1 mL of 1 N acetic acid and 0.25 mL of iodine solution were added. The mixture was stirred and allowed to incubate for 30 minutes and the absorbance was read at 620 nm. Amylose content of the sample was determined in reference to a standard curve and expressed on percent basis.

Pasting properties of the rice samples were determined with a Rapid Visco Analyser (RVA Super 4, Newport Scientific, Warriewood, Australia). Approximately 3 g of flour were combined with 25 mL of deionized water in an aluminum cylinder. The exact quantities of rice flour were adjusted according to samples MC at a 12% moisture basis. The flour and water were mixed briefly with a plastic paddle, forming slurry, before the sample cylinder and paddle were inserted into the viscometer. The slurry was first heated to 50 °C and held at that temperature for 1.5 min, before heating at a rate of 12°C/min to 95 °C, holding for 2.5 min, then cooling to 50 °C at a rate of 12 °C/min, while stirring and measuring viscosity continuously. A thermogram was produced by the viscometer software showing change in viscosity over the cycle duration, as well as summary statistics of peak viscosity, trough viscosity, breakdown (peak-trough viscosity), final viscosity, setback (final-peak viscosity), peak time, and pasting temperature.

Thermal properties, such as onset, peak, and conclusion gelatinization temperatures (GT), of rice samples were measured using a differential scanning calorimeter in modulating mode (DSC-Q100, TA Instruments, New Castle, DE, U.S.A.). Approximately, 4 mg of rice flour were placed into an aluminum DSC pan with 8 µl of distilled water added via a micro syringe. After sealing, pan was equilibrated at room temperature for 1 h prior to heating from 25 °C to 120 °C at 10 °C/min.

Finally, crude protein content of milled-rice samples was determined by scanning approximately 60 g of head-rice kernels using NIR spectroscopy (NIR-DA 7200, Perten Instruments, Huddinge, Sweden). All the analyses were evaluated in triplicate.

2.5 Cooking qualities

Optimum cooking duration (OCD) was measured by Ranghino test for milled rice (Juliano and Bechtel, 1985). In a 250 mL beaker, about 100 ml distilled water was boiled (98 ± 1 °C) and 5 g of head rice samples were placed into the boiling water. Measurement of cooking duration was started immediately. After 10 min and every minute thereafter, 10 grains of rice were removed and pressed between two clean glass plates. The first time was determined when at least 90% of the grains no longer had opaque core or uncooked centers. Afterwards, the rice was then allowed to simmer for additional 2 min to ensure that rice was completely cooked. OCD included the additional 2 min of simmer. The measurement was done by triplicate and averaged among the three replications.

Length expansion ratio was calculated as a ratio of the length of cooked grain to that of the raw grain. In a similar way, width expansion ratio was calculated as the ratio of the width of the cooked rice to the initial width of the raw rice (Juliano and Bechtel, 1985). Length and width dimensions of 100-kernel (approximately 1 g) sample were measured. Subsequently rice was cooked until optimum cooking duration and both dimensions were measured after cooking. This procedure was done by triplicate.

2.6 Descriptive sensory analysis

Descriptive sensory analysis of cooked rice was conducted at the University of Arkansas Sensory Service Center (Fayetteville, AR, U.S.A.). Nine professionally trained panelists, each with an average experience of greater than 1,000 hours in evaluating a variety of food products, including rice, participated in the descriptive analysis. Prior to the assessment of the samples, orientation/training sessions (for 6 hours) conforming to the Spectrum method (Sensory Spectrum Inc., Chatham, NJ, U.S.A.) were conducted. Table 2 lists the definitions and reference intensities of individual flavor and texture attributes that were evaluated.

Each rice subsample (300 g) was cooked in an electric rice cooker (RC3314W rice cooker, Black & Decker, Beachwood, OH, U.S.A.) with a 1:1.8 rice-to-water mass ratio. After being cooked, the rice was allowed to set for five minutes. Cooked rice samples were mixed and fluffed in the rice cooker using a plastic fork to ensure homogeneity, and then dipped using a plastic spoon and presented to the panelists. Each of the cooked-rice subsamples was presented at 71 ± 1 °C in a glass bowl and covered with a watch glass. Each subsample was randomly presented to the panelists, one after another. Intensities of the sensory attributes were evaluated on a 15-point scale basis. A 10 min break was allowed between sample presentations. The entire test was repeated, on a different day, to provide two replicate sensory analyses of the cooked rice samples.

2.7 Texture profile analysis

Cooked rice of each subsample was collected during sensory analysis, and the texture profile analysis (TPA) was performed on the same day. TPA was conducted using a texture analyzer (TA-XT2i, Stable Micro Systems, Ltd., Godalming, Surrey, U.K.) with a 5-kg load cell and a cylinder probe of 20-mm in diameter. The data were acquired using Texture Exponent 32 (Stable Micro Systems, Ltd.).

A two-cycle compression was set on three intact rice kernels that were placed on a clean flat aluminum base. The compression probe traveled for a distance defined to compress the kernels to 70% of their original height. The crosshead pretest, test, and post-test speeds were 0.5 mm/s, 3.0 mm/s, and 0.5 mm/s, respectively. The rice samples were analyzed for four TPA parameters: hardness (N), adhesiveness (N × s), cohesiveness, and chewiness (Saleh and Meullenet, 2007). Measurements were repeated five times for each rice subsample.

2.8 Statistical analysis

Statistical analyses were performed using JMP Pro (version 12.0, SAS Institute Inc., Cary, NC, U.S.A.). two-way analyses of variance (ANOVA) were used to determine the effects of thickness grading and cultivar on physicochemical properties and cooking qualities. If a significant difference in means was indicated by the ANOVA, post hoc comparisons between variables were performed using a Tukey's honest significant difference (HSD) test. Sensory data were analyzed using a two-way ANOVA treating fraction and cultivar as fixed effects. A statistically significant difference was defined as $P < 0.05$.

3. Results and Discussion

3.1 Effect of thickness grading on milling yields and physical characteristics

Thickness grading of rough rice resulted in thick fractions ranging from 34% to 78% of the bulk rice on a mass basis (Figure 1). Hybrid cultivars XP760 and XL753 showed the lowest percentage of thin kernels with 22% and 24% of thin mass fractions respectively. Pureline cultivar V3501 showed a thin mass fraction of ~39%, which is nearly two times higher compared to the two hybrid cultivars. In contrast, in cultivar Cheniere, the percentage of thin kernel fraction (66%) was higher than that of thick kernel fractions (34%). Such a low percentage of thick kernels found in Cheniere showed a non-favorable scenario in a realistic setting if thickness grading was applied. Matsue et al. (2001) showed a narrower proportion, 85% to 97%, of thick kernels (≥1.9 mm) in three rice cultivars. More recently, Siebenmorgen and Grigg (2013) reported that thickness grading returned thick kernels (>2.0 mm) between 67% and 90% for four long-grain cultivars. They suggested that even though genetic differences among cultivars explain some of the variation on kernel thickness distribution, for different lots of the same cultivar the variation is even larger due to environmental conditions such as soil composition and fertilization management which may have a greater impact on kernel thickness distribution than the cultivars effect.

Figure 2 shows the effect of thickness grading on HRY for the four long-grain cultivars. Rice graded by thickness showed a significantly higher HRY compared to the unfractioned rice portion in all of the evaluated cultivars [*F*(3, 16) = 21.75, *P* < 0.001]. These results are in accordance with the findings of Siebenmorgen and Grigg (2013) where thicker kernels produced dramatically greater HRYs when compared to unfractioned rice. Similarly, for broken kernels, a significant interaction between cultivars and thickness grading was found [*F*(3, 16) = 10.32, *P* < 0.001] (Figure 3). For pureline cultivars V3501 and Cheniere, the percentage of broken kernels was significantly higher in the unfractioned rice, compared to in the fractioned rice. Hybrid cultivars XP760 and XL753 showed the same numerical trend, but the trend was not statistically significant probably due to the lower mass percentage of thin kernels compared to Cheniere and V3501. Previous research has shown than thin kernels reach a target SLC during milling in a shorter time compared to thick kernels (Jindal and Siebenmorgen, 1994; Chen et al., 1998). Since unfractioned bulk rice was milled for the same duration, without any distinction on kernel thickness, the thin kernels were more likely overmilled, which in turn caused a higher susceptibility for breakage and further reduction of rice yields.

Chalkiness of rice was also affected by thickness grading [*F*(1, 16) = 15.49, *P* = 0.001]. The unfractioned portion showed a higher amount (up to 32%) of chalky kernels than the fractioned portion regardless of the cultivar (Figure 4). Previous research demonstrated association between thin kernels and chalkiness in rice since these are commonly immature incomplete-filled kernels and chalkiness is associated to the process of starch accumulation during ripening (Wardsworth et al., 1979). Thus, the presence of immature thin kernels in the unfractioned portion increased the proportion of grains with the undesirable characteristic. The larger amount of chalky kernels may also explain the previous finding of a lower HRY in the unfractioned portion since earlier evidence has shown that chalky kernels are more prone to fissures and breakage during milling (Siebenmorgen et al., 2006).

As shown in Table 3, degree of whiteness and discoloration of seeds showed no significant differences between unfractioned and fractioned rice ($P > 0.05$ for all). Mathews et al. (1982) reported that thinner fractions of rice were perceptively darker than the thicker fractions across six different lots of long-grain rice. Consequently, since unfractioned rice included thinner kernels it was expected to observe a higher amount of discoloration in the unfractioned rice. However, in the present study rice color showed to be unaffected by the presence or absence of thinner kernels.

3.2 Effects of thickness grading on chemical properties

The two-way ANOVA showed no significant interactions between cultivar and thickness grading on amylose content and crude protein content ($P > 0.05$ for both cases). Insoluble amylose content ranged from 18 % to 25 % across all the cultivars, which fit under the category of intermediate amylose-content according to the rice classification indicated by Juliano (1979). Overall, unfractioned rice showed a significantly higher content of insoluble amylose compared to fractioned rice [$F(1, 16) = 27.27$, $P < 0.001$]. Matsue et al. (2001) and Siebenmorgen et al. (2006) reported differences of the amylose content as a function of rice thickness fraction. More specifically, amylose-amylopectin ratio of rice was found to increase with an increment of thickness. Since amylose content is positively correlated with intrapanicle rice kernel weight, immature-thin kernels would have lower amylose content than completely mature thick kernels (Siebenmorgen et al., 2006). In the present study, since unfractioned rice contained both thick and thin kernels, the results were probably the consequences of an additive effect of all kernel thickness compared to the fractioned portion which was only composed of thick kernels. Similarly, unfractioned rice exhibited higher protein contents than fractioned rice [$F(1, 16) = 5.40$, $P < 0.001$]. Overall, protein contents were in the range of 7.63% and 8.37% across all the rice samples. Mathews et al. (1981) found that contrary to the relationship with amylose content, thinner kernels show higher protein contents than thicker kernels. Siebenmorgen et al. (2006) showed a positive correlation between protein content and α-amylase activity (a starch-hydrolyzing enzyme); the activity is greater when rice kernel is immature (Del Rosario et al., 1968). Additionally, cultivar differences were found in insoluble amylose [$F(1, 16) = 26.09$, $P < 0.001$] and protein contents [$F(3, 16) = 15.17$, $P < 0.001$]. As shown in Table 4, Cheniere and V3501 showed a higher amylose content compared to hybrid cultivars XP760 and XL753, and XP760 showed a significantly lower protein content than XL753 and V3501.

Figure 5 shows the pasting profiles of the unfractioned and the thickness-fractioned portions for the four long-grain cultivars evaluated. A significant interaction between cultivar and thickness grading was found in peak viscosity [$F(3, 16) = 14.6$, $P < 0.001$]. Hybrids XP760 and XL753 showed a significant reduction of approximately 6% and 15%, respectively in their peak viscosities when thickness grading was applied. However, purelines Cheniere and V3501 seemed to be unaffected after the thickness fractionation condition ($P > 0.05$). Matsue et al. (2001) reported differences on peak viscosities among different thickness levels of rice kernels. As a consequence of having higher starch contents, thicker kernels also showed greater peak viscosities compared to thinner kernels. Wardsworth et al. (1979) reaffirmed these results and also reported higher peak viscosities in the unfractioned portion compared to the thickness-graded rice. Interestingly, final viscosities did not seem to display this trend. The two-way ANOVA revealed an interaction between cultivar and thickness grading in the final viscosity [F

(3, 16) = 22.37, $P < 0.001$]. For the pureline Cheniere the final viscosity was significantly higher in the fractioned portion compared to the unfractioned portion of the same cultivar. However, an opposite trend was observed for cultivars XP760 and XL753, where the final viscosities showed a significant decrement after thickness fraction.

Onset gelatinization temperature of hybrids XP760 and XL753 was significantly influenced by the fractionation process [$F(3, 16) =7.52$, $P = 0.002$]. The onset gelatinization temperatures varied from 70 to 73 °C in the evaluated samples, which are typical values of long-grain varieties in an intermediate gelatinization temperature range (Juliano, 1979). As shown in Figure 6, onset gelatinization temperature increased up to 1.36 % for XP760 and up to 1.26 % for XL753 when the rice samples were fractioned. However, the increment-trend in onset gelatinization temperatures for Cheniere and V3501 cultivars were not statistically significant ($P > 0.05$). Correspondingly, peak gelatinization temperatures were also significantly higher for the fractioned rice compared to the unfractioned rice, regardless of the cultivar [$F(1, 16) = 4.98$, $P = 0.04$]. Siebenmorgen et al. (2006) and Wardstworth (1979) found that thickness grading has little effect on gelatinization temperatures. However this study contradicts these results, and shows a potential inverse relationship between amylose content and gelatinization temperatures. Flipese et al. (1996) reported that since amylopectin plays a major role in starch granule crystallinity, the presence of amylose decreases the melting temperature of crystalline regions and the energy for starting gelatinization. More energy is needed to initiate melting in the absence of amylose-rich amorphous regions (Krueger et al., 1987). This correlation indicates that starch with higher amylose content has more amorphous region and less crystalline, lowering gelatinization temperature and endothermic enthalpy (Sasaki et al., 1999).

No significant differences in terms of end gelatinization temperatures and gelatinization enthalpies were found between the unfractioned and fractioned portions for any of the cultivars ($P > 0.05$ for all). Overall, hybrid XL753 showed a significantly higher end temperature, compared to purelines Cheniere and V3501 ($P = 0.001$) and Cheniere displayed a lower enthalpy compared to XP760 and XL753 ($P < 0.001$).

3.3 Effects of thickness grading on cooking qualities

The rice cooking qualities were evaluated in terms of OCD and grain elongation during cooking. As shown in Figure 7, OCD seemed to be significantly different between unfractioned and fractioned rice samples in hybrids XP760 and XL753. For XP760 the OCD increased from ~21 to 24 minutes and for XL753 from ~22 to 23 minutes when rice was fractioned. Even though such trends were observed in purelines Cheniere and V3501, the differences were not statistically significant. Bhattacharya and Snowbhagya (1971) and Oko et al. (2012) demonstrated a positive correlation between gelatinization temperature and OCD. Thus, since thickness-fractioned rice showed higher onset and peak gelatinization temperature values than the unfractioned rice, this was reflected on longer cooking durations. In addition, thickness of the grain has shown to have a significant effect on the cooking duration of rice (Mohapatra and Bal, 2006) due to quicker diffusion of moisture in thinner grains that were present exclusively in the unfractioned portion.

Length elongation is often used as a good quality indicator in rice, which was significantly dependent on the cultivar but not on the fractionation process [$F(3, 16) = 4.91$, $P = 0.003$]. Cultivar Cheniere demonstrated less length elongation in comparison to hybrids XL753 and XP760. Conversely, width expansion was significantly dependent on the fractionation process regardless of the cultivar. Fractioned rice showed a higher elongation with respect to girth than that of the unfractioned portion [*F*(1, 16) = 5.45, *P* = 0.022]. This characteristic is not desirable on rice quality since it is associated with rice bursts during cooking, a non-appealing defect for consumers. Bhattacharya (2011) reported that a good quality indicator is a rice that expands on length but not so much in girth.

3.4 Descriptive sensory analysis and texture profile analysis

There was neither significant interaction nor significant main effects between thickness grading and cultivar in all sensory attributes evaluated (*P* > 0.05 for all) (Table 6). These results indicate that untrained consumers may not be able to detect differences in appearance, flavor or textural attributes of milled-rice samples if thickness grading was applied.

Table 7 shows mean scores of each TPA parameter as a function of cultivar and thickness grading. The extra process step did not seem to have any impact on the hardness, cohesiveness and chewiness parameters of the rice samples (*P* > 0.05 for all). The results were similar to those reported by Siebenmorgen et al. (2006) where any significant differences were found in hardness among different rice kernel thickness. On the other hand, thickness fractionation decreased stickiness of rice samples for all cultivars [*F*(1, 16) = 4.35, *P* = 0.04]. Greater stickiness values are correlated with lower amylose and protein contents. However, the results obtained in this study contradict the expectation of this inverse relationship since fractioned rice showed lower protein and amylose content compared to unfractioned rice. Siebenmorgent et al. (2006) reported that the higher water uptake ratio the greater stickiness in rice, which may support the results of this study.

There were cultivar differences with respect to hardness, stickiness, and cohesiveness of the four rice samples. The varieties Cheniere and XP760 showed higher values of hardness [*F*(3,

16) = 6.75, *P* < 0.001], but lower values of cohesiveness [*F*(3, 16) = 5.04, *P* = 0.003] compared to their counterpart cultivars XL753 and V3501. In addition, hybrids XL753 and XP760 showed a higher stickiness than purelines Cheniere and V3501 [*F*(3, 16) = 4.14, *P* = 0.009].

4. Conclusions

The present study demonstrated the effects of thickness grading on the physicochemical properties, cooking qualities, and sensory aspects in the four long-grain rice cultivars. Thickness fraction of rice resulted in significantly greater HRY when compared to unfractioned rice. Additionally, physical characteristics such as broken kernels and chalkiness of kernels were significantly benefited by the thickness grading process. However, not so positive impacts were also obtained from the thickness grading procedure. More specifically, a reduction in protein content in fractioned rice may impose a dilemma in how rice nutritional value might seem to be affected by this process. Additionally, cooking qualities of rice were also adversely impacted by thickness grading (i.e., longer cooking-duration and greater width-expansion). These characteristics are usually not very appealing for the consumer, which may decrease the economic value of rice.

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Table 1. Discrimination of various rice kernel thickness as a function of cultural background and cultivar

		Cultural Background		
Cultivar	**Thickness Fraction**	**Asians**	**Caucasians**	**Hispanics**
V3501	1.60 mm	1.14 (± 0.96)	1.74 (± 2.24)	1.50 (± 2.01)
	1.70 mm	1.19 (± 1.33)	1.41 (± 2.02)	1.40 (± 1.90)
	1.80 mm	1.62 (± 1.07)	1.76 (± 2.17)	2.30 (± 2.54)
	1.90 mm	1.14 (± 1.42)	1.85 (± 2.44)	1.90 (± 2.13)
	2.00 mm	1.24 (± 1.04)	1.74 (± 2.43)	1.90 (± 2.33)
	Unfractioned	1.10 (± 1.09)	1.52 (± 1.88)	1.50 (± 1.78)
XL753	1.60 mm	1.67 (± 2.15)	2.11 (± 2.32)	0.90 (± 0.88)
	1.70 mm	1.14 (± 1.90)	1.70 (± 2.25)	1.30 (± 1.57)
	1.80 mm	1.24 (± 1.76)	1.93 (± 2.36)	1.00 (± 1.15)
	1.90 mm	1.52 (± 1.78)	1.39 (± 1.76)	1.00 (± 1.15)
	2.00 mm	1.81 (± 2.46)	1.78 (± 2.45)	1.20 (± 1.23)
	Unfractioned	1.29 (± 2.28)	1.72 (± 2.32)	1.40 (± 1.51)

Table 2. Lexicon of appearance, aromatic, and texture attributes developed for cooked rice

Term	Definition	References [a]	
Appearance			
Degree of whiteness	The degree to which the sample is pure white.	Reference E Reference D (Yellow to White)	13.0 6.0
Grain size	The overall dimensions of the rice kernels in terms of width and length	Reference E	7.5
Texture			
Manual stickiness	The force required to separate the fingers after compressing the sample between the thumb and forefinger.	Rice A (None to much)	5.0
Initial cohesion	The degree to which the un-chewed sample sticks together.	Rice C Rice A Rice E (Loose to tight)	1.0 3.0 11.0
Hardness	The force required to compress the sample.	Rice E Rice A Rice C Rice D (Soft to hard)	1.0 4.0 5.0 10.0
Crunchy cores	The amount of crunchy centers perceived in the sample while chewing the sample 4-5 chews	Rice A Rice D	5.0 12.0
Tooth pull	The force required to separate the teeth during mastication.	Rice C Rice A (None to much)	2.0 4.0
Aroma/ Aromatics			
Starchy	The aromatic associated with the starch of a particular grain source.	UAS [b]	
Grainy	A general term used to describe the aromatics of raw or cooked grains, which cannot be tied to a specific grain type.	UAS	
Cardboard / papery	The aromatic associated with early stages of oxidation.	UAS	
Sweet aromatic	The aromatic associated with materials that also have a sweet taste, such as molasses, caramelized sugars, cotton candy, maple syrup, maltol.	UAS	

(Continued)

Term	Definition	References [a]
Metallic	The aromatic associated with metals, tinny or irony.	UAS
Burlap	The aromatic associated with burlap.	UAS
Floral / minty	The aromatic associated with a non-specific floral note and sometimes described as minty.	UAS

[a] Reference A: 30 g Riceland Extra Long-Grain Brown Rice (Riceland Foods, Stuttgart, AR); Reference C: 30 g Uncle Ben's Converted Brown Rice (Mars Food, McLean, VA); Reference D: 30 g Riceland Extra Long-Grain Brown Rice (Riceland Foods, Stuttgart, AR) Reference E: 30 g Riceland Extra Lon- Grain Rice (Riceland Foods, Stuttgart, AR).

[b] UAS: aroma intensities were rated based on the universal aromatic scale, with a modification: soda note in Nabisco Premium Original Saltine Crackers (Mondelez Global LLC, East Hanover, NJ, USA) =3.0; cooked-apple aroma in Mott's Natural Applesauce Mott's LLP, Plano, TX, USA) =7.0.

Table 3. Physical properties as a function of cultivar and fractionation process[a]

	XP760		XL753		V3501		Cheniere	
	Unfractioned	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**
Chalky area (%)	2.6 (± 0.1)	2.1 (± 0.3)	1.2 (± 0.2)	0.8 (± 0.3)	0.5 (± 0.4)	0.2 (± 0.1)	0.8 (± 0.2)	0.3 (± 0.3)
Discolored area (%)	3.3 (± 5.8)	3.3 (± 5.8)	6.3 (± 6.5)	13.3 (± 1.5)	20.0 (± 3.0)	14.3 (± 3.5)	12.3 (± 2.9)	15.3 (± 4.5)
Broken Kernels (%)	8.0 (± 1.5)	6.2 (± 0.4)	5.8 (± 0.2)	4.8 (± 0.3)	15.1 (± 0.7)	12.0 (± 0.5)	7.5 (± 0.6)	3.4 (± 0.2)
Whiteness (L*)	71.9 (± 0.5)	71.6 (± 0.3)	70.6 (± 0.5)	70.4 (± 0.4)	69.9 (± 0.1)	70.0 (± 0.4)	70.9 (± 0.2)	70.5 (± 0.4)

[a] Values represent the mean (± standard deviation) of three replications.

Table 4. Chemical composition as a function of cultivar and fractionation process[a]

	XP760		**XL753**		**V3501**		**Cheniere**	
	Unfractioned	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**
Apparent Amylose (%)	20.9 (± 0.3)	19.6 (± 0.3)	19.8 (± 0.3)	18.2 (± 0.2)	22.5 (± 0.5)	20.7 (± 0.9)	24.0 (±1.7)	21.8 (±1.0)
Crude Protein (%)	7.7 (± 0.1)	7.8 (± 0.0)	8.3 (± 0.0)	8.1 (± 0.1)	8.2 (± 0.2)	7.9 (± 0.2)	8.0 (± 0.1)	7.9 (± 0.2)
Onset GT (◦ C)	71.2 (± 0.1)	72.2 (± 0.1)	72.0 (± 0.4)	72.9 (± 0.2)	70.3 (± 0.2)	70.4 (± 0.2)	70.7 (± 0.2)	70.9 (± 0.2)
Peak GT (◦ C)	76.7 (± 0.1)	76.9 (± 0.1)	77.4 (± 0.2)	77.9 (± 0.2)	75.5 (± 0.3)	75.4 (± 0.0)	75.4 (± 0.2)	75.5 (± 0.1)
End GT (◦ C)	84.1 (± 0.8)	81.6 (± 3.5)	84.9 (± 0.3)	84.2 (± 0.2)	81.5 (± 0.6)	81.4 (± 0.0)	81.0 (± 0.4)	81.0 (± 0.2)
Enthalpy (J/g)	10.4 (± 1.5)	9.4 (± 0.6)	11.5 (± 0.9)	10.1 (± 1.2)	8.7 (± 1.4)	9.3 (± 0.3)	7.4 (± 1.8)	7.1 (± 1.2)

[a] Values represent the mean (± standard deviation) of three replications.

GT: gelatinization temperature

Table 5. Cooking quality characteristics as a function of cultivar and fractionation process[a]

	XP760		XL753		V3501		Cheniere	
	Unfractioned	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**
OCD (min)	21.0 (± 0.0)	23.7 (± 0.6)	21.7 (± 0.6)	23.3 (± 0.6)	19.7 (± 0.6)	20.7 (± 0.6)	22.0 (± 0.0)	22.3 (± 0.6)
LER	2.3 (± 1.0)	1.3 (± 1.1)	2.1 (± 0.8)	1.8 (± 0.9)	2.2 (± 0.6)	1.9 (± 0.6)	0.9 (± 0.3)	1.3 (± 1.1)
WER	0.8 (± 0.2)	1.2 (± 0.4)_	1.0 (± 0.3)	1.0 (± 0.3)	0.9 (± 0.3)	1.3 (± 0.7)	1.1 (± 0.2)	1.0 (± 0.3)

[a] Values represent the mean (± standard deviation) of three replications.

OCD: optimum cooking duration; LER: length expansion ratio; WER: width expansion ratio

Table 6. Sensory attributes as a function of cultivar and fractionation process[a]

	XP760		XL753		V3501		Cheniere	
	Unfractioned	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**
Appearance								
Whiteness	12.3 (± 0.6)	12.4 (± 0.6)	12.4 (± 0.7)	12.6 (± 0.6)	12.5 (± 0.5)	12.4 (± 0.7)	12.6 (± 0.5)	12.6 (± 0.7)
Grain size	6.7 (± 0.6)	6.9 (± 0.6)	6.7 (± 0.7)	6.6 (± 0.8	6.5 (± 0.6)	6.7 (± 0.7)	6.9 (± 0.6)	6.8 (± 0.8)
Aromatics								
Starchy	5.5 (± 0.6)	5.4 (± 0.8)	5.4 (± 0.7)	5.3 (± 0.8)	5.3 (± 0.8)	5.3 (± 0.8)	5.2 (± 0.9)	5.2 (± 0.9)
Grainy	4.0 (± 0.6)	3.7 (± 1.1)	3.9 (± 0.6)	3.7 (± 1.1)	3.7 (± 1.1)	3.7 (± 1.1)	3.7 (± 1.1)	3.8 (± 0.7)
Cardboard	2.3 (± 1.6)	2.4 (± 1.5)	2.4 (±1.4)	2.4 (± 1.5)	2.6 (± 1.3)	2.2 (± 1.6)	2.4 (± 1.5)	2.2 (± 1.6)
Sweet Aromatic	0.2 (± 0.8)	0.0 (± 0.0)	0.2 (± 0.8)	0.0 (± 0.0)	0.0 (± 0.0)	0.0 (± 0.0)	0.2 (± 0.8)	0.0 (± 0.0)
Metallic	0.9 (± 1.6)	1.0 (± 1.6)	0.9 (± 1.6)	1.1 (± 1.7)	1.0 (± 1.6)	0.9 (± 1.6)	1.1 (± 1.6)	1.0 (± 1.6)
Burlap	1.2 (± 1.6)	1.4 (± 1.7)	1.5 (± 1.6)	1.3 (± 1.7)	1.3 (± 1.6)	1.3 (± 1.7)	1.1 (± 1.7)	1.5 (± 1.7)
Floral	0.7 (± 1.4)	0.4 (± 1.0)	0.7 (± 1.4)	0.7 (± 1.4)	0.7 (± 1.4)	0.5 (± 1.3)	0.9 (± 1.5)	0.7 (± 1.4)
Texture								
Manual Stickiness	6.3 (± 0.7)	6.2 (± 1.1)	6.4 (± 1.1)	6.0 (± 0.8)	6.1 (± 1.4)	6.0 (± 1.2)	6.3 (± 0.9)	6.4 (± 1.2)
Initial Cohesion	10.1 (± 1.8)	9.4 (± 2.3)	9.1 (± 2.3)	9.4 (± 2.2)	8.9 (± 2.9)	9.3 (± 2.2)	9.1 (± 2.4)	9.0 (± 2.1)
Hardness	1.8 (± 0.5)	1.9 (± 0.7)	2.1 (± 0.8)	1.9 (± 0.6)	2.1 (± 0.8)	1.8 (± 0.6)	2.2 (± 1.0)	2.2 (± 0.9)
Crunchy Cores	1.3 (± 1.0)	1.3 (± 1.3)	1.5 (± 1.3)	1.4 (± 1.3)	1.3 (± 1.2)	1.1 (± 1.2)	1.6 (± 1.2)	1.4 (± 1.1)
Tooth Pull	3.4 (± 0.9)	3.7 (± 0.8)	3.5 (± 0.9)	3.5 (± 1.0)	3.4 (± 0.9)	3.6 (± 1.0)	3.7 (± 0.8)	3.7 (± 0.9)

[a] Values represent the mean (± standard deviation) of two replications

Table 7. Texture Profile Analysis parameters as a function of cultivar and fractionation process[a]

	XP760		XL753		V3501		Cheniere	
	Unfractioned	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**	**Unfractioned**	**Fractioned**
Hardness (N)	14.6 (± 2.1)	13.2 (± 1.7)	15.2 (± 1.7)	15.7 (± 2.5)	13.6 (± 1.6)	13.4 (± 1.4)	15.6 (± 1.8)	15.5 (± 1.2)
Stickiness (N x sec)	0.6 (± 0.2)	0.6 (± 0.2)	0.7 (± 0.3)	0.6 (± 0.2)	0.5 (± 0.2)	0.4 (± 0.2)	0.6 (± 0.2)	0.3 (± 0.2)
Cohesiveness	0.4 (± 0.0)	0.4 (± 0.0)	0.4 (± 0.0)	0.4 (± 0.0)	0.4 (± 0.0)	0.4 (± 0.0)	0.4 (± 0.0)	0.4 (± 0.0)
Chewiness	0.7 (± 0.7)	0.7 (± 0.9)	0.7(± 0.7)	0.7 (± 1.5)	0.8 (± 1.1)	0.7 (± 0.7)	0.7 (± 1.0)	0.7 (± 0.6)

[a] Values represent the mean (± standard deviation) of ten replications **.**

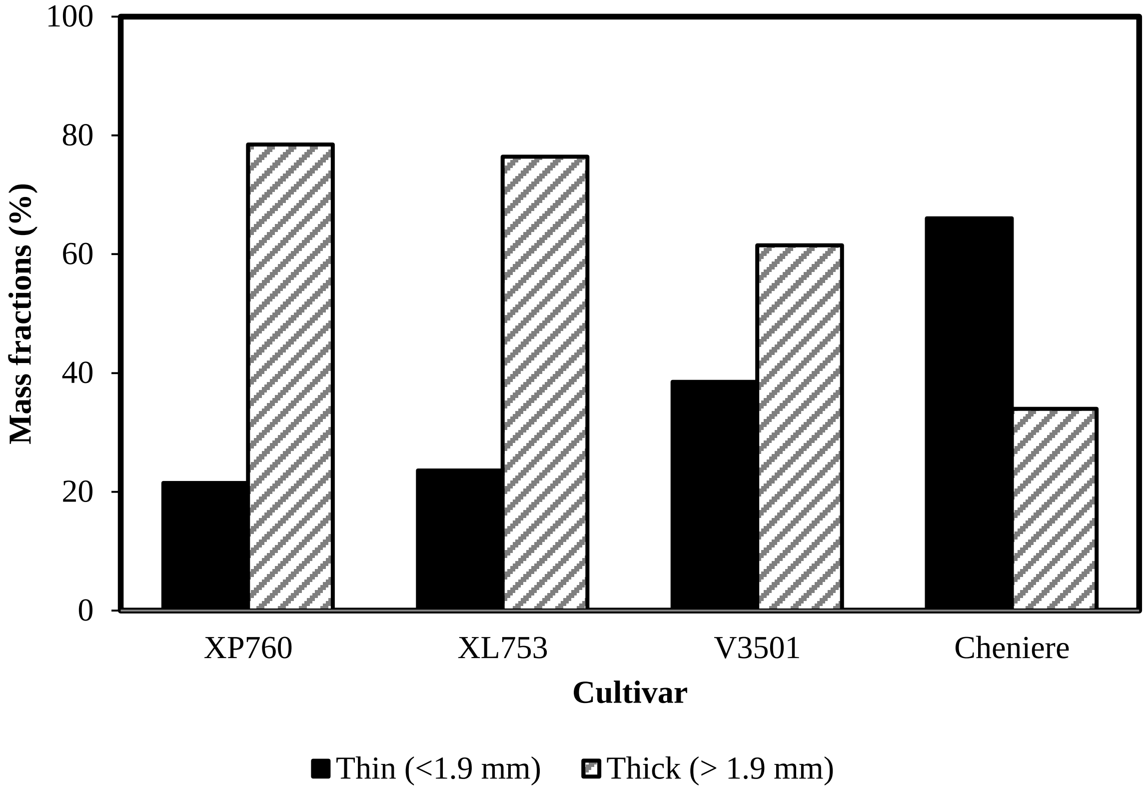

Figure 1. Mass fractions of thin and thick kernels resulting after thickness fractionation for each long-grain cultivar.

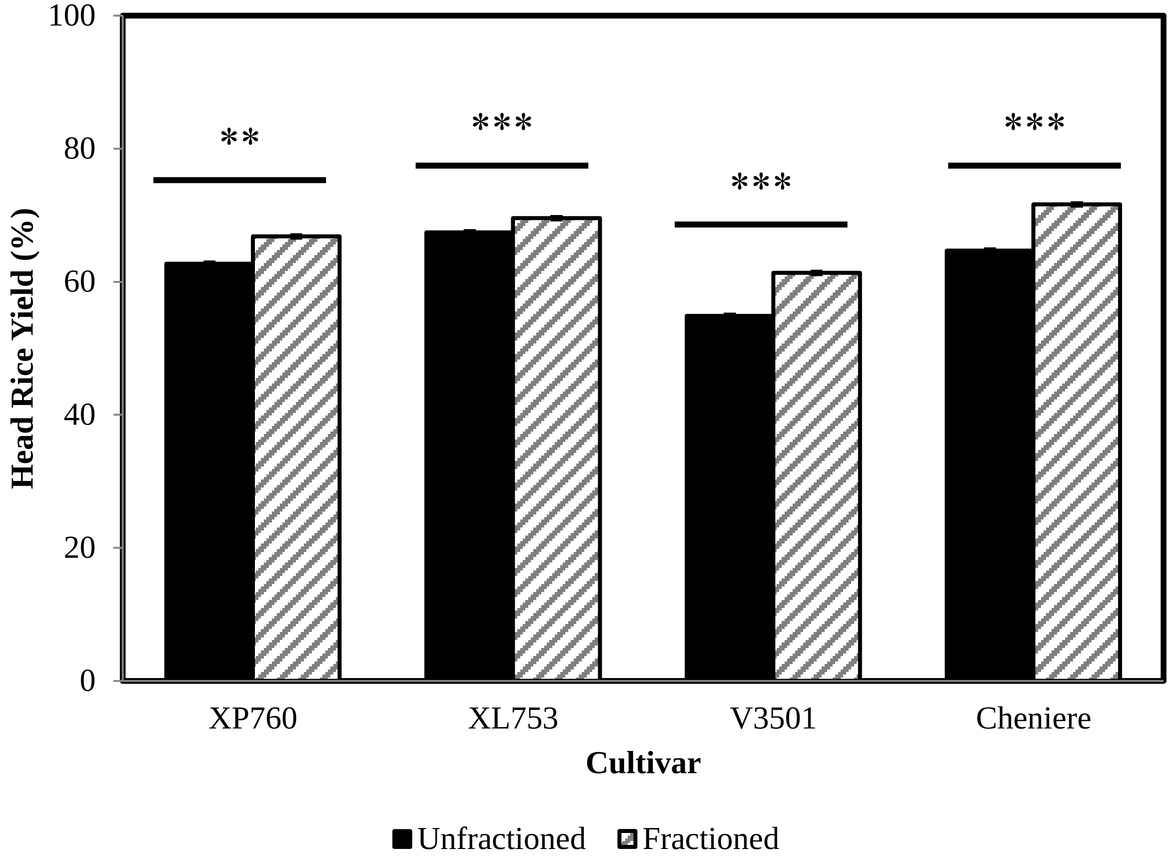

Figure 2. Head rice yield (HRY) in response to thickness grading of rough rice of four long-grain cultivars. ** and *** represent a significant difference at $P < 0.01$ and at $P < 0.001$, respectively. Error bars represent standard error of the means.

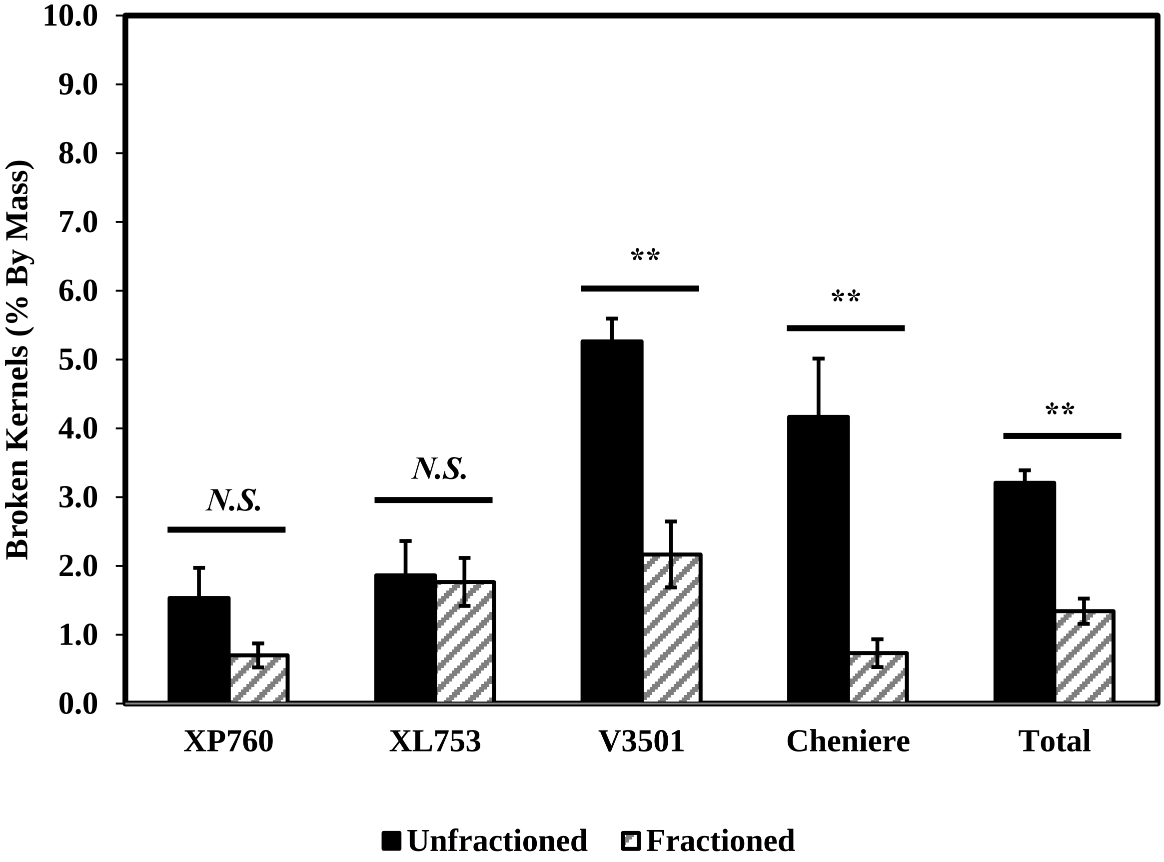

Figure 3. Mean broken kernels as a function of cultivar and fractionation process. ** represent a significant difference at $P < 0.01$. *N.S.* represents no significant difference at $P < 0.05$. Error bars represent standard error of the means.

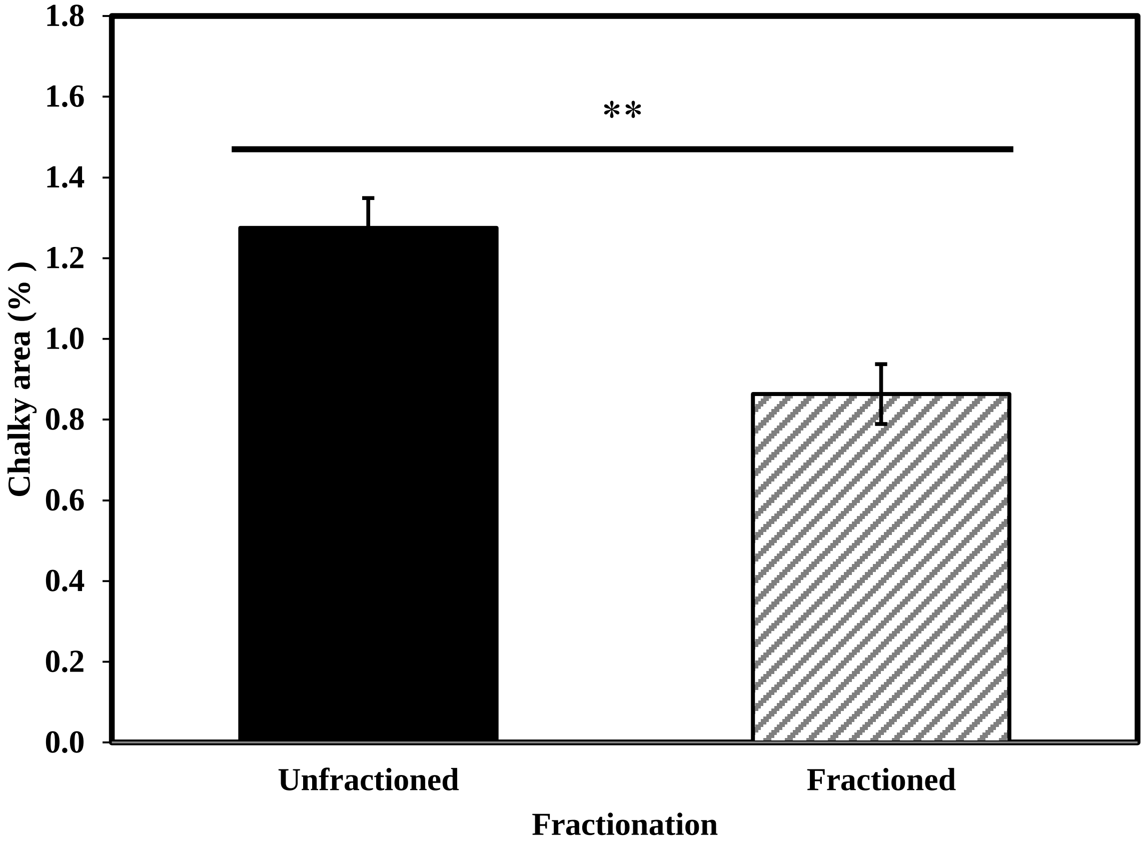

Figure 4. Mean chalky area percentage as a function of cultivar and fractionation process. ****** represent a significant difference at *P* < 0.01. Error bars represent standard error of the means.

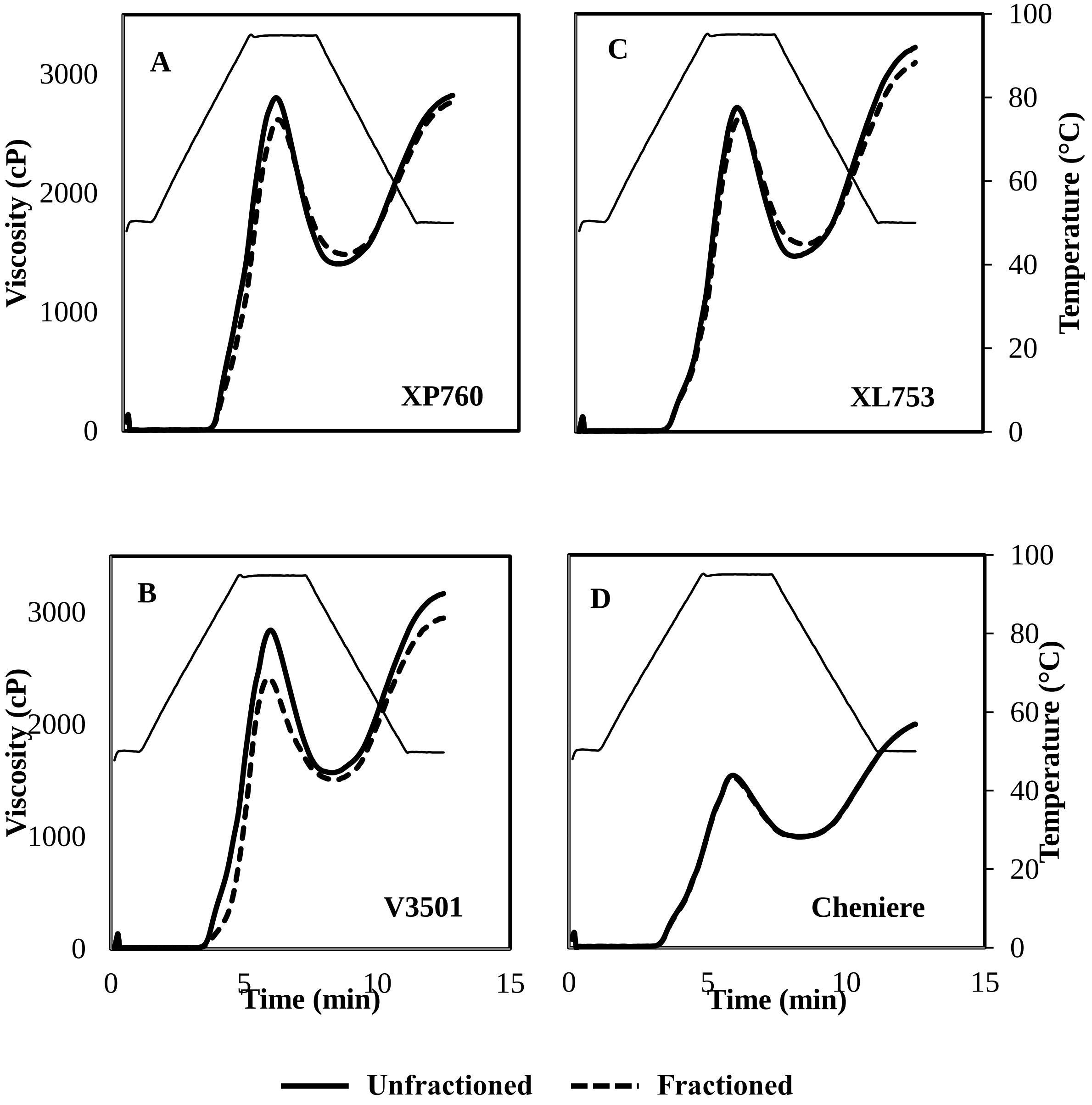

Figure 5. Pasting profiles of the evaluated long-grain rice cultivars as a function of the fractionation process.

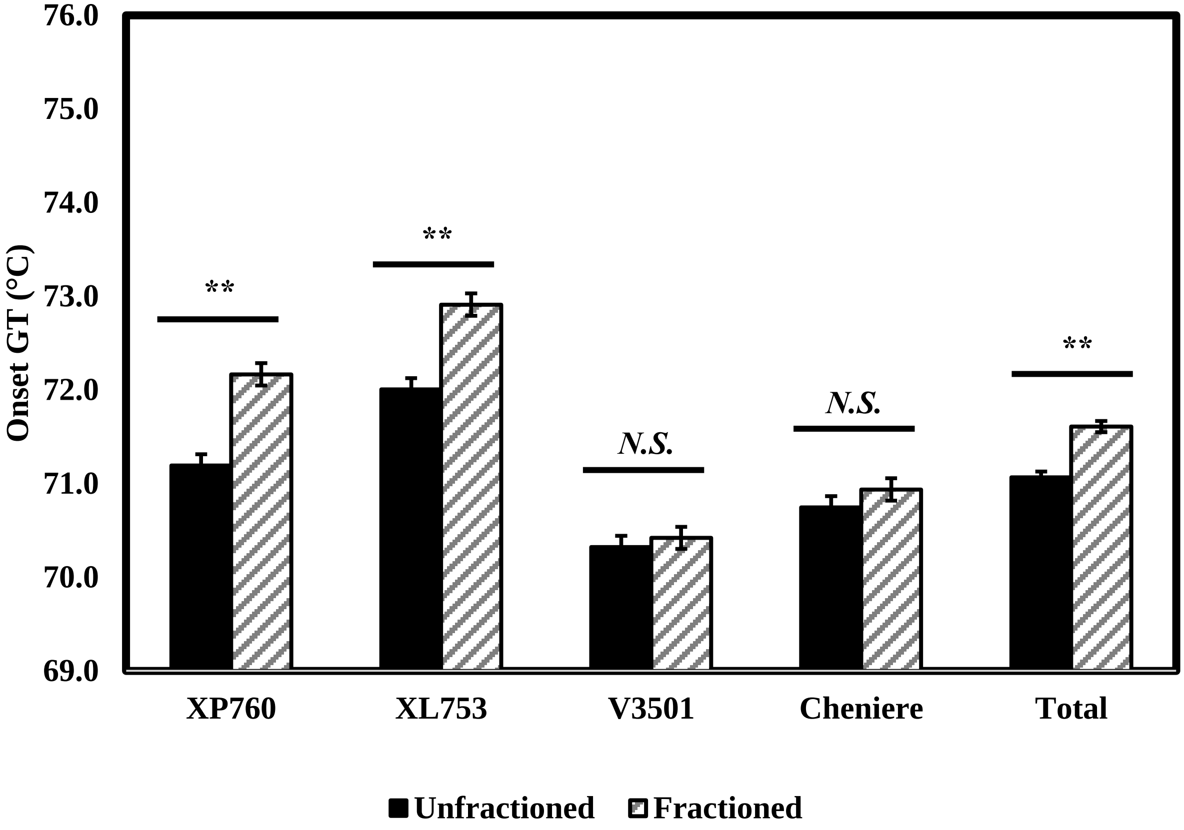

Figure 6. Mean onset gelatinization temperatures as a function of cultivar and fractionation process. ** represent a significant difference at *P* < 0.01. *N.S.* represents no significant difference at *P* < 0.05. Error bars represent standard error of the means.

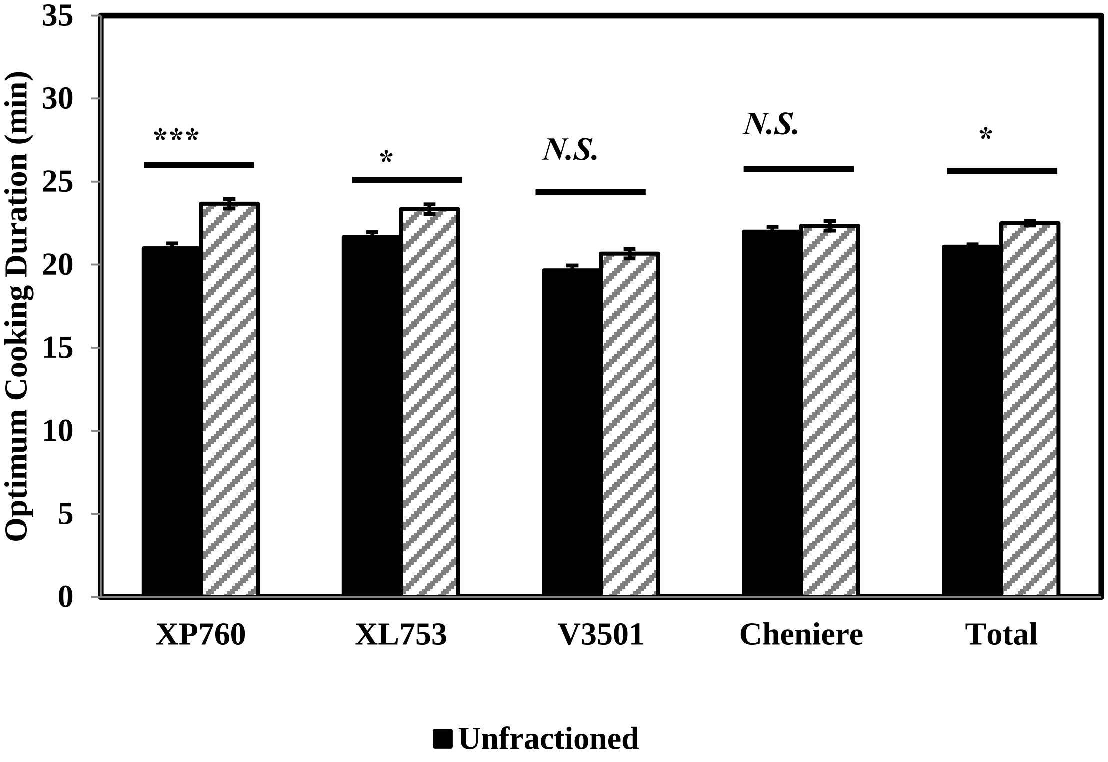

Figure 7. Mean optimum cooking durations as a function of cultivar and fractionation process. * and *** represent a significant difference at *P* < 0.05 and at *P* < 0.001, respectively. *N.S.* represents no significant difference at *P* < 0.05. Error bars represent standard error of the means.

Chapter 4.

Effects of harvest moisture content on physicochemical properties and cooking qualities of long-grain rice (*Oryza sativa* L.)

Abstract

The objective of this study was to investigate the effect of harvest moisture content (HMC) on the physicochemical properties and cooking qualities of long-grain rice. Two long-grain pureline rice cultivars (Cheniere and V3501) and two hybrid rice cultivars (XL753 and XP760) were grown and harvested in Harrisburg, AR. Samples of each cultivar were harvested at three different levels of HMC, high (>22.0% on a wet basis), medium (18.0-22.0%), and low HMC levels (<18 %). Milling qualities, physicochemical properties, and cooking qualities of rice samples were evaluated. A quadratic relationship was found between head rice yields (HYC) and HMC. Overall, rice harvested at medium moisture contents showed the highest HYC and less broken kernels. Additionally, chalkiness of rice decreased as HMC decreased, and medium HMC showed lower whiteness values across all the cultivars. Insoluble amylose content and peak viscosity seemed uninfluenced by HMC. However, crude protein content and gelatinization temperatures increased as HMC decreased. HMC was found to have no significant influence on cooking qualities of long-grain rice samples. The present study demonstrates the importance of determining the best date for harvesting or the optimum HMC, in order to maximize the economic returns through greater HRYs and better physicochemical qualities.

1. Introduction

Rice qualities, with respect to physicochemical properties, cooking qualities, and sensory aspects, play an important role in determining rice economic value as well as consumer acceptance. Such rice qualities have been found to be affected by many aspects including cultivar (genetic difference), pre-harvest factors, and post-harvest factors. Pre-harvest factor refers to the group of environmental conditions in which rice has been cultivated and harvested, which includes time of planting and irrigation, nitrogen rates, panicle characteristics, kernel maturation, growing location, and harvest moisture content (Siebenmorgen, 2013).

Harvest moisture content (HMC) of rice decreases as rice becomes mature in the field. Previous research has shown that harvesting rice while the kernels are immature (high moisture contents) decreases total and head rice yields. As the rice continues to be mature (i.e., decreasing moisture content), the head rice yield (HYC) reaches a maximum and then decreases. Siebenmorgen et al. (2007) suggested that the general ranges of optimal HMCs were 19% to 22% for long-grain rice cultivars.

Similarly, moisture content at harvest has been found to affect metabolic processes, starch composition and structure, and protein content (Champagne et al., 2005). More specifically, Champagne et al. (2005) showed that even though harvest date had little to non-effect on amylose content, it did influence rice protein content, showing a decline of protein content with earlier harvest dates. Additionally, pasting and textural characteristics of rice were found to be affected by HMC (Wang et al., 2004; Champagne et al., 2005). Harvesting at the earliest date resulted in rice with higher setback and lower breakdown than at the latter dates and, subsequently, the early harvested rice, when cooked, was harder, more cohesive, and absorbed less saliva in the mouth (Saleh and Meullenet, 2007; Champagne et al., 2005). However, the differences that were found in textural characteristics by trained panel were allegedly too small to detect them by untrained consumers.

Cooking qualities of milled rice include grain volume expansion, water absorption, solids in cooking water, and cooking duration (Juliano, 1982), which have been found to be associated with physicochemical properties of rice. For example, rice samples with amylose content of more than 25% were found to absorb more water and have a fluffy texture upon cooking (Perez et al., 1987). The physicochemical changes may be easily induced by processing or environmental factors such as moisture content (MC) at harvest. However, little attention has been focused onto the effects of HMC on cooking qualities of long-grain rice. Therefore, the objective of this study was to investigate the effect of HMC on physicochemical properties and cooking qualities of long-grain rice samples.

2. Materials and Methods

2.1 Rice samples conditioning and milling properties

Two long-grain pureline rice cultivars (Cheniere and V3501) and two hybrid rice cultivars (XL753 and XP760) cultivated in Harrisburg, AR in 2015 were used in this study. As shown in Table 1, samples of each cultivar were hand-harvested at various MCs (14.6 to 25.0% on a wet basis) to determine the effects of HMC on physicochemical properties and cooking qualities of long-grain rice. For further analyses, rice samples were classified into three groups: High HMC (>22.0% w.b.), medium HMC (18.0-22.0% w.b.), and low HMC (<18 % w.b.). Rough rice samples were cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, MN, U.S.A.). The cleaned lots were then conditioned to12.0 ± 0.5% (wet basis) moisture content using a climate controlled chamber (26 °C and 56% relative humidity), regulated by a stand-alone conditioner (Model 5580A, Parameter Generation & Control, Black Mountain, NC, U.S.A.). Rough rice of each cultivar was dehulled using a dehusker (THU-35, Satake, Hiroshima, Japan), and the resultant brown rice was milled using a laboratory miller (McGill number 2, RAPSCO, Brookshire, TX, U.S.A.). Based on a preliminary test, milling duration of each cultivar was determined based on the surface lipid content (mean ± standard deviation = 0.40 ± 0.05%) of head rice. Each rice sample was stored in a sealed container at 4 °C. The containers were placed at room temperature (22 °C) for 24 h prior to sample preparation and further analysis. Head rice yield was determined, with head rice being separated from broken kernels using a sizing device (Model 61, Grain Machinery Manuf. Corp., Miami, FL) and maintained for determination of quality properties.

2.2 Physical properties

Physical properties, i.e., kernel dimensions, broken kernels, chalky kernels, and discoloration of head rice samples were measured using an image analysis system (SeedCount SC 5000, Next Instruments, Condell Park, Australia) as described in Chapter 3. In addition, degree of whiteness (L^*) was determined using near-infrared reflectance (NIR) spectroscopy (NIR-DA 7200, Perten Instruments, Huddinge, Sweden). All the analyses were evaluated in triplicate.

2.3 Chemical composition

A 60-g portion from one head rice sub-sample was ground into flour with a cyclone mill (3010-30, UDY, Fort Collins, CO, U.S.A.) with a 0.5 mm screen to determine the effects of growing location on moisture content, amylose content, pasting property, thermal property, and crude protein content of rice samples.

The moisture content of the rice flour was measured according to AACCI method (44 15.02). Amylose content was determined by the simplified iodine assay method (Juliano, 1971) as described in Chapter 3. Pasting properties of rice samples were determined using a Rapid Visco Analyser (RVA Super 4, Newport Scientific, Warriewood, Australia). A thermogram was produced by the viscometer software showing changes in viscosity over the cycle duration, as well as summary statistics of peak viscosity, trough viscosity, breakdown (peak-trough viscosity), final viscosity, setback (final-peak viscosity), peak time, and pasting temperature. Moreover, thermal properties, such as onset, peak, and conclusion gelatinization temperatures (GT), of rice samples were measured using a differential scanning calorimeter in modulating mode (DSC-Q100, TA Instruments, New Castle, DE, U.S.A.). Finally, crude protein content was determined by using NIR spectroscopy (NIR-DA 7200, Perten Instruments, Huddinge, Sweden). All the analyses were evaluated by triplicate.

2.4 Cooking qualities

Optimum cooking duration (OCD) was assessed by Ranghino test for milled rice (Juliano and Bechtel, 1985). Length expansion ratio and width expansion ratio were determined according to the methods by Juliano and Bechtel (1985).

2.5 Statistical analysis

Statistical analyses were performed using JMP Pro (version 12.0, SAS Institute Inc., Cary, NC, U.S.A.). To determine the effects of cultivar and HMC on physicochemical properties and cooking qualities, two-way analyses of variance (ANOVA) were used. If a significant difference in means was indicated by the ANOVA, post hoc comparisons between variables were performed using a Tukey's honest significant difference (HSD) test. A statistically significant difference was defined as $P < 0.05$.

3. Results and Discussion

3.1 Effect of HMC on physical properties

Overall, HRYs were in the range of 51.91% to 67.44% across all the cultivars and HMC levels. A significant interaction was found between cultivar and HMC for HRY [$F(6,24) = 5.51$, $P = 0.001$). More specifically, while cultivar XP760 showed no significant differences among the three levels of HMC, cultivars XL753, V3501, and Cheniere showed higher HRYs when they were harvested at a medium HMC compared to when harvested at a high HMC. Figure 1 shows the relationship between HRY and HMC for all the cultivars described using a quadratic equation as defined by Siebenmorgen et al. (2007). The quadratic equations significantly described the HRY trends with R^2 values greater than 0.79 with the exception of cultivar V3501 whose R^2 value was 0.58. The results from this study are in line with the findings of Siebenmorgen et al. (1992) and Jodari and Linscombe (1996) where it was reported that there is a HMC value to which HRY is optimum for each variety, and above or below this HMC the HRY tend to decrease. For example, at extremely high HMCs the percentage of immature kernels is too high, which can cause an increase of breakage during milling. On the other hand, at low HMCs the percentage of kernels that could fissure due to rapid moisture adsorption increases, ultimately resulting in lower HRYs. This susceptibility to breakage at high and low HMCs, due to immature and fissured kernels respectively, was evidenced in the amount of broken kernels as shown in Figure 2. Overall, the medium MC at harvest showed the less percentage of broken kernels compared to the broken kernels percentage at high and low HMC [$F(2, 24) = 15.48$, $P < 0.001$]. Siebenmorgen et al. (2007) found that the general range of optimal HMCs was between 19 to 22% for seven long-grain cultivars grown in Arkansas, whereas the optimum range of HMCs for medium grain, Bengal, was between 21.5 to 24.0%.

Table 2 shows mean scores of physical properties of rice samples as a function of cultivar and HMC. There were no significant interactions between cultivar and HMC in any of the physical properties of rice samples ($P > 0.05$ for all). However, differences across cultivars and the HMC levels were found for some attributes. Specifically, the whiteness of the rice samples ranged from 69.73 to 72.54. As shown in Figure 3, L^* values of the rice were significantly affected by HMC [$F(2, 24) = 9.53$, $P < 0.001$]. Overall, rice harvested at a medium level of HMC showed the lowest degree of whiteness as compared to high and low HMCs. Kester et al. (1963) found similar results in the three cultivars where rice harvested at mid-season reached the lowest lightness and whiteness values compared to rice harvested in earlier and later dates. A possible explanation to this trend is sustained by the changes in the chlorophyll content in the rice grain during maturation and the chalkiness in the grain. As shown in Figure 4, chalkiness in rice kernels decrease as the HMC decreased [$F(2, 24) = 29.86$, $P < 0.001$]. Previous research demonstrated that chalkiness, a white opaque region in the kernel, has an effect on rice color (Kester et al., 1963; Lanning et al., 2011). For immature kernels, at a higher HMC the chalkiness of rice is higher and the reflection of light from this increases the whiteness values. Kester et al. (1963) indicated that as the rice matures in the field the chlorophyll content (green pigment) and chalkiness decreases which in turn decreases the whiteness values. This trend continues into some point, where at later harvest dates the rice becomes progressively whiter and lighter than those at mid harvest points (Kester et al., 1963).

Kernel discoloration was influenced by the cultivar, but not by the HMC [*F*(3, 24) = 592.08, $P < 0.001$]. Pureline cultivar V3501 showed the highest discoloration percentage compared to the cultivars Cheniere, XP760, and XL753. Belefant-Miller (2007) reported that some cultivars are more prone to discoloration than others because of genetic differences. However, the mechanisms and reasons why this occurs are still unknown.

3.2 Effect of HMC on Chemical properties

No interaction was found between cultivar and HMC for insoluble amylose content ($P > 0.05$). Insoluble amylose content ranged from 19.5 to 25.9 across all the cultivars and HMC levels. Overall, purelines Cheniere and V3501 showed higher contents of amylose than did hybrids XP760 and XL753 [*F*(3, 24) = 52.57, $P < 0.001$]. However, HMC did not have any significant influence on amylose content. Similarly, Champagne et al. (2005) and Chrastil (1993) reported no significant differences in amylose content from earlier to later harvest dates. Other authors had reported increases in amylose content as HMC decreases (Siebenmorgen et al., 2006). They sustained that this was due to the fact that enzymatic activities from α-amylase are higher in the earlier dates, reflecting lower contents of amylose. Then, as the rice matures and the moisture content decreases this enzymatic activity is reduced and the amylose content increases. However, this study did not observe this tendency and found that amylose content was not influenced by HMC.

Figure 5 shows the influence of HMC on the crude protein content of the four long-grain cultivars evaluated. Overall, protein content and HMC seemed to have an inversely proportional relationship; lower HMCs showed higher protein contents. This tendency was observed for all the cultivars except V3501 where the protein content between High and Low HMCs was not significantly different. Contrastingly, Saleh and Meullenet (2007) found a direct relationship between protein content and HMC. They reported that at higher HMC protein content in long – grain cultivars was slightly higher than corresponding low harvest MC samples due to a greater percentage of immature kernels which are known to be richer in protein. On the other hand, Chrastil (1993) reported higher protein contents in low HMCs since the number of rice protein disulfide bonds increased slightly as the kernel matured.

The pasting profiles of the varieties as a function of the MC at which they were harvested are shown in Figure 6. Even though differences among varieties were observed, the majority of the viscosity parameters seemed to be unaffected by HMC (peak, through, breakdown and/or setback) ($P > 0.05$ for all). Wang et al. (2004) reported that peak viscosity of rice flour increased as the rice harvest moisture content decreased. These variations were supported due to changes in amylase activity, and enzymes related with starch synthesis, which activity is maximized at earlier harvest dates and then decreases gradually causing an increase in peak viscosities (Baun et al., 1970). However, the results from the present study did not show this trend. On the other hand, final viscosity showed a significant interaction between cultivar and HMC [$F(6, 24) = 4.28$, $P = 0.005$]. Final viscosity values of pureline cultivars Cheniere and V3501, were unaffected by the different HMC's. However, higher final viscosities were observed in the lower levels of HMCs for hybrids XP760 and XL753, where viscosities increased up to ~3-4 % when the HMC lowered down (Figure 5). A significantly negative correlation was found between final viscosities and amylose content ($r = -0.86$, $P < 0.001$) (Table 5). Asano et al. (2000) reported that a decrease in amylose content may occur as rice matures in the field, to which finally may originate a decrease in the final viscosity. Onset gelatinization temperatures varied from 70.15 to

72.45 °C across the evaluated cultivars, these values are typical of long-grain varieties with intermediates gelatinization temperatures, according to the classification made by Juliano, 1979. Onset [*F*(6, 24) = 11.48, *P* < 0.001] and peak gelatinization [*F*(6, 24) = 6.48, *P* < 0.001] temperatures showed an interaction between cultivar and HMC. Figure 6 shows that onset gelatinization temperature was unaffected by HMC for the three out of the four cultivars evaluated, except V3501. Hybrid V3501 harvested at a medium level of MC showed lower onset and peak gelatinization temperatures compared to that harvested at high or low MC. As shown in Table 5, a significative negative correlation was observed between amylose content and onset gelatinization temperatures (*r* = -0.68, *P* = 0.016). Similar correlation was also observed in the study by Sasaki et al. (1999) and indicates that starch with higher amylose content has more amorphous region and less crystalline, lowering gelatinization temperature and endothermic enthalpy. Finally, end gelatinization temperatures and enthalpy were not different for any of the cultivars, at any HMCs (*P* > 0.05).

3.3 Effect of HMC on cooking qualities

The two-way ANOVA revealed no significant interactions between cultivar and HMC in the cooking qualities of rice, including optimum cooking duration (OCD) and kernel expansion (*P* > 0.05 for all) (Table 4). Additionally, HMC did not have any significant effect on any of the rice cooking qualities that were evaluated.

Overall, only cultivar-related differences were observed in OCD [*F*(3, 24) = 14.54, *P* < 0.001] and length expansion [*F*(3, 24) = 8.15, *P* < 0.001]. Cultivars XL753, XP760 and Cheniere showed a significantly longer OCD compared to cultivar V3501, and pureline Cheniere expanded less in terms of length compared to the other three cultivars. Pureline cultivars showed the highest amylose content and a significantly negative correlation was found between length expansion and amylose content (r = -0.59, P = 0.035). Overall, these differences between rice cultivars may be due to genetic differences and in their amylose contents and granular structures. The long amylopectin chains may crystallize with an amylose molecule, which might extend through adjacent ‘clusters’, thereby contributing to double helices in several crystallites, which could result in a lower degree of swelling (Singh et al., 2004).

4. Conclusions

This study demonstrates the influences of harvest moisture content on rice physicochemical properties and cooking qualities. Overall, the harvest date was found to show little effect on rice cooking qualities. However, it was confirmed the importance of acknowledging what is the most adequate HMC level at which rice physical characteristics can be optimize and yield returns can be maximized.

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Table 1. Harvest dates, and harvest moisture contents (HMCs) of the rough rice used in the tests

HMC Level	Harvest Dates (DD-MM-YY)	Cultivar	HMC (% w.b)
High	09-15-2015	XP760	25.0
		XL753	25.0
		V3501	22.0
		Cheniere	25.0
Medium	09-21-2015	XP760	19.2
		XL753	18.5
		Cheniere	20.3
	09-24-2015	V3501	20.5
Low	10-02-2015	XP760	14.9
		XL753	14.6
		V3501	15.2
		Cheniere	14.8

Table 2. Physical properties as a function of cultivar and harvest moisture content (HMC)[a]

HMC Level	Cultivar	Chalky area (%)	Discolored area (%)	Broken Kernels (% By Mass)	Whiteness (L*)
High	XP760	3.6 (± 0.3)	9.7 (± 2.5)	9.2 (± 0.9)	72.3 (± 0.3)
	XL753	1.6 (± 0.1)	8.7 (± 3.5)	7.4 (± 0.8)	71.1 (± 0.3)
	V3501	0.8 (±0.3)	16.3 (± 5.5)	18.8 (± 2.0)	70.4 (± 0.4)
	Cheniere	1.0 (± 0.2)	8.7 (± 4.5)	10.7 (± 1.6)	71.3 (± 0.2)
Medium	XP760	2.6 (± 0.1)	3.3 (± 5.8)	8.0 (± 1.5)	71.9 (± 0.5)
	XL753	1.2 (± 0.2)	6.3 (± 6.5)	5.8 (± 0.2)	70.6 (± 0.5)
	V3501	0.5 (± 0.4)	20.0 (± 3.0)	15.1 (± 0.7)	69.9 (± 0.1)
	Cheniere	0.8 (± 0.2)	12.3 (± 2.9)	7.5 (± 0.6)	70.9 (± 0.2)
Low	XP760	2.4 (± 0.2)	10.3 (± 2.1)	9.0 (± 0.3)	72.2 (± 0.2)
	XL753	0.9 (± 0.3)	14.7 (± 2.1)	7.6 (± 0.6)	71.2 (± 0.6)
	V3501	0.3 (± 0.2)	19.3 (± 4.0)	17.6 (± 0.9)	71.1 (± 0.4)
	Cheniere	0.5 (± 0.3)	12.7 (± 0.6)	7.4 (± 1.0)	71.1 (± 0.3)

[a] Values represent the mean (± standard deviation) of three replications

Table 3. Chemical composition as a function of cultivar and harvest moisture content (HMC)[a]

HMC Level	Cultivar	Apparent Amylose (%)	Crude Protein (%)	Gelatinization Temperature (˚C)			Enthalpy (J/g)
				Onset	Peak	End	
High	XP760	20.9 (± 0.2)	7.1 (± 0.1)	71.7 (± 0.1)	76.7 (± 0.1)	84.5 (± 1.3)	12.0 (± 2.8)
	XL753	20.4 (± 0.3)	7.7 (± 0.1)	71.8 (± 0.1)	77.4 (± 0.1)	84.4 (± 0.7)	10.8 (± 1.3)
	V3501	22.4 (± 1.8)	8.9 (± 0.2)	71.3 (± 0.2)	76.7 (± 0.1)	82.0 (± 0.1)	7.1 (± 0.6)
	Cheniere	25.3 (± 0.2)	7.3 (± 0.1)	70.9 (± 0.1)	75.5 (± 0.2)	80.8 (± 0.3)	6.6 (± 1.7)
Medium	XP760	20.9 (± 0.3)	7.7 (± 0.1)	71.2 (± 0.1)	76.7 (± 0.1)	84.1 (± 0.8)	10.4 (± 1.5)
	XL753	19.8 (± 0.3)	8.3 (± 0.0)	72.0 (± 0.4)	77.4 (± 0.2)	84.9 (± 0.3)	11.5 (± 0.9)
	V3501	22.5 (± 0.5)	8.2 (± 0.2)	70.3 (± 0.2)	75.5 (± 0.3)	81.5 (± 0.6)	8.7 (± 1.4)
	Cheniere	24.0 (± 1.7)	8.0 (± 0.1)	70.7 (± 0.2)	75.4 (± 0.2)	81.0 (± 0.4)	7.4 (± 1.8)
Low	XP760	21.3 (± 0.3)	8.0 (± 0.0)	71.3 (± 0.1)	76.6 (± 0.2)	84.0 (± 0.5)	10.6 (± 0.8)
	XL753	20.9 (± 0.8)	8.1 (± 0.3)	71.6 (± 0.1)	77.1 (± 0.1)	84.0 (± 0.3)	10.1 (± 1.4)
	V3501	20.4 (± 0.9)	8.9 (± 0.1)	70.9 (± 0.3)	76.6 (± 0.3)	82.7 (± 0.5)	9.9 (± 0.7)
	Cheniere	25.6 (± 0.5)	8.1 (± 0.2)	70.7 (± 0.1)	75.5 (± 0.2)	81.1 (± 0.2)	8.0 (± 0.1)

[a] Values represent the mean (± standard deviation) of three replications

Table 4. Cooking quality parameters as a function of cultivar and harvest moisture content (HMC)[a]

HMC Level	Cultivar	Optimum Cooking Duration (min)	Length Expansion Ratio	Width Expansion Ratio
High	XP760	21.0 (± 0.0)	2.2 (± 0.6)	1.1 (± 0.3)
	XL753	22.3 (± 0.6)	2.2 (± 1.0)	0.8 (± 0.3)
	V3501	19.7 (± 1.2)	2.3 (± 0.6)	1.0 (± 0.3)
	Cheniere	21.3 (± 0.6)	1.8 (± 0.7)	1.1 (± 0.2)
Medium	XP760	21.0 (± 0.0)	2.3 (± 1.0)	0.8 (± 0.2)
	XL753	21.7 (± 0.6)	2.1 (± 0.8)	1.0 (± 0.3)
	V3501	19.7 (± 0.6)	2.2 (± 0.6)	0.9 (± 0.3)
	Cheniere	22.0 (± 0.0)	0.9 (± 0.3)	1.1 (± 0.2)
Low	XP760	21.3 (± 1.5)	1.8 (± 0.5)	1.2 (± 0.3)
	XL753	21.3 (± 1.2)	2.6 (± 0.9)	0.9 (± 0.4)
	V3501	19.7 (± 0.6)	2.1 (± 0.3)	0.9 (± 0.2)
	Cheniere	21.7 (± 0.6)	1.7 (± 0.7)	1.0 (± 0.3)

[a] Values represent the mean (± standard deviation) of three replications

Table 5. Descriptive statistics and Pearson correlations among the various physico-chemical and cooking properties

	Mean	*s.d*	(1)	(2)	(3)	(4)	(5)	(6)
(1)Amylose	22.03	1.96						
(2)Crude Protein	8.02	0.54	-0.17					
(3)Onset GT	71.20	0.51	-0.67*	-0.18				
(4)Final Viscosity	2745.16	568.79	-0.86**	0.41	0.46			
(5)OCD	21.05	0.92	0.11	-0.55	0.39	-0.44		
(6)LER	2.01	0.42	-0.59*	0.11	0.45	0.77**	-0.40	
(7)WER	0.97	0.12	0.28	-0.17	-0.07	-0.39	0.08	0.55

GT: gelatinization temperature; OCD: optimum cooking duration; LER: length expansion ratio; WER: width expansion ratio

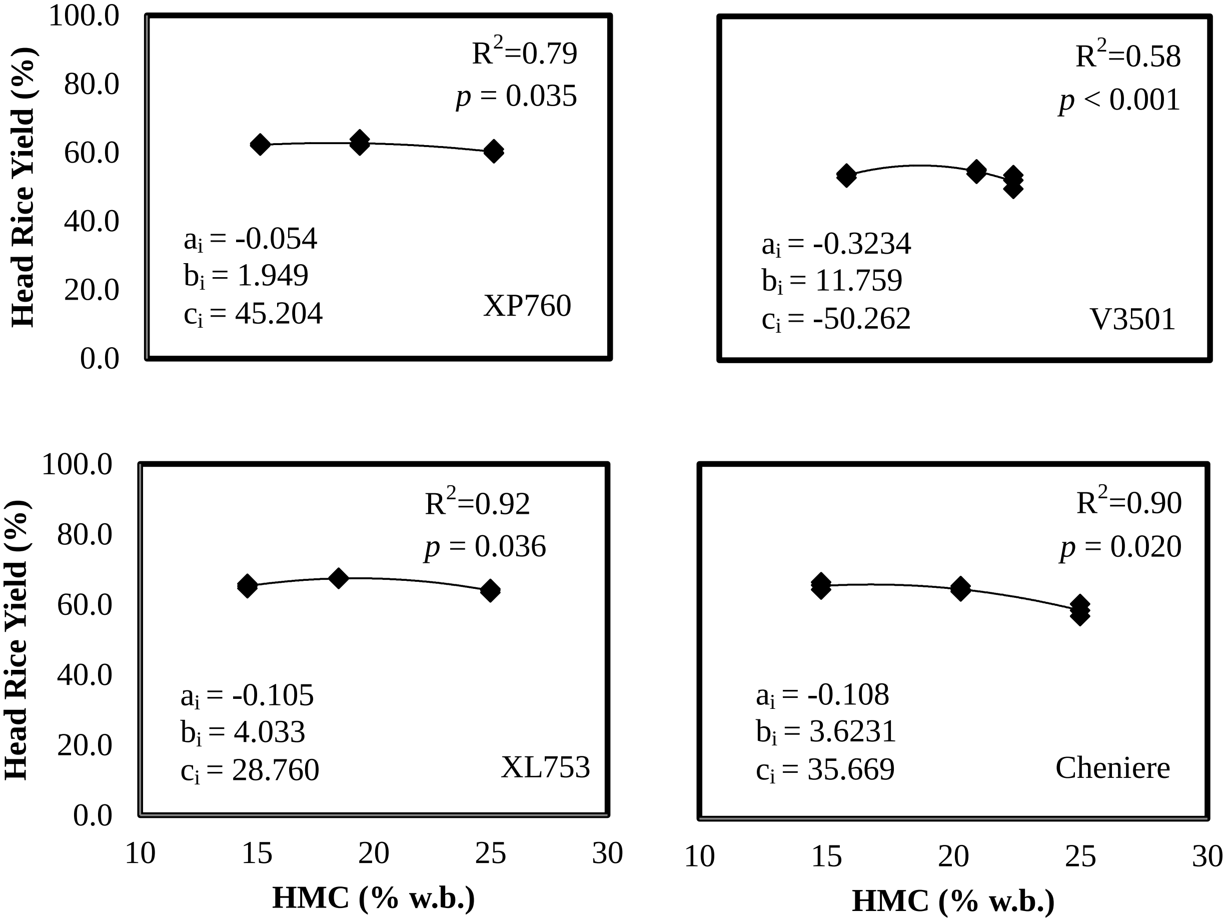

Figure 1. Head rice yields (HRYs) as a function of harvest moisture content for the indicated long-grain cultivars. a_i, b_i, and c_i indicate the regression variables of fitting the quadratic equation: HRY % = a_i HMC^2 + b_i HMC + c_i (Siebenmorgen et al. 2007). The subscript i refers to each cultivar set.

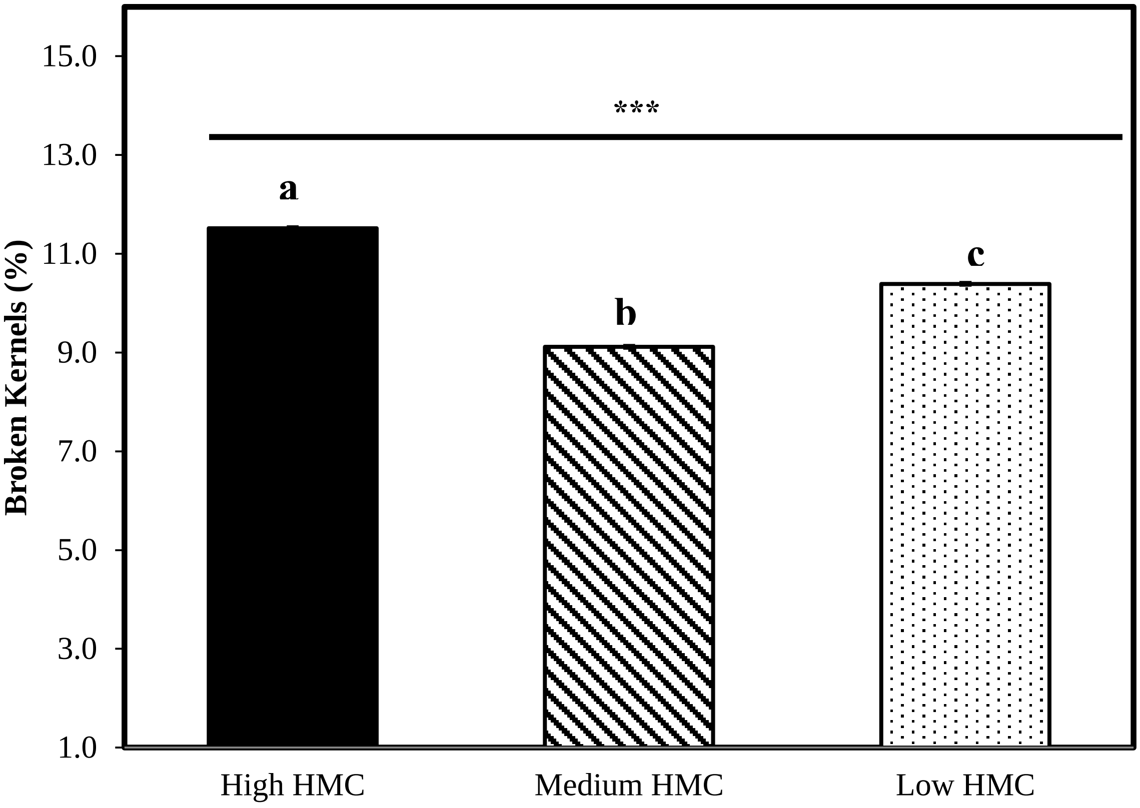

Figure 2. Mean broken kernels as a function of cultivar and harvest moisture content (HMC). *** represent a significant difference at $P < 0.001$. Mean ratings with different letters are significantly different ($P < 0.05$). Error bars represent standard error of the means.

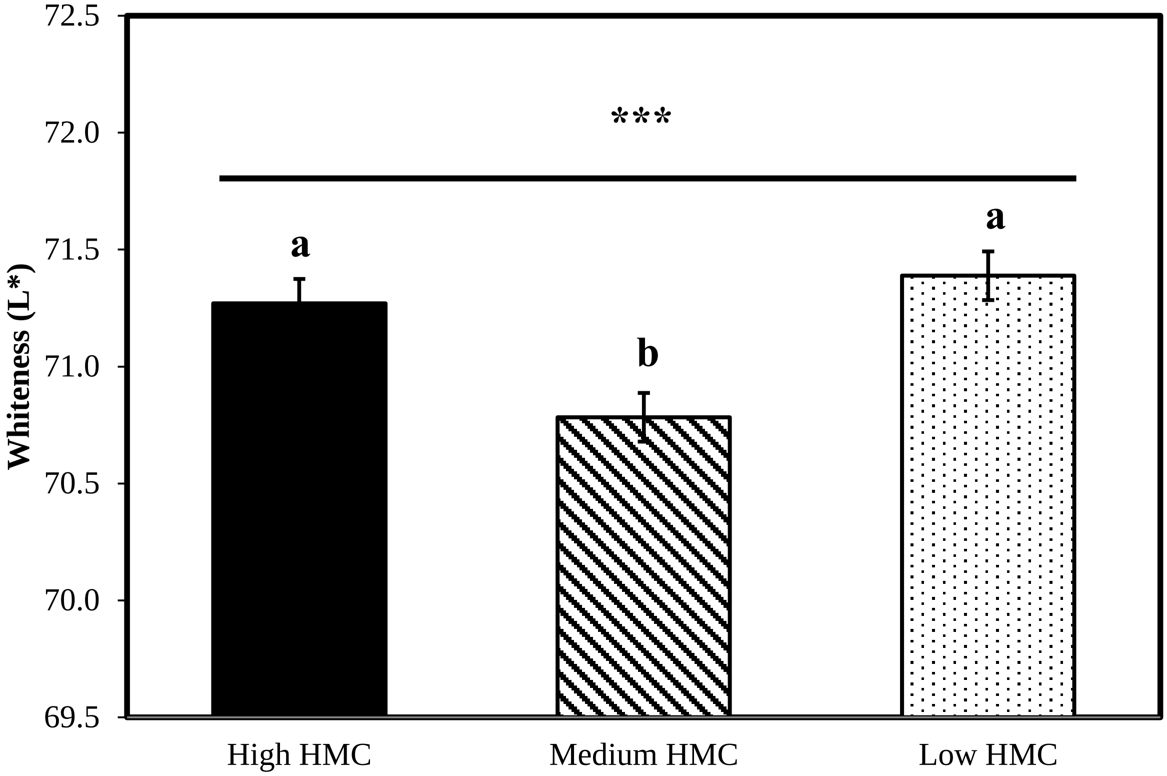

Figure 3. Mean whiteness values as a function of cultivar and harvest moisture content (HMC). *** represent a significant difference at $P < 0.001$. Mean ratings with different letters are significantly different ($P < 0.05$). Error bars represent standard error of the means.

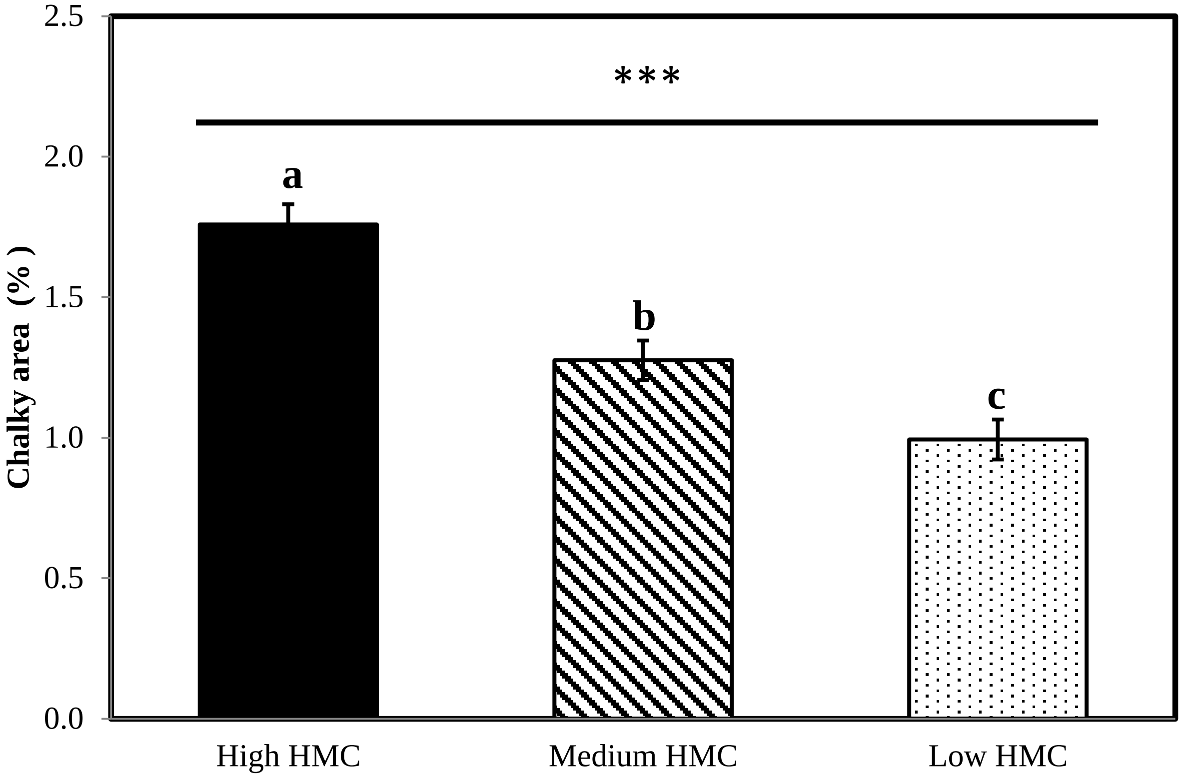

Figure 4. Mean chalky area percentage as a function of cultivar and harvest moisture content (HMC). *** represent a significant difference at $P < 0.001$. Mean ratings with different letters are significantly different ($P < 0.05$). Error bars represent standard error of the means.

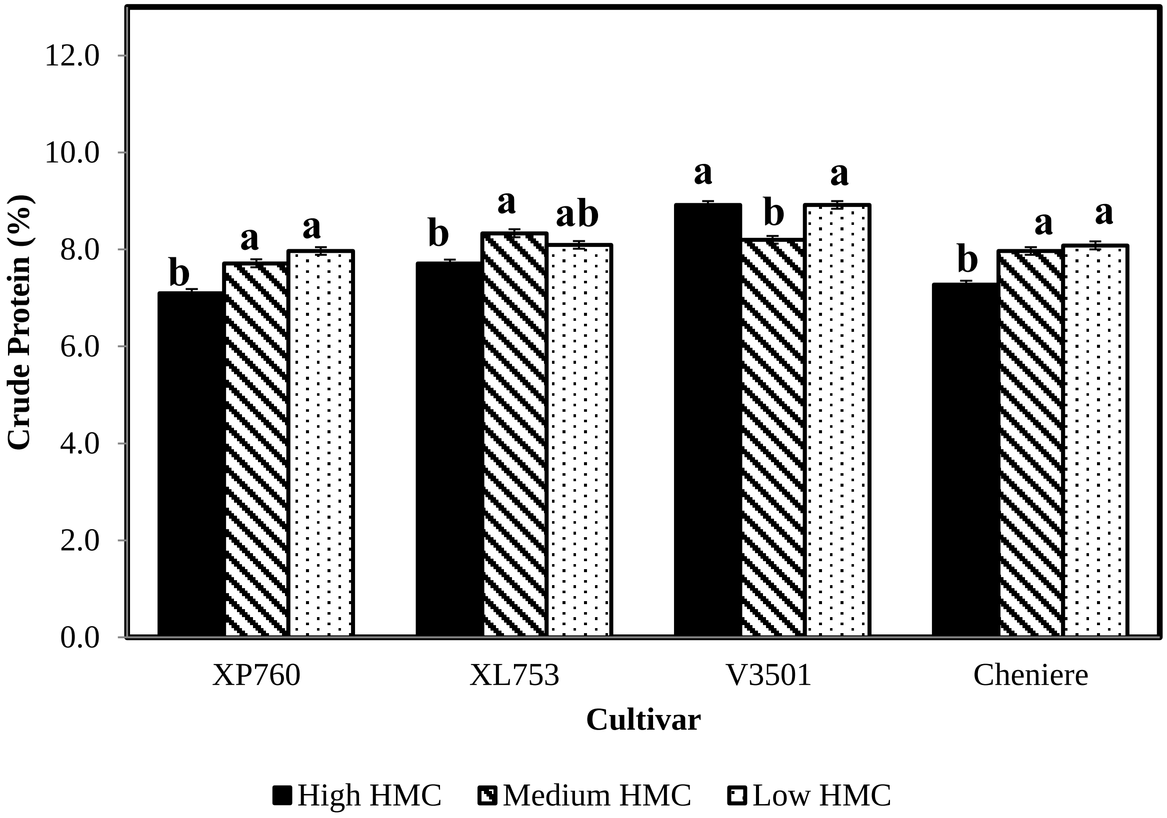

Figure 5. Mean crude protein content as a function of cultivar and harvest moisture content (HMC). Mean ratings with different letters are significantly different ($P < 0.05$). Error bars represent standard error of the means.

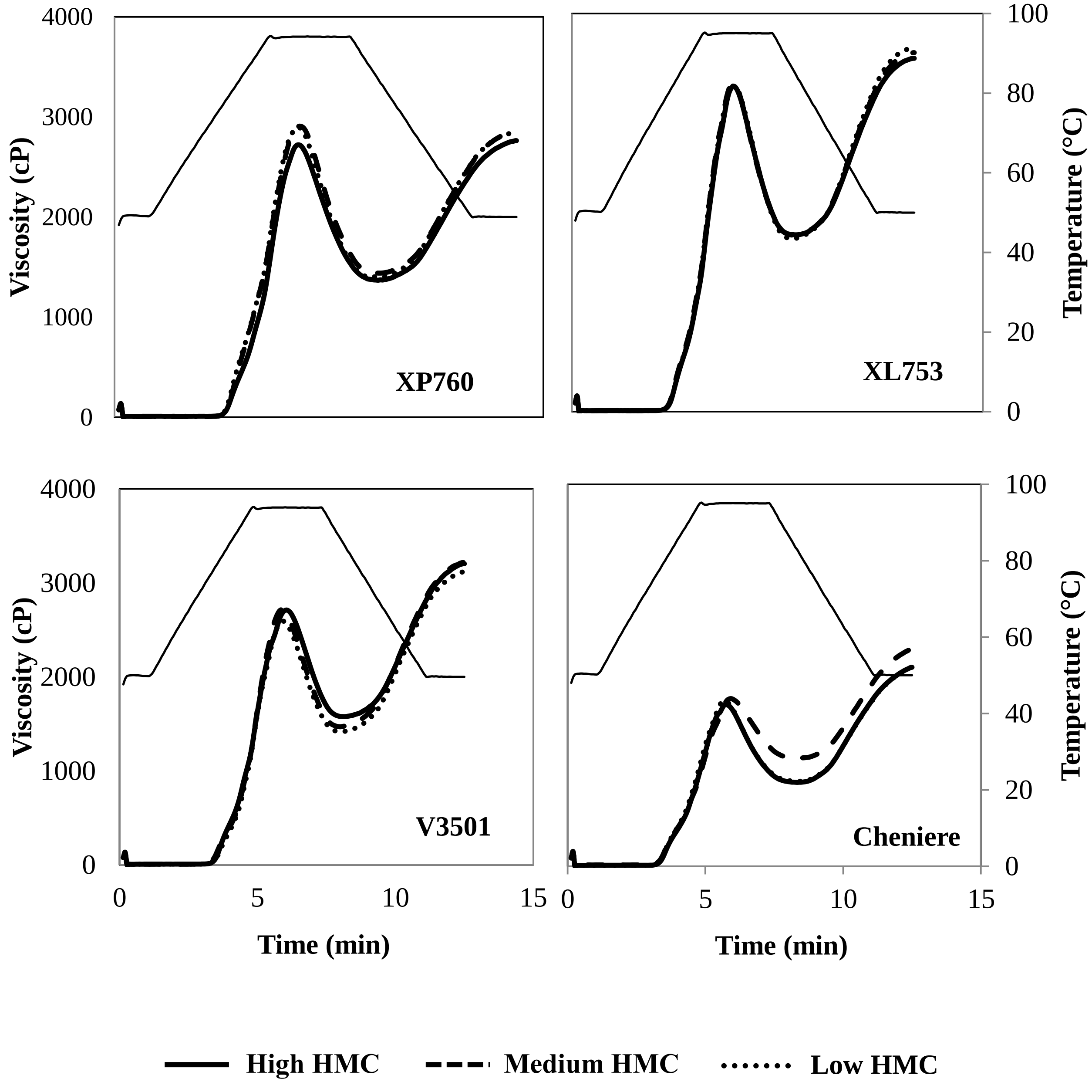

Figure 6. Pasting profiles of the evaluated long-grain rice cultivars as a function of the harvest moisture content (HMC).

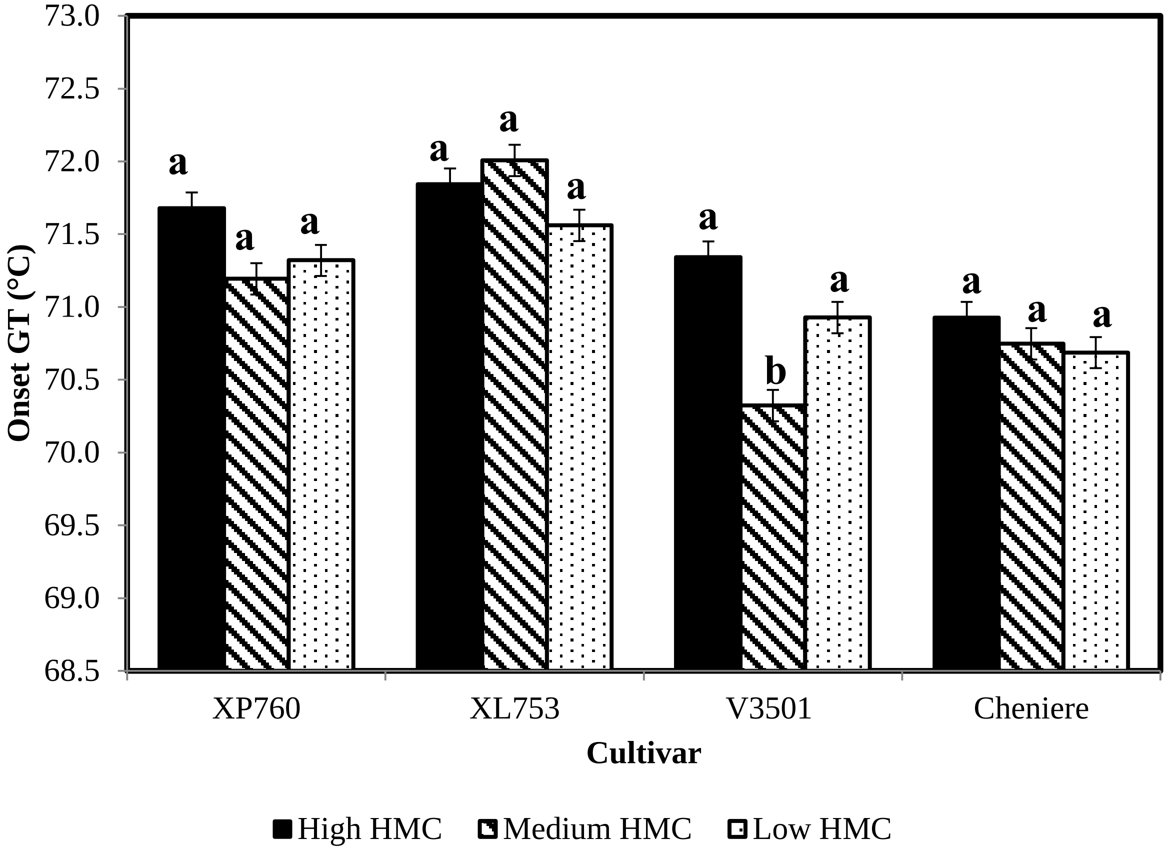

Figure 7. Mean onset gelatinization temperatures as a function of cultivar and harvest moisture content (HMC). Mean ratings with different letters are significantly different (*P* < 0.05). Error bars represent standard error of the means.

Chapter 5.

Effects of cultivating location on physicochemical properties and cooking qualities of long-grain rice (*Oryza sativa* L.)

Abstract

Environmental variations across different cultivating locations have found to have a direct impact on milling yields and physicochemical properties of rice. However, little attention has been paid to the influence of cultivation location on cooking and sensory qualities of rice. This study aimed to determine whether cultivating location can affect physicochemical properties, cooking qualities, and sensory characteristics of long-grain rice. Four long-grain cultivars (XP760, XL753, V3501, and Cheniere) cultivated in Harrisburg (Arkansas) and Alvin (Texas) were harvest at a medium level of moisture content in fall 2015 and these were compared between the two cultivation locations with respect to physicochemical properties, cooking qualities, and sensory characteristics. Rice samples grown in Alvin had more broken, chalky, and discolored kernels than those grown in Harrisburg, reducing head rice yields. In addition, rice samples grown in Alvin showed lower amylose and protein contents, lower peak viscosities, and higher gelatinization temperatures than those grown in Harrisburg. Rice samples grown in Alvin showed undesirable cooking qualities such as longer cooking duration and greater width-expansion when compared to those grown in Harrisburg. When cooked, rice samples grown in Alvin showed greater intensities of starchy flavor and tooth-pull characteristics than did those grown in Harrisburg. The present study demonstrated that physicochemical properties, cooking qualities, and sensory characteristics of long-grain rice cultivars can be different between their grown locations.

1. Introduction

Rice is grown in all five continents in the world and around 90 % of the world's rice is cultivated in Asia. Inherently, genetic variations across the different geographical locations throughout the world could make rice quality as one of the most variable aspects in rice production. In the same fashion, within the same country different growing locations have shown to express different milling and quality traits in rice. Siebenmorgen et al. (2006) found that rice growth location (Lodge Corner in AR versus Essex in MO) affects kernel thickness distributions, green kernel content, fissured kernel content, and head rice yield (HRY), which might be due to the differences in nighttime air temperatures (NTATs) during the kernel development stage and soil composition between the two different locations evaluated. For example, elevated NTATs during kernel development stage has been found to influence physicochemical properties (Aboubacar et al. 2006; Lanning et al, 2012, Patindol et al., 2014), and milling qualities of rice (Siebenmorgen et al., 1998; Peng et al., 2004). An increase on undesirable characteristics such as chalkiness and fissures in rice grain was found to be linked to elevated NTATs during kernel development stage (Siebenmorgen et al., 1998; Lanning and Siebenmorgen, 2013). Lisle et al. (2000) in a study performed in three long-grain cultivars, reported that when rice was grown at higher NTATs (day/nighttime air temperature: 38/21°C) in a glasshouse, the amount of chalky kernels was significantly greater than when grown at lower air temperatures (26/15°C). Similarly, Fitzgerald and Resurreccion (2009) reported that the formation of chalky rice is presumably explained due to a decreased in the substrate supply from the soil to the rice panicle and a reduction in enzymatic activity in high temperatures during critical developmental stages of rice growth. In addition, elevated NTATs has been found to influence starch accumulation, i.e., a decrease in total starch and amylose content in the endosperm (Ahmed et al., 2014); however, other components such as protein and lipid and rice flour pasting properties seemed to be unaffected by NTATs (Cooper et al., 2008).

Cooking qualities and sensory aspects of rice are major elements in rice producer countries or in countries where rice is a staple food. These aspects are directly influenced by rice physical properties and chemical composition such as amylose, amylopectin, and protein. Based on previous findings regarding the effects of different growing location on physicochemical properties and milling qualities, there is a question as to whether growing locations can also influence cooking qualities and sensory aspects of rice. Therefore, this study aims to determine whether cultivating location affects physicochemical properties, cooking qualities, and sensory characteristics of long-grain rice, with a case of study in the two locations: Alvin in Texas (TX) and Harrisburg in Arkansas (AR).

2. Materials and Methods

2.1 Rice samples conditioning and milling properties

Two long-grain pureline cultivars (Cheniere and V3501) and two hybrid cultivars (XL753 and XP760) were used in this study. Each cultivar was cultivated in two different locations: Alvin, TX (Latitude 29° 25' 25.8492" N; Longitude 95° 14' 38.7672" W) and Harrisburg, AR (Latitude 35°33' 51.29" N; Longitude 90°43' 0.4" W). Rice samples were hand-harvested at a medium level (18.5-20.3 % on a wet basis) of harvest moisture content (HMC). HMC of the first hand-stripping 200 kernels of rough rice from six randomly selected panicles were measured using a single-kernel moisture meter (CTR 800E, Shizuoka Seiki, Shizuoka, Japan). Rough rice samples were cleaned using a dockage tester (XT4, Carter-Day, Minneapolis, MN, U.S.A.). The cleaned lots were then conditioned to12.0 ± 0.5% (wet basis) moisture content using a climate controlled chamber (26 °C and 56% relative humidity), regulated by a stand-alone conditioner (Model 5580A, Parameter Generation & Control, Black Mountain, N.C.). Rough rice of each cultivar was dehulled using a dehusker (THU-35, Satake, Hiroshima, Japan), and the resultant brown rice was milled using a laboratory miller (McGill number 2, RAPSCO, Brookshire, TX, U.S.A.). Based on a preliminary test, milling duration of each cultivar was determined based on the surface lipid content (mean ± standard deviation = 0.40 ± 0.05%) of head rice. Each rice sample was stored in a sealed container at 4 °C. The containers were placed at room temperature (22 °C) for 24 h prior to sample preparation and further analysis. Head rice yield was determined, with head rice being separated from broken kernels using a sizing device (Model 61, Grain Machinery Manuf. Corp., Miami, FL) and maintained for determination of quality properties.

2.2 Physical properties

Physical properties, i.e., kernel dimensions, broken kernels, and chalkiness of head rice samples were measured using an image analysis system (SeedCount SC 5000, Next Instruments, Condell Park, Australia) as described in Chapter 3. In addition, degree of whiteness ($L*$) was determined using near-infrared reflectance (NIR) spectroscopy (NIR-DA 7200, Perten Instruments, Huddinge, Sweden). All the analyses were evaluated in triplicate.

2.3 Chemical composition

A 60-g portion from one head rice sub-sample was ground into flour with a cyclone mill (3010-30, UDY, Fort Collins, CO, U.S.A.) with a 0.5 mm screen to determine the effects of growing location on moisture content, amylose content, pasting property, thermal property, and crude protein content of rice samples.

The moisture content of the rice flour was measured according to AACCI method (44 15.02). Amylose content was determined by the simplified iodine assay method (Juliano, 1971) as described in Chapter 3. Pasting properties of rice samples were determined using a Rapid Visco Analyser (RVA Super 4, Newport Scientific, Warriewood, Australia). A thermogram was produced by the viscometer software showing changes in viscosity over the cycle duration, as well as summary statistics of peak viscosity, trough viscosity, breakdown (peak-trough viscosity), final viscosity, setback (final-peak viscosity), peak time, and pasting temperature. Moreover, thermal properties, such as onset, peak, and conclusion gelatinization temperatures (GT), of rice samples were measured using a differential scanning calorimeter in modulating mode (DSC-Q100, TA Instruments, New Castle, DE, U.S.A.). Finally, crude protein content was determined by using NIR spectroscopy (NIR-DA 7200, Perten Instruments, Huddinge, Sweden). All the analyses were evaluated by triplicate.

2.4 Cooking qualities

Optimum cooking duration (OCD) was assessed by Ranghino test for milled rice (Juliano and Bechtel, 1985). Length expansion ratio, and width expansion ratio were determined according to the methods by Juliano and Bechtel (1985).

2.5 Texture profile analysis of cooked rice

Texture profile analysis (TPA) of rice samples was conducted as described in Chapter 3.

2.6 Descriptive sensory analysis of cooked rice

Descriptive sensory analysis of rice samples was conducted according to the procedures described in Chapter 3 at the University of Arkansas Sensory Service Center (Fayetteville, AR, U.S.A.). Both fractioned and unfractioned rice samples of each cultivar were used, so there were a total of 16 sub-samples (i.e., 4 cultivars x 2 fractions x 2 cultivating locations). Nine descriptive panelists rated intensities of 19 sensory attributes (4 appearance-, 3 texture-, 4 taste-, 7 flavor-, and 1 feeling factor-related attributes) on continuous numerical scales ranging from 0 to 15 (Meilgaard et al., 2007) conforming to the Spectrum method (Sensory Spectrum Inc., Chatham, NJ, U.S.A.). To minimize sensory fatigue, a 5-min break was allowed between sample presentation. During the break, spring water (Clear Mountain Spring Water, taylor Distributing, Heber Springs, AR, U.S.A.) and unsalted crackers (Nabisco Premium Unsalted Tops Saltine Crackers, Mondelēz Global LLC, East Hanover, NJ, U.S.A.) were presented for palate cleansing. The entire analysis was repeated, on the different day, to provide two replicate sensory analyses of the cooked-rice samples.

2.7 Statistical analysis

Statistical analyses were performed using JMP Pro (version 12.0, SAS Institute Inc., Cary, NC, U.S.A.). To determine the effects of cultivar and cultivating location on physicochemical properties, cooking qualities, and textural characteristics, two-way analyses of variance (ANOVA) were used. If a significant difference in means was indicated by the ANOVA, post hoc comparisons between variables were performed using a Tukey's honest significant difference (HSD) test. Sensory data were analyzed using a two-way ANOVA treating cultivar and cultivating location as fixed effects. A statistically significant difference was defined as $P < 0.05$.

3. Results and Discussion

3.1 Effects of cultivating location on physical properties

HRY significantly differed between the two locations across all the cultivars [$F(3,16) = 123.51$; $P < 0.001$) . As shown in Figure 1, cultivars that were grown in Harrisburg, AR showed up to 28 % higher HRYs compared to the same cultivars cultivated in Alvin, TX. Based on the field temperatures recorded throughout the critical grain-filling stages (R6-R8) in the two evaluated locations (Table 1), daytime (7:00 am to 7:00 pm) and nighttime temperatures (8:00 pm to 6:00 am) were on average 4˚C greater in Alvin, TX than in Harrisburg, AR. Many studies have established the effect of elevated NTATs in contributing to a decrease on head rice yields (Peng et al., 2004; Sheehy et al., 2006; Huang et al., 2016). Perhaps, one of the most extensive research regarding the relationship between rice yield and temperature was done by Peng et al. (2004) using data from irrigated field experiments conducted during 1992 to 2003. The authors reported a reduction by as much as 10% for every 1 °C increase in night time minimum temperature. Additionally, Huang et al. (2016) reported in a comparison study between two locations in South of China, a decrease of 28 % of grain yield in the location with approximately 5 °C higher NTATs. These results are often associated with a decrease on panicle mass (Ziska and Manalo, 1996) and kernel dimensions when rice is subjected to high NTATs. Siebenmorgen and Copper (2006) found that head rice yield is highly sensitive to the thickness distribution pattern of a population of rice kernels and, by altering the thickness distribution of kernels, an increase in nighttime temperature could reduce head rice yield.

Table 2 shows mean values of the physical properties of rice samples as a function of cultivar and cultivating location. There was a significant interaction between cultivar and cultivating location on the percentage of chalky kernels [$F(3,16) = 42.27$; $P < 0.001$]. For all the cultivars the numerical mean of chalky kernels was higher in Harrisburg than in Alvin. However, statistically significant differences were only reflected in cultivars XP760 and XL753. In accordance to the temperature data obtained from the two locations, the high NTATs recorded in Alvin could explain the increase in the amount of chalky kernels in this location. Similar results were reported by Lisle et al. (2000) where the amount of chalky kernels was significantly greater at higher NTATs (21 °C) than at lower NTATs (15 °C) in three long-grain cultivars. It has been proposed that the relationship between chalkiness and NTATs is not strictly linear, and it is highly dependent on the cultivar. For example, Yoshida and Hara (1977) found a quadratic relationship between chalkiness and NTATs in indica (IR20) and japonica (Fujisaka 5) rice cultivars, with an increase on chalkiness in temperatures above and below 18 °C. Ambardekar et al. (2011) also reported a second-order relationship between NTATs and chalkiness of four long-grain cultivars, suggesting the probability of a specific temperature where the enzymatic activity in charge of the packing of starch granules during the grain-filling stage is optimum.

Degree of whiteness designated by L^* values (greater values indicate a whiter rice) was found to be influenced by cultivating location [$F(1, 16) = 59.63$, $P < 0.001$]. For all the cultivars, rice grown in Alvin had greater L^* values than those grown in Harrisburg. Since chalkiness is typically manifested as a white opaque region in the rice kernel, it is frequently shown a direct relationship between chalkiness and whiteness of rice (Lanning et al., 2011). Thus, since the high NTATs might cause a greater level of chalkiness in rice grown in Alvin, which in turn might result in higher L* values.

There was a significant interaction between cultivar and cultivating location on broken kernels [*F*(3, 16) = 59.62, *P* < 0.001] (Table 2). Hybrids XP760 and XL753 and pureline Cheniere grown in Alvin showed a significantly higher amount of broken kernels compared to those grown in Harrisburg. However, for cultivar V3501 the difference between the two locations was not statistically significant (*P* > 0.05). Siebenmorgen et al. (1998) reported that elevated air temperature levels produced higher amounts of fissured and broken kernels across a range of relative humidities due to an expansion on the outer portions of the kernel and a pulling apart force from the central region when the temperature increases causing the kernel to fissure. The greater presence of chalky kernels grown in Alvin might have influence the percentage of broken kernels and the posterior reduction of rice yields, since chalky kernels tend to be more susceptible to fissures and breakage during milling (Siebenmorgen et al., 2006).

3.2 Effects of cultivating location on chemical properties

As shown in Figure 2, a significant interaction was found between cultivar and cultivating location on crude protein content [*F*(3, 16) = 9.690, *P* < 0.001]. The hybrid cultivars XP760 and XL753 grown in Alvin showed lower percentage of protein content compared to those grown in Harrisburg, but such a trend was not observed in the pureline cultivars. The greater percentage of protein content in the hybrid cultivars grown in Alvin might be associated with the higher NTATs of the cultivating location in comparison to the NTATs of Harrisburg. Laning et al. (2012) reported a negative correlation between crude protein content and NTATs, indicating that protein content decreased with elevated NTATs for all seven long-grain cultivars, which might be due to insufficient accumulation of starch during the filling stage. Yamakawa et al. (2007) also demonstrated that elevated temperatures during the ripening period might suppress expression levels of various genes associated with seed-protein development. However, since contrasting results, i.e., an increase of protein content with an increase of air-temperatures in the field, have been also reported (Maeshige, 1981; Tamaki et al., 1989), further studies are needed in this regard.

The insoluble amylose contents of cultivars XL753 and V3501 were found to be lower when grown in Alvin compared to when grown in Harriburg [$F(3, 16) = 10.434$, $P < 0.001$] as shown in Figure 3. The effect of NTATs on starch composition of rice has been widely studied (Aboubacar et al. 2006; Lanning et al., 2012; Patindol et al., 2014). Overall, elevated NTATs cause the amylose content in the endosperm to decrease (Resurreccion et al., 1977; Asaoka et al., 1984; Asaoka et al., 1985). The decrease in amylose content is usually explained by the reduced activity of the key enzyme that catalyzes amylose biosynthesis, granule bound starch synthase or GBSS. However, these results are sometimes dependent on the cultivar and are more sensitive to cultivars in the presence of a single-nucleotide polymorphism of AGGTATA to AGTTATA, in the allele encoding for GBSS. Such polymorphism is sensitive to temperature and those cultivars with the AGTTATA allele result in fewer mature GBSS transcripts at high NTATs (Larkin and Park, 1999).

Pasting profiles of the four cultivars evaluated as a function of the growing location are illustrated in Figure 4. The two- way ANOVA showed no significant interaction between cultivar and cultivating location for peak viscosity ($P > 0.05$). The growing location, on the other hand, significantly influenced peak viscosity in long-grain rice [$F(1, 16) = 115.20$, $P < 0.001$]. For all the cultivars that were grown in Alvin the peak viscosity increased up to 12 % compared to those grown in Harrisburg. In addition, breakdown [$F(1, 16) =65.25$, $P < 0.001$] and final viscosity [$F(1, 16) = 125.68$, $P < 0.001$] were significantly higher in the rice samples grown in Alvin than those grown in Harrisburg. However, setback values were the other way around [$F(1, 16) = 76.80$ $P < 0.001$]. In the two-year study comparing the NTAT effect on four long-grain rice cultivars, Patindol et al. (2014) showed that amylose content was negatively correlated with peak, final, and breakdown viscosities, whereas it was positively correlated with setback and total setback viscosity. Additionally, changes in amylopectin chains as affected by elevated air temperatures, i.e., a decrease in the percentage of amylopectin short chains (DP $\leq$ 18) and a corresponding increase in the percentage of long chains (DP $\geq$ 19), were also positively correlated with rice flour pasting properties.

Gelatinization temperatures significantly differed between the two cultivating locations. As shown in Figure 5, long-grain rice cultivars grown in Alvin had a significantly higher onset gelatinization temperature than those grown in Harrisburg [$F(1, 16) = 509.24$, $P < 0.001$]. Similarly, rice samples grown in Alvin showed higher peak [$F(1, 16) = 2158.71$, $P < 0.001$] and end gelatinization temperatures [$F(1, 16) = 150.04$, $P < 0.001$]. Enthalpy values, on the other hand, were unaffected by the cultivation location ($P > 0.05$). Suzuki et al. (2003) reported a significantly decreased in onset, peak, and conclusion gelatinization temperatures, with lower environmental temperatures during seed development. In a similar vein, Lanning et al. (2012) showed positive correlations of gelatinization temperatures and NTATs.

3.3 Effects of cultivating location on cooking qualities

Table 4 shows the mean values of the cooking quality parameters as a function of cultivar and cultivating location. Optimum cooking duration, a parameter that is often measured in rice cooking quality, showed significant differences between the two locations [$F(1, 16) = 36.00$ $P < 0.001$]. The long-grain rice samples grown in Alvin took a significantly longer cooking duration than those grown in Harrisburg, which might due to the high gelatinization temperatures and the lower content of insoluble amylose reported in Alvin, since gelatinization temperature has been positively correlated with cooking duration of rice, and amylose content has shown a negative correlation (Bhattacharya and Snowbhagya, 1971; Singh et al., 2005). Additionally, according to Bhattacharya and Snowbhagya (1971), cooking duration is primarily related to the surface area of the milled rice which has also shown to be affected by NTATs (Siebenmorgen and Copper, 2006).

Long-grain rice samples grown in Alvin showed a greater width expansion compared to those grown in Harrisburg [$F(1, 16) = 8.00$, $P = 0.006$]. Length-wise expansion without a corresponding increase in girth is considered as a highly desirable trait of rice grain quality. This undesirable characteristic is often associated to lowest amylose content, as it was evidenced by the long-grain rice samples grown in Alvin (Singh et al., 2005). Furthermore, cultivating location was found to have no effects on length expansion for any of the cultivars evaluated ($P > 0.05$) (Table 4).

3.4 Effects of cultivating location on sensory and textural characteristics of cooked rice

A Two-way ANOVA was conducted to determine the effect of growing location and cultivar on the sensory characteristics of long-grain rice. There no significant interactions on any sensory characteristics ($P > 0.05$ for all) (Table 5). Cultivating location was found to have a significant effect on the starchy flavor [$F(1, 136) = 9.30$, $P = 0.003$] and tooth-pull textural characteristics [$F(1, 136) = 6.16$, $P = 0.001$]. As shown in Figures 6 and 7, rice samples grown in Alvin showed significantly higher intensity ratings on both attributes than those grown in Harrisburg.

Cultivating location affected a couple of texture profile analysis (TPA) parameters, hardness [$F(1, 72) = 20.08$, $P = 0.037$] and cohesiveness [$F(1, 72) = 20.62$, $P < 0.001$]. Rice samples grown in Harrisburg showed higher hardness and cohesiveness values compared to those grown in Alvin (Figures 8 and 9). Since starch is the main component of rice, changes in the starch component can influence textural characteristics of rice. For example, the result, i.e., the higher values of amylose content in the rice samples grown in Harrisburg than those grown in Alvin, could explain these differences since previous studies have shown a positive correlation between amylose and hardness of cooked rice samples (Sowbhagya et al., 1987; Singh et al., 2005). Additionally, Singh et al. (2005) reported that cohesiveness was positively correlated with amylose content, but it was negatively correlated with cooking duration.

4. Conclusions

This study demonstrated the impacts of cultivating locations on cooking qualities and sensory characteristics of long-grain rice samples. Rice samples grown in Alvin had more broken, chalky, and discolored kernels than those grown in Harrisburg, reducing head rice yields. In addition, rice samples grown in Alvin showed lower amylose and protein contents, lower peak viscosities, and higher gelatinization temperatures than those grown in Harrisburg. Rice samples grown in Alvin showed longer cooking duration and greater width-expansion than those grown in Harrisburg. When cooked, rice samples grown in Alvin showed greater intensities of starchy flavor and tooth-pull characteristics than those grown in Harrisburg. The present study showed that physicochemical properties, cooking qualities, and sensory characters of long-grain rice cultivars can be different between their grown locations, which might be related to the elevated nighttime air temperatures.

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Table 1. Maximum, minimum and average day and nighttime temperatures registered in the two evaluated locations during grain filling stages.

	Daytime Temperatures (° C)			**Nighttime Temperatures (° C)**		
	Maximum	Minimum	Mean	Maximum	Minimum	Mean
Harrisburg, AR	33.89	9.40	26.20	28.82	9.41	21.08
Alvin, TX	35.37	23.10	30.76	28.98	23.33	25.88

Table 2. Physical properties as a function of cultivar and cultivating location [a]

Location	Cultivar	Chalky area (%)	Broken kernels (%)	Whiteness (L*)
Harrisburg, AR	XP760	2.6 (± 0.1)	8.0 (± 1.5)	71.9 (± 0.5)
	XL753	1.2 (± 0.2)	5.8 (± 0.2)	70.6 (± 0.5)
	V3501	0.5 (± 0.4)	15.1 (± 0.7)	69.9 (± 0.1)
	Cheniere	0.8 (± 0.2)	7.5 (± 0.6)	70.9 (± 0.2)
Alvin, TX	XP760	9.8 (± 1.4)	14.4 (± 1.2)	73.5 (± 0.7)
	XL753	7.0 (± 0.5)	19.6 (± 0.7)	72.3 (± 0.1)
	V3501	1.5 (± 0.6)	16.4 (± 0.6)	70.5 (± 0.4)
	Cheniere	2.0 (± 0.3)	12.0 (± 0.5)	72.0 (± 0.4)

[a] Values represent the mean (± standard deviation) of three replications

Table 3. Chemical compositions as a function of cultivar and cultivating location [a]

Location	Cultivar	Apparent Amylose (%)	Crude Protein (%)	Gelatinization Temperature (˚ C)			Enthalpy (J/g)
				Onset	Peak	End	
Harrisburg, AR	XP760	20.9 (± 0.3)	7.7 (± 0.1)	71.2 (± 0.1)	76.7 (± 0.1)	84.1 (± 0.8)	10.4 (± 1.5)
	XL753	19.8 (± 0.3)	8.3 (± 0.0)	72.0 (± 0.4)	77.4 (± 0.2)	84.9 (± 0.3)	11.5 (± 0.9)
	V3501	22.5 (± 0.5)	8.2 (± 0.2)	70.3 (± 0.2)	75.5 (± 0.3)	81.5 (± 0.6)	8.7 (± 1.4)
	Cheniere	24.0 (± 1.7)	8.0 (± 0.1)	70.7 (± 0.2)	75.4 (± 0.2)	81.0 (± 0.4)	7.4 (± 1.8)
Alvin, TX	XP760	18.9 (± 0.2)	7.1 (± 0.2)	75.2 (± 0.2)	80.1 (± 0.3)	86.2 (± 0.7)	11.0 (± 2.2)
	XL753	17.4 (± 1.0)	7.4 (± 0.2)	76.0 (± 0.1)	80.9 (± 0.0)	86.4 (± 0.4)	9.5 (± 0.7)
	V3501	20.2 (± 0.2)	8.0 (± 0.1)	75.4 (± 0.1)	79.9 (± 0.1)	85.2 (± 0.1)	10.9 (± 0.5)
	Cheniere	25.9 (± 0.7)	7.7 (± 0.1)	74.6 (± 1.2)	78.4 (± 0.0)	83.8 (± 0.3)	8.6 (± 0.6)

[a] Values represent the mean (± standard deviation) of three replications

Table 4. Cooking quality parameters as a function of cultivar and cultivating location [a]

Location	Cultivar	Optimum Cooking Duration (min)	Length Expansion Ratio	Width Expansion Ratio
Harrisburg, AR	XP760	21.0 (± 0.0)	2.3 (± 1.0)	0.8 (± 0.2)
	XL753	21.7 (± 0.6)	2.1 (± 0.8)	1.0 (± 0.3)
	V3501	19.7 (± 0.6)	2.2 (± 0.6)	0.9 (± 0.3)
	Cheniere	22.0 (± 0.0)	0.9 (± 0.3)	1.1 (± 0.2)
Alvin, TX	XP760	24.0 (± 1.7)	1.9 (± 0.5)	1.0 (± 0.4)
	XL753	25.7 (± 0.6)	1.8 (± 0.6)	1.1 (± 0.3)
	V3501	20.7 (± 1.2)	2.1 (± 0.6)	1.2 (± 0.4)
	Cheniere	22.0 (± 0.0)	1.3 (± 0.6)	1.3 (± 0.2)

[a] Values represent the mean (± standard deviation) of three replications

Table 5. Sensory characteristics as a function of cultivar and cultivating location [a]

	Harrisburg, AR				Alvin, TX			
	XP760	XL753	V3501	Cheniere	XP760	XL753	V3501	Cheniere
Appearance								
Whiteness	12.3 (± 0.6)	12.4 (± 0.7)	12.5 (± 0.5)	12.6 (± 0.5)	12 (± 0.6)	12.5 (± 0.4)	12.3 (± 0.4)	11.9 (± 2.0)
Flavor								
Starchy	5.5 (± 0.6)	5.4 (± 0.7)	5.3 (± 0.8)	5.2 (± 0.9)	5.7 (± 0.8)	5.8 (± 0.7)	5.7 (± 0.7)	5.7 (± 0.7)
Grainy	4.0 (± 0.6)	3.9 (± 0.6)	3.7 (± 1.1)	3.7 (± 1.1)	3.7 (± 1.2)	3.6 (± 1.5)	3.5 (± 1.5)	3.7 (± 1.1)
Cardboard	2.3 (± 1.6)	2.4 (± 1.4)	2.6 (± 1.3)	2.4 (± 1.5)	2.4 (± 1.6)	2.1 (± 1.7)	2.1 (± 1.7)	2.3 (± 1.6)
Sweet aromatic	0.2 (± 0.8)	0.2 (± 0.8)	0.0 (± 0.0)	0.2 (± 0.8)	0.3 (± 1.0)	0.4 (± 1.1)	0.4 (± 1.1)	0.3 (± 1.0)
Metallic	0.9 (± 1.6)	0.9 (± 1.6)	1.0 (± 1.6)	1.1 (± 1.6)	0.9 (± 1.4)	1.5 (± 1.6)	1.4 (± 1.7)	0.9 (± 1.5)
Burlap	1.2 (± 1.6)	1.5 (± 1.6)	1.3 (± 1.6)	1.1 (± 1.6)	1.6 (± 1.7)	1.5 (± 1.6)	1.5 (± 1.6)	1.4 (± 1.6)
Floral	0.7 (± 1.4)	0.7 (± 1.4)	0.7 (± 1.4)	0.9 (± 1.4)	1.0 (± 1.5)	0.7 (± 1.4)	0.7 (± 1.3)	0.7 (± 1.3)
Texture								
Manual Stickiness	10.1 (± 1.8)	9.1 (± 2.3)	8.9 (± 2.9)	9.1 (± 2.4)	9.8 (± 1.5)	9.5 (± 1.8)	9.4 (± 1.8)	7.9 (± 2.8)
Initial Cohesion	1.8 (± 0.5)	2.1 (± 0.8)	2.1 (± 0.8)	2.2 (± 1.0)	1.9 (± 0.9)	2.0 (± 1.0)	1.9 (± 0.8)	2.1 (± 0.9)
Hardness	1.3 (± 1.0)	1.5 (± 1.3)	1.3 (± 1.2)	1.6 (± 1.2)	1.7 (± 1.3)	1.4 (± 1.3)	1.1 (± 1.2)	1.3 (± 1.2)
Crunchy Cores	3.4 (± 0.9)	3.5 (± 0.9)	3.4 (± 0.9)	3.7 (± 0.8)	4.2 (± 1.6)	4.1 (± 1.6)	3.9 (± 1.4)	3.9 (± 1.5)
Tooth Pull	6.3 (± 0.7)	6.4 (± 1.1)	6.1 (± 1.4)	6.3 (± 0.9)	5.9 (± 1.5)	6.6 (± 1.2)	6.3 (± 1.1)	5.9 (± 1.0)

[a] Values represent the mean (± standard deviation) of two replications

Table 6. Texture profile analysis (TPA) parameters as a function of cultivar and cultivating location [a]

Location	Cultivar	Hardness (N)	Adhesiveness (N x sec)	Cohesiveness	Chewiness
Harrisburg, AR	XP760	14.6 (± 2.1)	0.6 (± 0.2)	0.4 (± 0.0)	4.6 (± 0.7)
	XL753	15.2 (± 1.7)	0.7 (± 0.3)	0.4 (± 0.0)	4.2 (± 0.7)
	V3501	13.6 (± 1.6)	0.5 (± 0.2)	0.4 (± 0.0)	4.3 (± 1.1)
	Cheniere	15.6 (± 1.8)	0.6 (± 0.2)	0.4 (± 0.0)	4.3 (± 1.0)
Alvin, TX	XP760	15.5 (± 2.7)	0.8 (± 0.4)	0.4 (± 0.0)	4.9 (± 1.4)
	XL753	13.7 (± 2.4)	0.9 (± 0.3)	0.4 (± 0.0)	3.5 (± 0.8)
	V3501	11.0 (± 2.5)	0.7 (± 0.2)	0.4 (± 0.0)	3.2 (± 1.4)
	Cheniere	14.8 (± 1.8)	0.4 (± 0.2)	0.4 (± 0.0)	4.4 (± 1.1)

[a] Values represent the mean (± standard deviation) of ten replications

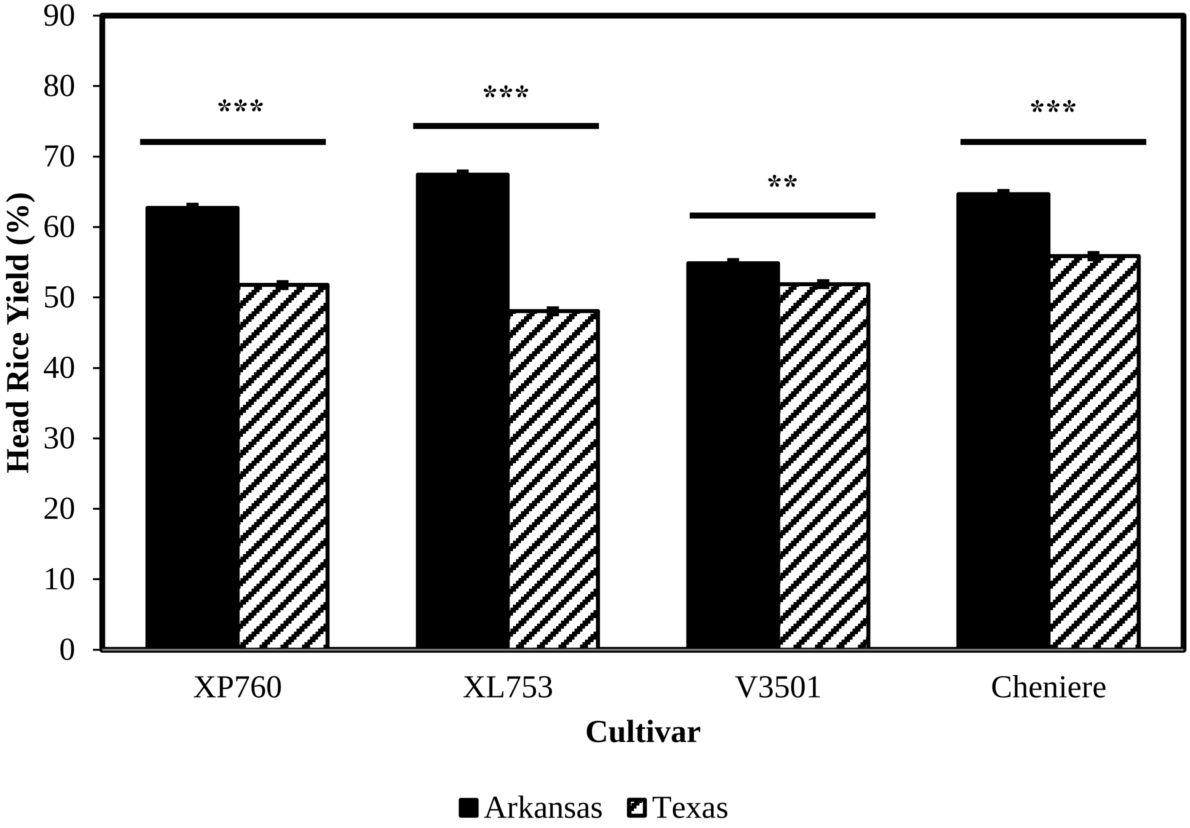

Figure 1. Mean head rice yield (HRY) as a function of cultivar and growing location. ** and ******* represent a significant difference at $P < 0.01$ and at $P < 0.001$, respectively. Error bars represent standard error of the means.

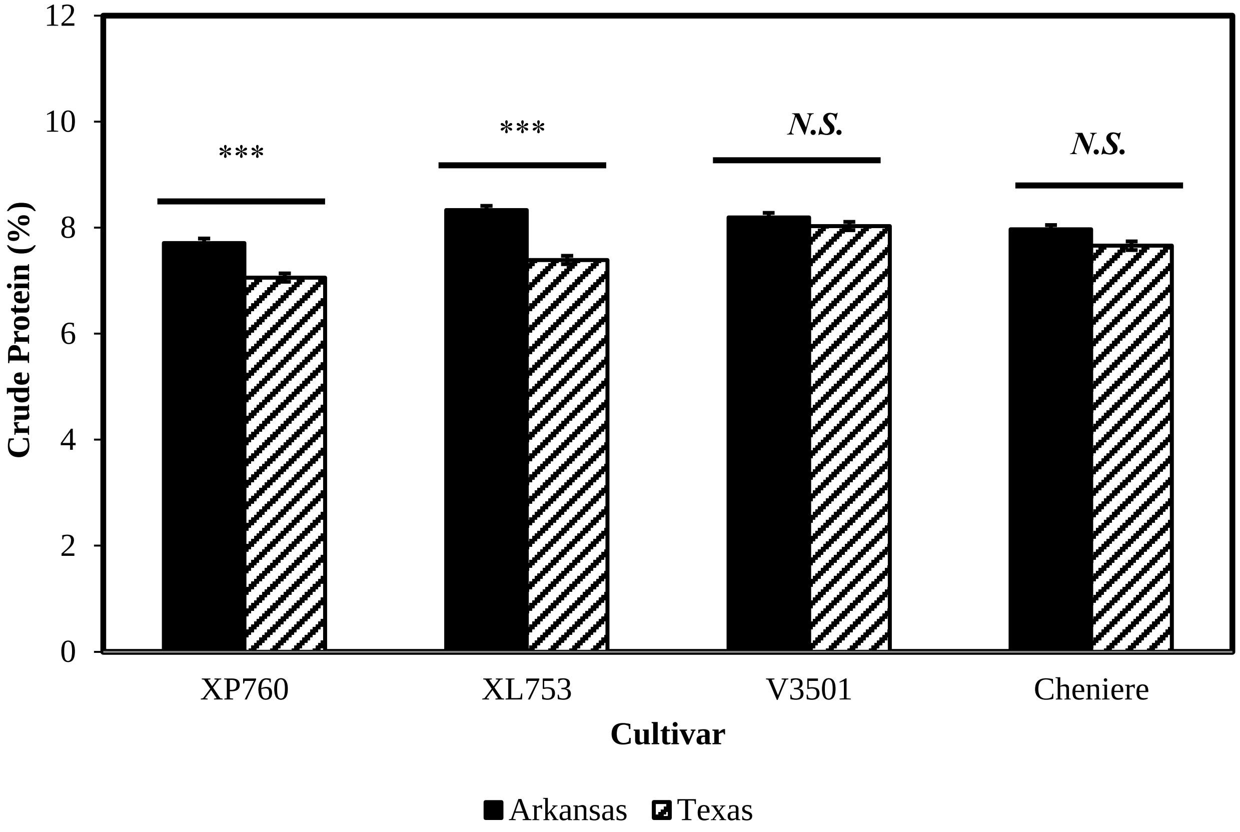

Figure 2. Mean protein content as a function of cultivar and growing location. ***: denote a significant difference at $P < 0.001$; *N.S.* denotes no significant difference at $P < 0.05$. Error bars represent standard error of the means.

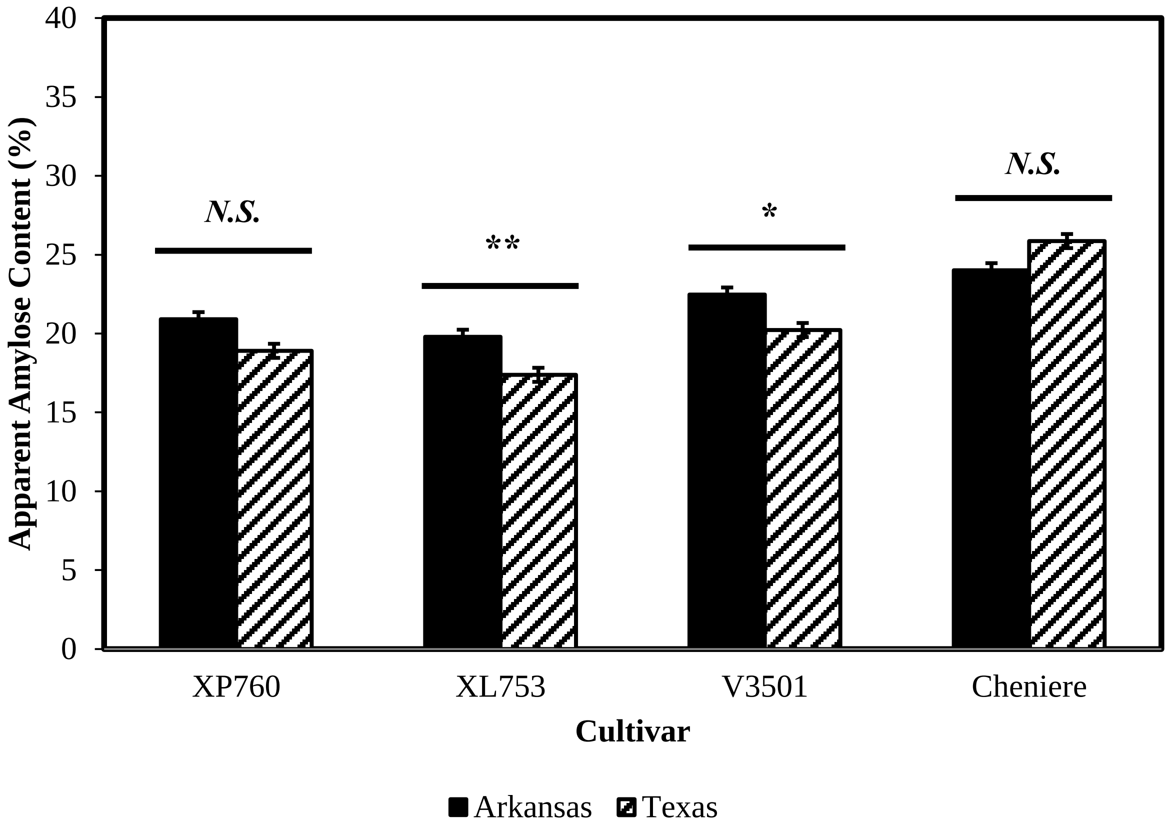

Figure 3. Mean apparent amylose content as a function of cultivar and growing location. * and ** represent a significant difference at *P* < 0.01, respectively; *N.S.* represents no significant difference at *P* < 0.05. Error bars represent standard error of the means.

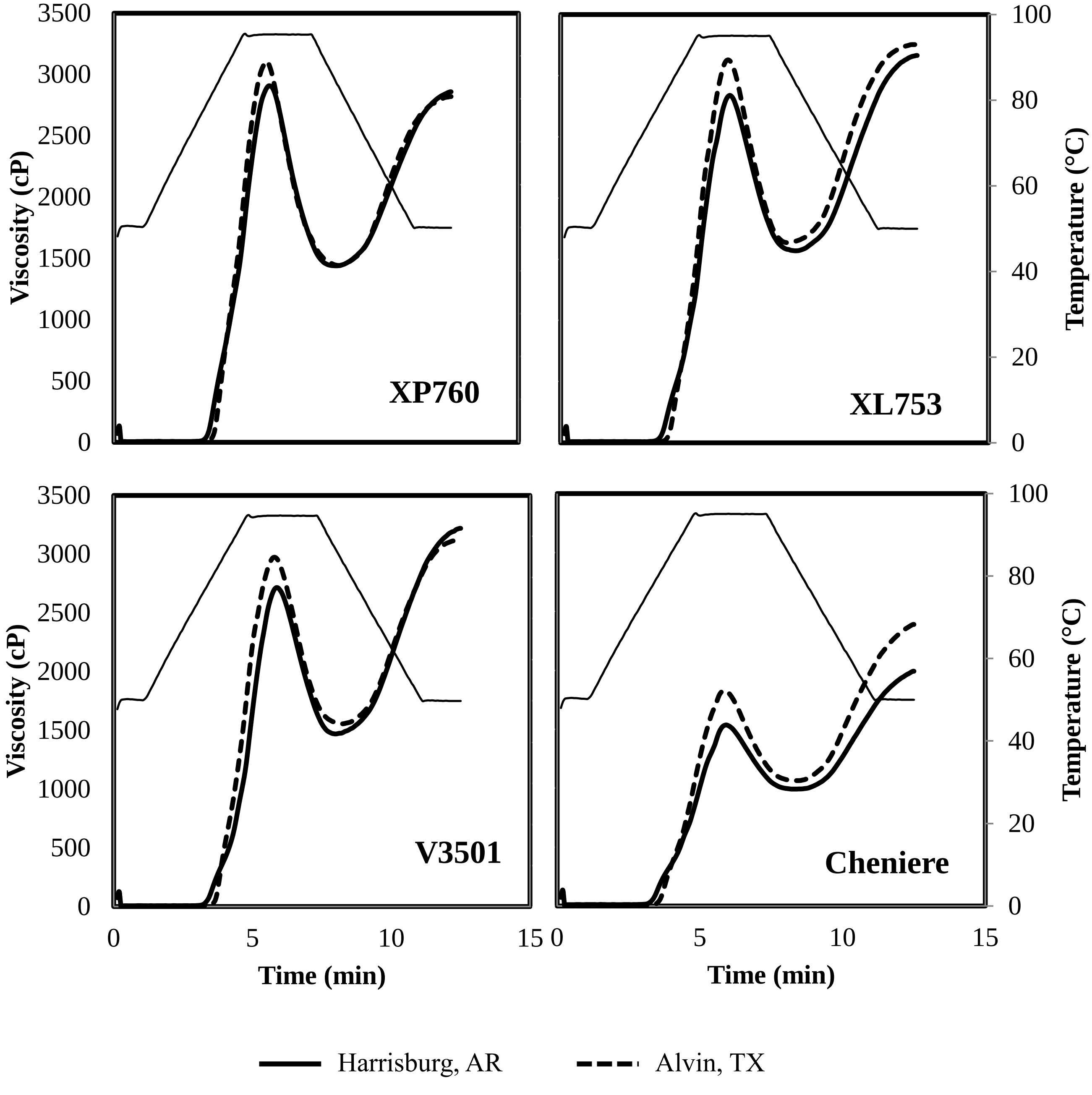

Figure 4. Pasting profiles of the evaluated long-grain rice cultivars as a function of the cultivating location.

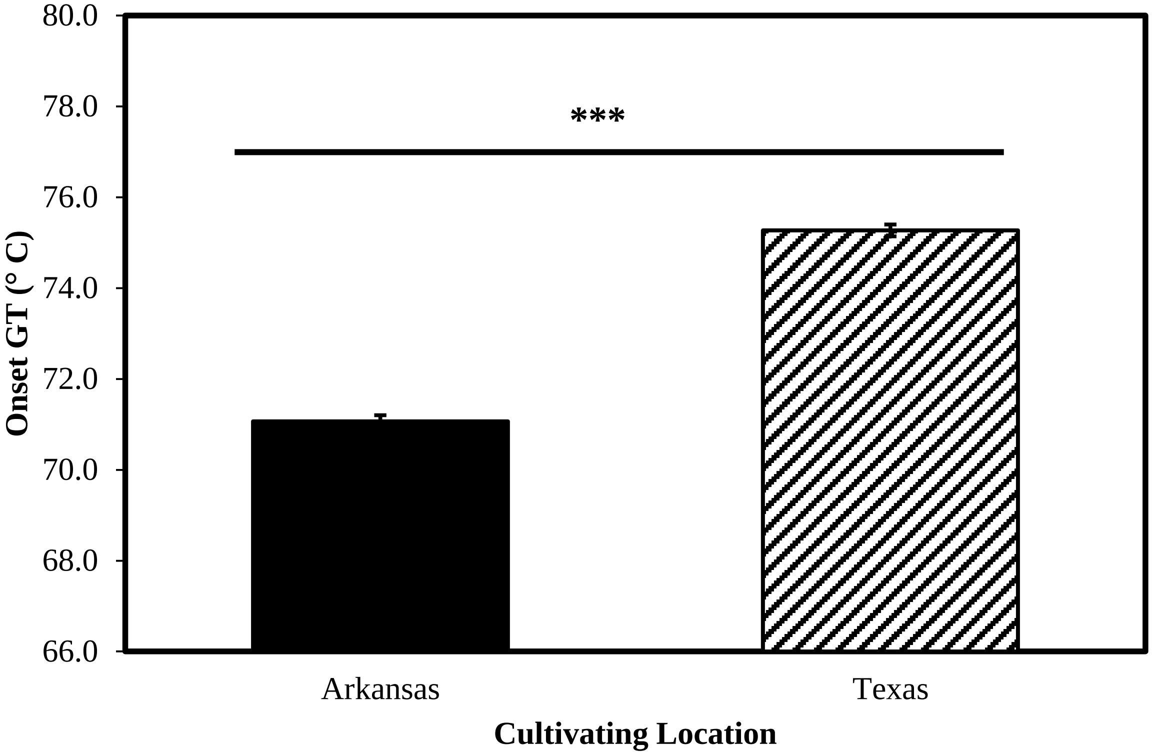

Figure 5. Mean onset gelatinization temperatures as a function of cultivating location. ***: represent a significant difference at $P < 0.001$. Error bars represent standard error of the means.

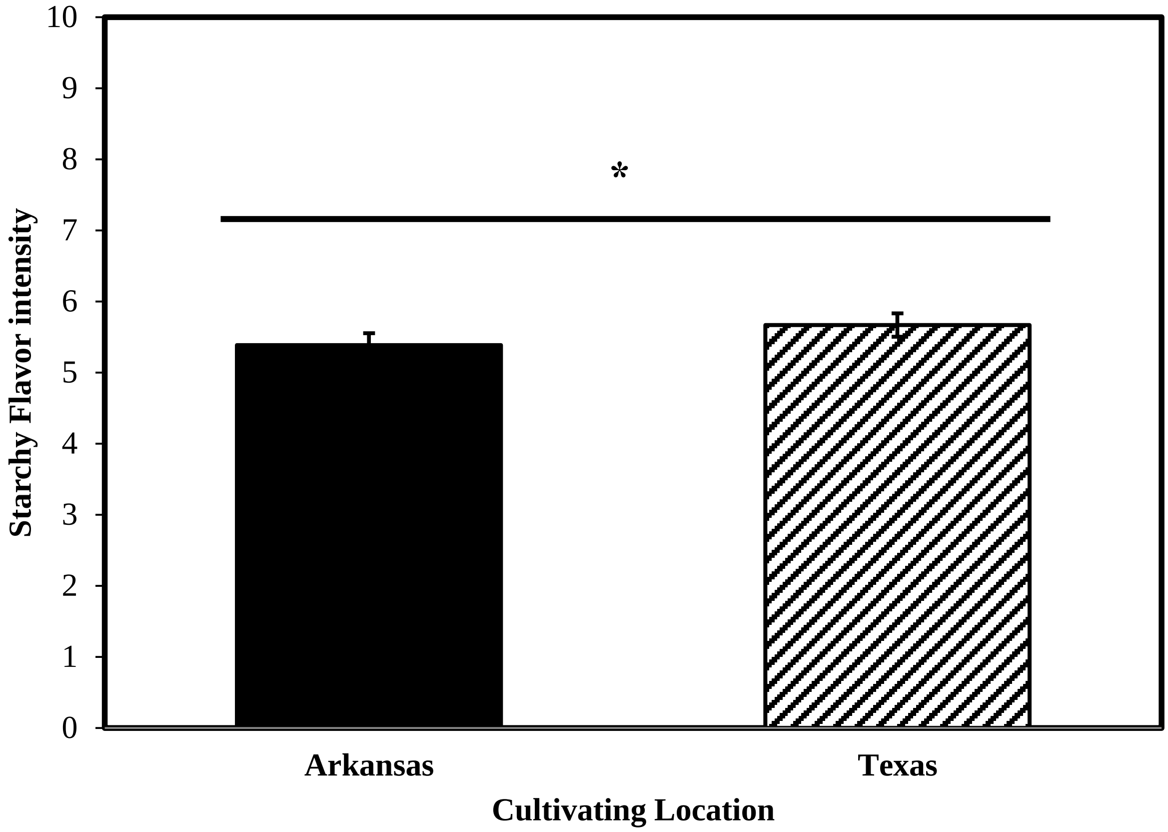

Figure 6. Mean comparison of starchy flavor intensity between the two cultivating locations. ***** represents a significant difference at $P < 0.05$. Error bars represent standard error of the means.

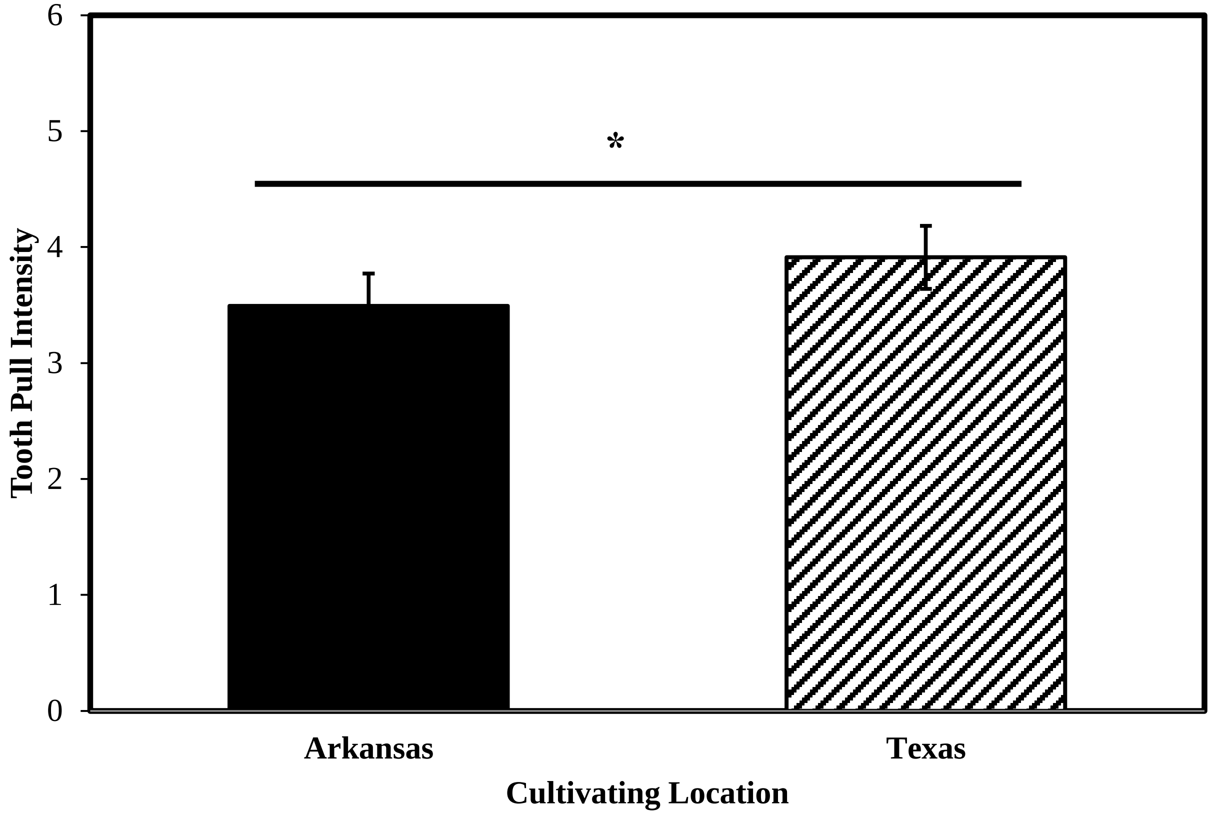

Figure 7. Mean comparison of tooth-pull intensity between the two cultivating locations. *: represents significant difference at $P < 0.05$. Error bars represent standard error of the means.

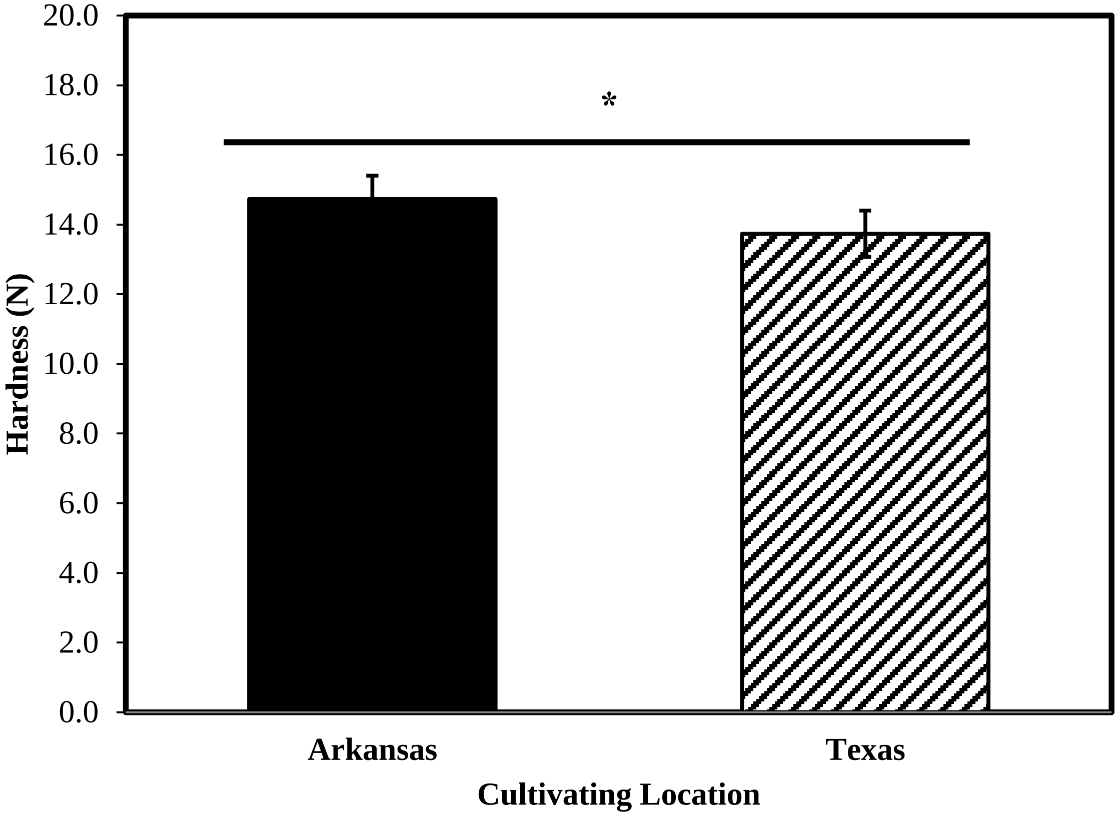

Figure 8. Mean comparison of the texture profile analysis (TPA) hardness between the two cultivating locations. * represents a significant difference at $P < 0.05$. Error bars represent standard error of the means.

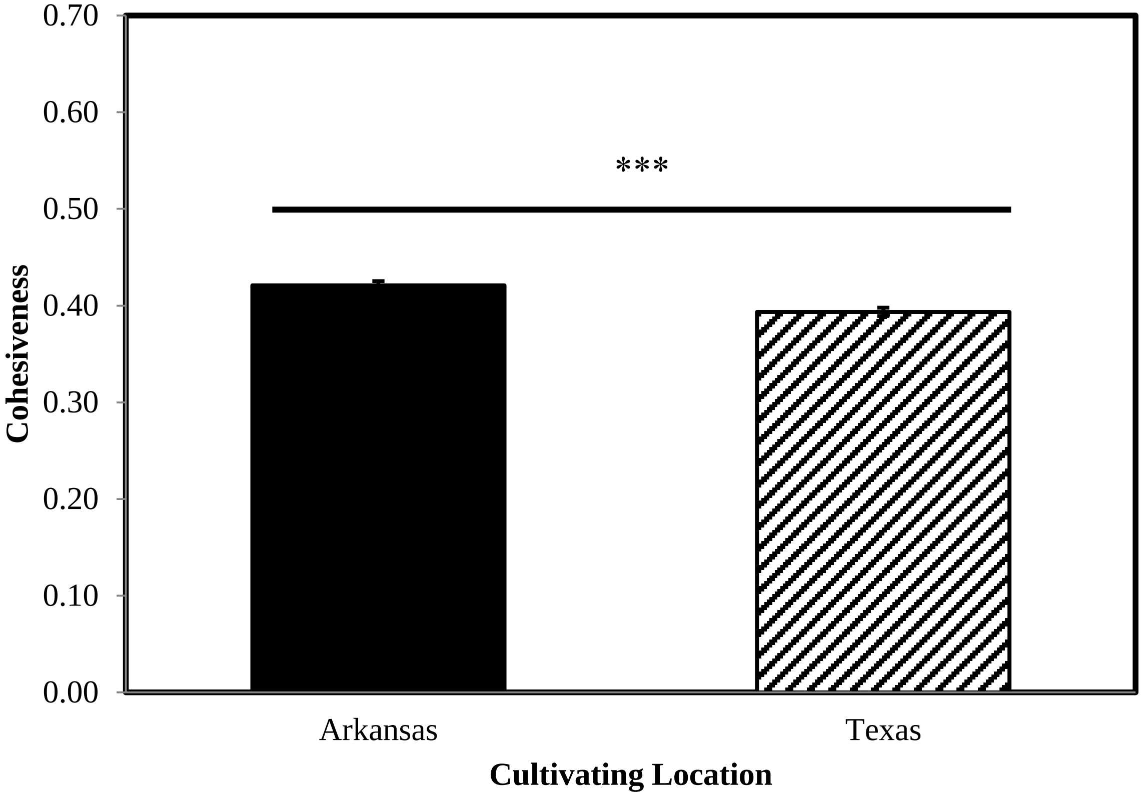

Figure 9. Mean comparisons of the texture profile analysis (TPA) cohesiveness between the two cultivating locations. *** represent a significant difference at $P < 0.001$. Error bars represent standard error of the means.

Chapter 6.

Overall conclusion

To summarize, this thesis demonstrates that cultivating location, harvest and processing conditions affect rice qualities in terms of physicochemical properties, cooking qualities, and sensory characteristics. The present findings can provide better understanding of the impacts of environmental (cultivating location and moisture content at harvest) and processing conditions (thickness grading) on rice qualities to rice farmers, processors, sensory professionals, marketers, and consumers.

Appendix 1.

Research compliance protocol letters

UNIVERSITY OF ARKANSAS

Office of Research Compliance
Institutional Review Board

April 27, 2016

MEMORANDUM

TO:	Han-Seok Seo Tonya Tokar Sara Jarma Arroyo Won-Seok Choi
FROM:	Ro Windwalker IRB Coordinator
RE:	PROJECT MODIFICATION
IRB Protocol #:	15-09-150
Protocol Title:	*Cross-Cultural Effect on Sensory Aspects of Food*
Review Type:	☒ EXEMPT ☐ EXPEDITED ☐ FULL IRB
Approved Project Period:	Start Date: 04/27/2016 Expiration Date: 10/26/2016

Your request to modify the referenced protocol has been approved by the IRB. **This protocol is currently approved for 600 total participants.** If you wish to make any further modifications in the approved protocol, including enrolling more than this number, you must seek approval *prior to* implementing those changes. All modifications should be requested in writing (email is acceptable) and must provide sufficient detail to assess the impact of the change.

Please note that this approval does not extend the Approved Project Period. Should you wish to extend your project beyond the current expiration date, you must submit a request for continuation using the UAF IRB form "Continuing Review for IRB Approved Projects." The request should be sent to the IRB Coordinator, 109 MLKG Building.

For protocols requiring FULL IRB review, please submit your request at least one month prior to the current expiration date. (High-risk protocols may require even more time for approval.) For protocols requiring an EXPEDITED or EXEMPT review, submit your request at least two weeks prior to the current expiration date. Failure to obtain approval for a continuation *on or prior to* the currently approved expiration date will result in termination of the protocol and you will be required to submit a new protocol to the IRB before continuing the project. Data collected past the protocol expiration date may need to be eliminated from the dataset should you wish to publish. Only data collected under a currently approved protocol can be certified by the IRB for any purpose.

If you have questions or need any assistance from the IRB, please contact me at 109 MLKG Building, 5-2208, or irb@uark.edu.

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