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Effect of Germination and Parboiling on Milling, Physicochemical, and Textural Properties of Medium- and Long-grain Rough Rice

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Effect of Germination and Parboiling on Milling, Physicochemical, and Textural Properties of Medium- and Long-grain Rough Rice
Effect of Germination and Parboiling on Milling, Physicochemical, and Textural Properties of Medium- and Long-grain Rough Rice

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

by

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Abstract

Germinated brown rice is commonly consumed in Asia for its enhanced nutritional properties such as gamma-aminobutyric acid (GABA) and softer cooked texture. However germination decreases milling yield and alters some physicochemical properties, and most germinated rice studies evaluated medium-grain and aromatic rice cultivars. This study compared the effects of germination duration and parboiling on milling, physicochemical, and textural properties of a medium- (Jupiter) and a long-grain (Wells) rice cultivars. Rough rice was soaked in water at 25°C for 12 hr, and then incubated at 30-34°C for varying germination durations, or combined with parboiling at 120°C for 20 min prior to drying. Germination resulted in an increase in brokens and a decrease in kernel weight for Wells. Parboiling increased milling yield and GABA content but decreased kernel whiteness and pasting profiles for both cultivars. Jupiter was consistently higher in soluble sugars, ash, and GABA content with germination progression compared with Wells. There were no significant changes in gelatinization temperatures and pasting properties between germination durations for parboiled and non-parboiled rice. Germination decreased cooked rice hardness of Wells and cooked rice stickiness of Jupiter for both non-parboiled and parboiled samples. Parboiling increased GABA content and cooked rice softness for both cultivars. The impacts of germination and subsequent parboiling on milling, physicochemical, and textural properties of rice were affected by grain type and germination duration.
Acknowledgements

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I. Introduction

Cooked rice texture largely depends on rice type. Long-grain rice produces drier and fluffy rice in comparison to medium- and short-grain rice. Medium- and short-grain rice are stickier and more adhesive upon cooking. Consumer preference is largely dependent on countries and regions. North and South America, Europe, Middle East, and parts of Africa prefer long-grain rice cultivars. Eastern and Southeastern countries such as Japan, China, and Vietnam are familiar with medium- and short-grain rice varieties. Retention of the bran in brown rice provides more nutrients than white rice but causes prolonged cooking duration and a harder cooked texture. The consumption of brown rice is low, only about 1.3%, despite a slight increase in table rice consumption in the United States from 1994-2004 (Batres-Marquez et al., 2009). Therefore, brown rice is rarely consumed as a staple food despite of its elevated bioactive compounds.

Germination is a biomodification process that activates enzymatic activities such as α-amylase, protease and lipase in the bran layer, which degrade starch, protein and lipid, respectively. As germination duration increases, the rice kernel and starch granule become weakened, thus resulting in softer, faster cooking rice with more nutrients retained. Germinated brown rice (GBR) is primarily known for significant gamma-aminobutyric acid (GABA) development. GABA is primarily an inhibitory neurotransmitter in the central nervous system often related to health benefits such as decreasing blood pressure, lowering LDL cholesterol, and inducing cancer cell apoptosis. Increased nutrients while producing sweeter and softer rice from enzymatic activity makes GBR a functional and palatable food. Nevertheless, the weakened germinated rice also becomes prone to fissures and processing damages. Parboiling is a hydrothermal process that significantly increases head rice yield of milled rice by sealing the
fissures with melted protein and starch. However the hydrothermal treatment could also enhance starch retrogradation and increases interactions among starch, protein and lipid, creating firmer cooked rice texture. By employing germination and parboiling processes, cooked rice texture may be enhanced while milling properties are improved.

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II. Literature Review

RICE BACKGROUND

Rice is the most consumed staple food in the world. The U.S. is a major rice-exporting country with a domestic per capita consumption of 24 lbs per year (USA Rice Federation, 2013). Rice varieties in the U.S. are classified as long-, medium-, and short-grain in accordance to grain dimension. Long-grain rice is typically used for entrees and is dry and fluffy when cooked. Medium-grain rice is more moist and tender than long-grain rice, and typically used for risotto and sushi. Short-grain rice is soft, plump, and almost round, and mostly used in sushi, desserts or puddings (USA Rice Federation).

Rice is harvested as paddy rice, which consists of the hull, including the lemmae, the palea, and the larger lemma, and the caryopsis. The caryopsis, or brown rice, comprises of the pericarp, seed coat, nucellus, aleurone layer, endosperm, and the embryo (Figure 1). Although its composition varies greatly depending on the variety and growing environment, milled rice is comprised of approximately 77.6% starch, 6.3-7.1% protein, 0.3-0.5% crude fat, 0.3-0.8% ash, and 0.2-0.5% crude fiber at 14% moisture (Juliano and Bechtel, 1985). The rice bran contains 12-15% protein, 15-20% lipid and 1% starch. It also constitutes 70% crude fiber, 51% ash, 65% thiamin, 39% riboflavin, and 54% niacin of the brown rice (Champagne et al., 2004). Protein is primarily in the embryo and aleurone layers (Shih, 2004). Lipids are mostly found in the aleurone layer, subaleurone and germ with a small amount present in the endosperm starch (Choudhury and Juliano, 1980). Phytic acid and minerals are also abundant in the aleurone layer (Tanaka et al., 1973). Phytic acid is an indigestible phytate form of inositol and the principle storage for phosphorus in seeds. It has an antioxidant function to preserve the seed through chelating iron and suppressing iron-catalyzed oxidative reactions (Graf and Eaton, 1990). When consumed, phytic
Acid is considered anti-nutritive due to its strong binding affinity to dietary minerals such as calcium, magnesium, iron, and zinc. The phytic acid content may be reduced via phytase activation after soaking and germinating rice.

Figure 1. General structure of a rice grain (Juliano, 1985).

RICE COMPOSITION

Starch

Starch is the major constituent of rice and exists as compound granules of 3-9 μm in size. Starch consists of an essentially linear fraction of amylose and a highly branched fraction of amyllopectin. The amylose content of milled rice varies and is affected by the genetic background.
and growing environment. Typically the amylose contents of waxy, short-grain, medium-grain, and long-grain rice are 0-2%, 15-23%, 14-18%, and 20-25% amylose, respectively (Mitchell, 2009). The rice amylose has an average degree of polymerization (DP) of 115 glucose units with 8-11 branches (Takeda and Hizukuri, 1987). Rice amylopectin molecules are broadly categorized into small (DP 700–2100), medium (DP 4400–8400), and large (DP 13,400–26,500) ranges but typically consists of all three. Regardless of rice type, rice contains a greater proportion amylopectin with a large DP range. Waxy rice has a similar proportion of medium and small range of amylopectin; short-grain and long-grain rices have a greater proportion of small range than the medium range of amylopectin (Takeda et al., 2003).

Amylopectin chains are classified as A, B and C types (Figure 2). The A chains have a DP range of 6-12 and are the chains attached to other chains but have no other chains attached to them. The B chains are chains attached to two or more chains and can be further divided into B1 (DP 13-24), B2 (DP 25-36), and B3+ (DP >37) chains. The B1 chains extend only one cluster, the B2 chains extend across two clusters, and the B3 reaches to three clusters (Hanashiro et al., 1996). The C chains are the only chains with a reducing end (Hizukuri, 1986). Starch is semi-crystalline in nature with alternating crystalline and amorphous structures. The crystalline structure is composed of amylopectin short chains forming parallel double helices with interhelical water present (Gidley, 1987); the amorphous structure consists of the branching regions. When viewed in polarized light, starch granules reveal a birefringent cross known as the maltese cross as a result of the semicrystalline structure (Whistler and BeMiller, 1997). Because of the crystalline structure, rice starch has the A-type X-ray diffraction with strong peaks at 20 diffraction angles of around 15.3, 17.1, 18.2, and 23.5°.
Starch undergoes five stages of transformation during cooking: glass transition, gelatinization, swelling, leaching, and retrogradation (Fitzgerald, 2004). Glass transition occurs when the amorphous regions in the starch transition from a rigid to a viscous, rubbery state in the presence of water. Water is a plasticizer that lowers starch glass transition temperature through thermal transition depression (Maurice et al., 1985). Gelatinization is an irreversible process where starch crystals collapse from hydration and excess heat, consequently losing birefringence. Once gelatinized, starch undergoes swelling by absorbing more water, and at the same time amylose and amyllopectin molecules leach out of the granules into the continuous phase, resulting in an increase in viscosity. Long-grain rice typically has an intermediate gelatinization temperature (GT) range of 70-74°C (Juliano 1972; Merca and Juliano, 1981). Waxy and low-amylose rices have high GTs at 74.5-79°, while medium- and short-grain rices have low GTs at 55-69.5°C (Juliano, 1972; 1985). Retrogradation occurs when gelatinized starch molecules reassociate and recrystallize (Slade and Levine, 1987). The reformation of these crystals consequently affects the pasting properties and cooked rice texture through hardening and gel formation (Panchan and Naivikul, 2009; Vandeputte et al., 2002).
Although the apparent amylose content is known to play a dominating role in cooked rice texture, hot-water-insoluble amylose equivalents was proposed to be a texture contributor and more positively correlated to textural hardness properties than apparent amylose (Chinnaswamy and Bhattacharya, 1986; Reddy et al. 1993). Cameron and Wang (2005) reported that insoluble amylose had a stronger correlation with the cooked rice hardness and stickiness than apparent amylose, and increasing proportions of A and short B amyllopectin chains decreased cooked rice hardness. The proportions of long B amyllopectin chains (DP 55-75) located at the exterior of the starch granular was proposed to be responsible for increased firmness, increased dryness, and decreased stickiness (Reddy et al. 1993). It was hypothesized that the long amyllopectin chains bound with lipids, proteins, and other carbohydrates to form complexes, thus increasing firmness (Ong and Blanshard, 1995a). Ong and Blanshard (1995b) studied 11 rice cultivars and concluded that amylose, short (DP ≤ 25) and long (DP 92-98) amyllopectin chains positively correlated with hardness and negatively correlated with stickiness of cooked rice. Ramesh et al. (1999) later proposed that cooked rice texture was determined by intermolecular interactions of long chain amylose and amyllopectin, which maintain starch granule rigidity.

**Protein**

Protein in rice bran consists primarily of water-soluble albumin, constituting 66% of the aleurone protein and 98% of the embryo protein. Proteins in the endosperm are mostly alkali-soluble glutelin (≥ 80%), i.e. oryzenin, along with 10% globulin (salt-soluble), 5% albumin, and < 5% prolamin (alcohol-soluble) (Cagampang et al., 1966). On average protein accounts for 9.5% of milled rice at 14% moisture content but may range 4.3-18.2% because it is sensitive to environmental conditions and genetic background (Gomez, 1979). Proteins in the bran layer are bound tightly to starch and form protein-starch complexes (Yang and Chang, 1999).
Functionally, protein in the endosperm restricts water penetration, and gelatinization and swelling of starch granules (Martin and Fitzgerald, 2002). As a result, rice with a high protein content tends to be less sticky and chewier (Tamaki et al., 1989). Starch and protein in the endosperm further complex during cooking, thus influencing cooked rice stickiness. Viscosity during cooking also increases through disulfide bond networks and the ability of proteins to bind water (Martin and Fitzgerald, 2002). An increase in the binding of oryzenin (glutelin protein) to starch negatively correlates with cooked rice stickiness (Chrstil, 1990). Disrupting oryzenin with reducing agents results in increased pasting viscosity (Hamaker and Griffin, 1990; Hamaker et al., 1991).

**Lipids**

Lipids are present within starch and throughout the caryopsis. Similar to protein, lipid content is also influenced by cultivar and environment. Rice lipids are mostly triglycerides (68-71%), glycolipids (5-7%), and monoglycerides (5-6%), with smaller amounts of phospholipids (3-4%) and free fatty acids (2-3%) (McCaskill and Zhang, 1999). The majority of lipids in brown rice are non-starch lipids, which are loosely associated with starch granules and concentrated in the bran layer (Godber and Juliano, 2004; Goffman et al., 2003). Because of the location and fatty acid type, the lipids on the bran layer surface are very susceptible to oxidation after the hull is removed. Therefore, non-starch lipids are the major cause of lipid rancidity in brown rice. The starch lipids present in the starch granule are mainly free fatty acids and phospholipids, which consist mostly of palmitic and linoleic acids (Zhou et al., 2002). Monoacyl lipids form inclusion complexes with amylose, which increase gelatinization temperature and cooking duration but decrease viscosity (Kaur and Singh, 2000; Szczodrak and Pomeranz, 1992). The more saturated or longer monoglycerides complexes are shown to be more resistant to enzymatic
breakdown due to structural stability. Thermal stability is also increased with saturation and decreased with unsaturation (Eliasson and Krog, 1985; Guraya et al., 1997).

**GERMINATION OF RICE**

Seedling germination encompasses when the seed begins water uptake and concludes when the embryonic axis elongates (Bewley and Black, 1994). Nevertheless, most rice germination studies for consumption purposes continue seedling growth onto various durations with individualized germination classifications. Counce et al. (2000) classified seedling growth into four growth stages (Figure 3) in an attempt to create a uniform system for rice development. The four stages include S0, the dry seed, S1 the emergence of the first embryonic growth, either coleoptile or radical, S2 the second embryonic growth, and S3 the prophyll emergence from the coleoptile. After the prophyll emergence, the rice begins vegetative crop growth.

<table>
<thead>
<tr>
<th>Growth Stage</th>
<th>S0</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
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<tbody>
<tr>
<td>Morphological Criteria</td>
<td>Dry, unimbibed seed</td>
<td>Emergence of coleoptile</td>
<td>Emergence of radicle</td>
<td>Emergence of prophyll from coleoptile</td>
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<tr>
<td>Illustration</td>
<td><img src="image1.png" alt="Image" /></td>
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**Figure 3.** Early process of rice seedling growth. S1 displays the emergence of the first embryonic growth (coleoptile depicted). S2 is the presence of both (emergence of radical with coleoptile) (Counce et al., 2000).
The minimum moisture content for germination was reported at 26.5%, however the typical moisture content for germination is 30-40% (Hunter and Erickson, 1952; Yoshida, 1981). The important factors besides moisture content on rice germination include temperature and darkness (Yoshida, 1981). Although variations occur among cultivars, the optimum germination temperatures are around 30-35°C, with the lowest reported value around 10°C and the highest 40-45°C (Nishiyama, 1976; Owen, 1971). Germination in darkness leads to more rapid degradation of endosperm starch and protein than under light exposure conditions (Palmiano and Juliano, 1972). The minimum time to reach early stage germination is approximately 14 hr, where 70% of rice shows protrusion through the hull (Panchan and Naivikul, 2009).

**Rice Composition Changes during Germination**

Once rice begins the germination process, enzymes in the grain are activated. Phytic acid is significantly reduced by the first day of germination due to increased phytase activity (Liang et al., 2008; Mukherji et al., 2006). When brown rice was germinated at 30°C, the decrease in phytic acid content progressed from 4% after 4 hr of soaking to 60% after germinating for 72 hr (Liang et al., 2008). Alpha-amylase, primarily responsible for starch transformation, becomes active by the first day of germination, but its activity increases exponentially at the fourth day (Murata et al., 1968). The aleurone layer contains most amylase activity in the presence of gibberellic acid, a plant growth hormone (Higgins et al., 1982). Both amylose and amylopectin are degraded by α-amylase, and the main breakdown products are dextrins and oligosaccharides with maltotriose constituting most of the oligosaccharides (Jiamyangyuen and Ooraikul, 2008; Murata et al., 1968; Palmiano and Juliano, 1972). Because reducing sugars increase and total starch content decreases, the pasting viscosity of germinated rice decreases from the breakdown
of starch. Germination duration is positively correlated with stickiness, sweetness, and softness of cooked rice, but negatively correlated with hardness, cooking time, water uptake and volume expansion (Jiamyangyuen and Ooraikul, 2008).

Proteases are synthesized in the aleurone layer in the presence of gibberellic acid (Jacobsen et al., 1967). By the second day of germination protease becomes significantly active but declines rapidly in activity by the third day. Glutelin is degraded and new enzymes are synthesized before being converted to free amino acids (Juliano and Palmiano, 1972). A similar decline is noted in albumin and globulin until a noted increase after the 3rd to 9th germination day, which thereafter steadily decreases (Pusztai and Duncan, 1970). However glycine, lysine, leucine, and valine amino acids are notably increased after a 24-hr germination study (Moongngarm and Saetung, 2010). Ultimately rice protein will degrade into soluble free amino acids and be readily available.

Lipase in the aleurone layer is initiated prior to α-amylase activation and provides the first step to gluconeogenesis (Palmiano and Juliano, 1973). There is an initial increase in palmitic, palmitoleic, and oleic acids, but they rapidly decrease after 72 hr of germination. Sterols and fatty acid methyl esters are not significantly influenced during a 96-hr germination observation (Shu et al., 2008).

**Gamma-aminobutyric acid (GABA)**

GABA is a non-protein amino acid and inhibitory neurotransmitter in the central nervous system. Studies have shown that GABA is beneficial for many disease treatments such as reducing blood pressure, improving sleeplessness, alcohol related symptoms, cardiovascular diseases, diabetes regulation, and limiting weight gain (Kayahara et al., 2001; Oh et al., 2003; Roohinejad et al., 2009). Consuming germinated rice with GABA has been shown to lower low-
density lipoprotein (LDL) cholesterol while raising high-density lipoprotein (HDL) and induce cancer cell apoptosis (Oh and Oh, 2004; Roohinejad et al., 2010). Lactating women fed with germinated rice also showed a decrease in depression, anger hostility, and fatigue (Sakamoto et al., 2007).

Although GABA content varies with rice varieties, germination significantly increases its content (Banchuen et al., 2009; Kayahara and Tsukahara, 2001; Kim et al., 2012; Maisont and Narkrugsa, 2010; Varanyond et al., 2005). The accumulation of GABA content is primarily in the embryo and influenced by stress conditions such as temperature shock, water stress, and oxygen deprivation, and therefore is considered a metabolic end product. GABA increases with increased oxygen supply and lower pH of the steeping water, with an optimal pH of 3 (Banchuen et al., 2009; Charoenthaikij et al., 2009; Varanyanond et al., 2005). The GABA content may continually increase in the rice grain until after 20 days of germination. However more GABA was accumulated in the developing young leaves than in the rice grain during the same 5-30 day germination duration (Jannoey et al., 2010).

Others

Soluble fibers increase while insoluble fibers decrease during germination (Jayadeep and Malleshi, 2011). However contradictory results have been reported for changes in tocopherols, tocotrienols, and γ-oryzanol content during germination. Some reported an increase of tocopherols, tocotrienols and γ-oryzanol (Kayahara and Tsukahara, 2001; Kim et al., 2012; Moongngarm and Saetung, 2010); some reported decreased total tocopherol and unchanged γ-oryzanol content (Banchuen et al., 2009; Jayadeep and Malleshi, 2011). These discrepancies may be due to differences in cultivars and/or environment.
PARBOILING

Parboiling is a hydrothermal treatment that traditionally involves soaking, heating, and drying of rough rice. The main purposes of parboiling are to increase total and head rice yield, to better retain nutrients after milling, to salvage wet or damaged rough rice, and to prepare rice according to consumer’s preference (Ali et al., 1976). The moisture content of the rough rice needs to be around 30-35% for effective parboiling (Bhattacharya, 1985). Because of increased yellowness and smells from soaking, and delayed heat transfer from the hull, brown rice is now also used for parboiling. The use of brown rice shortens parboiling time as a result of faster hydration and heat penetration from reduced weight and volume (Bhattacharya and Subba Rao, 1966a; Parnsakhorn and Noomhorm, 2008).

Parboiling Process

The first step of soaking is to increase the moisture content to about 30%. At soaking temperatures of 60°C or below, the water absorption of paddy rice is slow, and there is little effect on water uptake of the cooked rice after parboiling (Bhattacharya and Subba Rao, 1966a, 1966b). The absorption rate begins to increase at 70°C; however soaking at and above 70°C darkens the rice color and initiates starch gelatinization (Bhattacharya and Subba Rao, 1966a; 1996 b; Ojeda et al., 2000). Therefore soaking is typically at temperatures below70°C to minimize starch gelatinization prior to heat treatment. If water absorption is insufficient during the soaking stage, the grain core would not be fully gelatinized during the heating stage, resulting in a harder texture and ultimately increased processing breakage (Bhattacharya and Subba Rao, 1966b; Seki and Kainuma, 1982).
After soaking, rice is heated usually through steam. During the steaming step, the husk sometimes split from water absorption and swelling, while water-soluble nutrients migrate into the endosperm, and lipids migrate outwards (Bhattacharya, 2004; Roy et al., 2011). When the severity of steaming increases, the differences between raw and parboiled rice increase (Unnikrishnan and Bhattacharya, 1981). Starch undergoes gelatinization from high steam pressure (Mahanta and Bhattacharya, 1989). Steam pressure and duration negatively correlate with water uptake but positively correlate with cooked parboiled rice hardness due to an increase in starch retrogradation and amylose-lipid complexes (Bhattacharya, 1979; Islam et al., 2001; Lamberts et al., 2009).

The moisture content of the rice is around 35-38% after the steaming step and must be dried to 12-14% for proper storage and milling (Bhattacharya, 2004). Fissures may occur in rice kernels after drying as a result of cooling and a large moisture gradient in the kernel. As starch transitions from the rubbery state back to glassy state, moisture gradients within the kernel are created and cause fissuring. Fissured kernels are likely to break during the milling process and decrease head rice yield (Cnossen and Siebenmorgen, 2000). Parboiling significantly improves milling yield because gelatinized starch and melted protein bodies from the steaming process seal the fissures (Bhattacharya, 2004).

**Changes during Parboiling**

Parboiling reduces cooking duration because starch is already gelatinized. Parboiling results in an increase in retrograded amylopectin, amylose-lipid complexes, and amylose crystallites in relation to parboiling severity and amylose content (Derycke et al., 2005a; Lamberts et al. 2009). The high melting temperatures of amylose-lipids complexes and amylose crystallites likely contribute to the harder texture and decreased stickiness of parboiled rice as a
result of rigid starch granule and restricted swelling. Retrogradation of amylopectin from parboiling increases starch resistance to enzymatic degradation. In a human study, Type-2 diabetic subjects consuming severely parboiled rice experienced a reduction in the glycemic index compared to traditionally mild parboiled rice and a greater reduction compared to non-parboiled rice (Larsen et al., 2000). Newton et al. (2011) showed that parboiling variables could alter the proportion of rapidly digestible starch, slowly digestible starch and resistant starch in the resultant parboiled rice. Poquette et al., (2012) demonstrated that the increase of slowly digestible starch from parboiling brown rice resulted in decreased postprandial blood glucose and insulin response in healthy men.

After parboiling, protein solubility is reduced, and protein extraction is less effective due to the rupture of protein bodies (Rao and Juliano, 1970). Soaking increases protein, lipid, and ash content in parboiled brown rice compared with non-parboiled brown rice, which has been documented with the biosynthesis of new compounds from an initiated germination process during soaking (Sareepuang et al., 2008). Parboiling strengthens the protein barrier that encases the starch granule, further limiting the hydration of the endosperm and the leaching of soluble components, consequently resulting in harder and less sticky rice when cooked (Derycke et al., 2005b).

The total lipid content is unchanged after steaming, although the oil content of parboiled rice bran is higher than that of the raw form. The aleurone layer and germ contain the majority of the lipid bodies, which rupture from parboiling and migrate outwards to form a layer around the grain surface (Mahadevappa and Desikachar, 1968; Bhattacharya, 2004). Because of exposure and degradation of antioxidative contents in the bran, parboiling increases overall oxidative susceptibility compared with brown rice. Parboiled brown rice remains highly susceptible to
oxidation regardless of degree of milling due to destruction of antioxidant properties and lipid outward migration.

Parboiling may impart similar attributes as germination when enzymatic activity is increased from hydration. The extent of enzymatic activation and inactivation largely depends on parboiling conditions. Cold soaking activates most amylase, protease, phosphatase and β-glucosidase, whereas hot water soaking inactivates them. Parboiling with steam partially inactivates the enzymes, and pressure parboiling process results in their complete inactivation (Xavier and Raj, 1995). Ultimately reducing sugars and amino acids are increased, which accounts for the discoloration of parboiled rice.

Because of the inward diffusion of water solubles and possible husk splitting of parboiled brown rice, water-soluble vitamins may be lost during soaking and steaming (Bhattacharya, 2004). However total thiamine and nicotinic acid content is retained but reduced (Padua and Juliano, 1974). Fat-soluble riboflavin is unaffected and vitamin B1 is not significantly reduced by parboiling as well. Both GABA and mineral content are not significantly affected by parboiling (Roy et al., 2011). Other fat-soluble compounds such as tocopherols and tocotrienols are significantly reduced after parboiling, although oryzanol content is not significantly influenced (Khatoon and Gopalakrishna, 2004).

**Parboiling of Germinated Rice**

Besides rough and brown rice, recently germinated brown rice has been used as feedstock in parboiling. The yellowness and reducing sugar contents of parboiled and non-parboiled germinated brown rice significantly increased compared with untreated brown rice (P<0.05) (Panchan and Naivikul, 2009). Puangwerakul and Klaharn (2010) reported that parboiling and cooking did not significantly reduce vitamin B1 and GABA contents of germinated rice. Both
germinated brown rice and parboiled germinated brown rice in rough rice form displayed similar pasting properties such as decreased peak, trough, breakdown, final and setback viscosities compared with their ungerminated counterparts (Rattanadee and Naivikul, 2011). Therefore the enzymatic activity from germination in rough rice had more influences on texture than the parboiling process. Nevertheless, Cheevitsopon and Noomhorm (2011) observed parboiled germinated brown rice produced a textually harder cooked product than its non-parboiled counterpart.
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III. Effects of Germination on Milling, Physicochemical, and Textural Properties of Medium- and Long-grain Rice

ABSTRACT

Germinated brown rice is popular in Asia for its increased gamma-aminobutyric acid (GABA) content and sweeter and softer texture compared with conventional brown rice. However, most studies investigated germinated rice properties on medium-grain or aromatic rice but not on long-grain rice. The objective of this study was to compare differences between a medium-grain (Jupiter) and a long-grain (Wells) rice with similar germination conditions on their milling, physicochemical, and textural properties over the course of germination. Rough rice was soaked in water at 25°C for 12 hr, and then incubated at 30-34°C for four germination durations. Wells had a higher breakage percentage and a greater weight decrease than Jupiter. Soluble sugars, ash, and GABA content increased for both cultivars when germination progressed, where a greater increase in quantities was observed for Jupiter than for Wells. There were no significant changes in gelatinization temperatures and pasting properties of germinated rice from both cultivars at different germination durations. The cooked rice hardness from Wells decreased at the last germination duration, whereas Jupiter showed a more significant decrease in cooked rice stickiness from germination. The results demonstrate that the impacts of germination on physical, chemical and textural properties of rice were affected by grain type and germination duration.
INTRODUCTION

Brown rice is widely consumed for its higher retained vitamins, minerals and fiber content than white rice. However, the bran responsible for most nutrients in brown rice also imparts a tough chewy texture when cooked. Germination is a natural process in which the seed produces additional nutrients and enhances nutrient bioavailability as it transforms into a plant (Patil and Khan, 2011). Consuming germinated brown rice is a growing trend in some Asian countries mostly due to its high content of gamma-aminobutyric acid (GABA) developed through the biotransformation process. GABA serves primarily as an inhibitory neurotransmitter linked to numerous health benefits such as reducing blood pressure, improving sleeplessness, cardiovascular diseases, and diabetes regulation, and limiting weight gain (Kayahara et al., 2001; Oh et al., 2004; Roohinejad et al., 2009).

Although brown rice has a harder, chewier texture compared with white rice, germination results in a softer cooked brown rice texture. The softer texture is attributed to the activation of enzymes within the retained bran and endosperm, which degrades nutrients and weakens the seed structure. Alpha-amylase, proteases, and lipases are the primary enzymes responsible for breakdown of starch, protein, and lipids, respectively. Prolonged germination duration increases starch hydrolysis, resulting in an increase in sweetness, and softness of cooked rice with reduced water uptake and volume expansion (Jiamyangyuen and Ooraikul, 2008). Alpha-amylase is responsible for degrading starch into sugars and may be initiated on the first day of germination (Murata et al., 1968). Following α-amylase activation, proteases degrade proteins into free amino acids by the second day of germination (Palmiano and Juliano, 1972; Moongngarm and Saetung, 2010; Pusztai and Duncan, 1971). Protein affects rice chewiness by forming starch-protein complexes that restrict water penetration, gelatinization and swelling of starch granules (Martin
Proteolysis has been correlated with softer cooked rice texture by increasing water absorption and granular swelling (Saleh and Meullenet, 2007; Xie et al., 2008). Lipids could form amylose-lipid complexes in the endosperm, which are more resistant to enzymatic breakdown and have increased thermal stability (Eliasson and Krog, 1985; Guraya et al., 1997). Being the first enzyme to be activated, lipase in the aleurone layer initiates gluconeogenesis by producing free fatty acids (Palmiano and Juliano, 1973; Shu et al., 2008). It is believed that through enzymatic activities in germination, a softer cooked brown rice is produced.

Studies correlating textural characteristics with physicochemical properties of germinated brown rice are mostly based on Jasmine rice (Cheevitsopon, and Noomhorm, 2011; 2014; Jiamyangyuen and Ooraikul, 2008), except Tsuji (1981) on short-grain rice. These studies reported that pasting viscosity, amylose content, cooking duration, and cooked rice hardness decreased when α-amylase activity increased with germination time. Cooked rice texture is mainly influenced by amylose content and long amylopectin chains, where they maintain the starch granule integrity and thus cooked rice hardness (Ramesh et al., 1999). Because different grain types have distinctive physical characteristics and compositions, their germination behaviors and consequently the physicochemical and textural properties of the resultant germinated rices may be different. Miyoshi and Sato (1997) found differences between japonica and indica rice cultivars in their responses to germination stimulant treatments. Therefore the objective of this study was to compare the differences in milling, physicochemical properties, chemical composition and cooked brown rice texture between long-grain and medium-grain rice cultivars after varying germination durations.
MATERIAL AND METHODS

Materials

Foundation seeds from two rice cultivars, Wells of long-grain and Jupiter of medium-grain, from the 2012 crop were provided by the University of Arkansas Rice Research and Extension Center in Stuttgart, AR. Seeds were germinated in rough rice form and all rice were stored at 4°C.

Germination

Rough rice (400 g) was soaked in 1.25% NaClO at 25°C for 30 min for disinfecting (Yang et al., 2001). The sample was rinsed three times under tap water prior to a final rinse with deionized water, and then soaked in excess water in a 9 × 13× 2 inch stainless steel pan at 25°C in a water bath (OLS200, Grant Instruments, Cambridge, UK). The minimum soaking time to reach equilibrium moisture content was determined by establishing the water absorption curve for each cultivar. Rice samples were removed every 10 min for the first hour, then every hour up to 24 hr, pat dried, and weighed. The moisture content of the soaked rice was calculated based on the initial moisture content by using the equation below.

\[
\text{Moisture Content (\%)} = 100 \times \left(\frac{\text{Final wet weight} - \text{Initial dry weight}}{\text{Initial dry weight}}\right)
\]

All treated rice samples were soaked until the time when moisture content approached equilibrium.

After the soaking, the rough rice were drained and rinsed again with deionized water prior to the germination procedure. For germination, approximately 240 g of the soaked rice was placed in two damp cheese cloths spread on top of two 9 × 12 inch metal racks, which were
situated above two 9×13×2 inch stainless steel pans for aeration. Deionized water was filled up to one inch height of the pan. Aluminum foil and masking tape were used to insulate and seal the pan and rice before placed in an incubator (APT.line BF, Binder, Tuttlingen, Germany) at 30-34°C. Twenty random whole kernels were removed from the cheese cloths regularly to determine the germination degree by counting the number of kernels showing protrusion through the hull and the embryonic growth length (cm). The optimum germination time was determined when 70% of the rice population displayed hull protrusion; either S1 or S2 stages (Counce et al., 2000). Three additional germination times were selected: two prior to and one following the optimum time, and each at 8 hr increment. The germination durations were 10, 18, 26 (optimum), and 34 hr for Wells, and 24, 32, 40 (optimum), and 48 hr for Jupiter. The germinated rice were dried in an equilibrium moisture content drying chamber (dry bulb 26°C, wet bulb 13.5°C) until 12 ± 0.5% moisture content and stored at 4°C until further analyses. Two controls were used for each cultivar: one control was soaked for 12 hr without incubation (0 hr), and one was unsoaked and ungerminated brown rice (BR). All soaked and germinated samples were replicated twice.

Samples for measuring proximate composition, thermal properties, and starch characterization required more seed development uniformity due to kernel to kernel variation in growth rate (Figure 1). Therefore, germinated rice were further subcategorized by coleoptile lengths as 0 mm (a), 0.5-1 mm (b), 1.5-10 mm (c), 10.5-30 mm (d), and > 30 mm (e). The first germination duration (10 hr for Wells, 24 hr for Jupiter) was then categorized by 0 mm coleoptile length (a). The second germination duration (18 hr for Wells, 32 hr for Jupiter) consisted of two coleoptile categories combined to encompass 0-1 mm lengths (a, b). The third germination duration (26 hr for Wells, 40 hr for Jupiter) included combined coleoptile categories
of 0.5-10 mm (b, c), and the fourth germination duration (34 hr for Wells, 48 hr for Jupiter) included combined coleoptile categories ranging from 1.5-30 mm (c, d). Kernels with > 30 mm coleoptile length (e) were considered outliers and were omitted from any analyses. Germination durations 2-4 in this experiment were within the S1 or S2 growth stage and no emergence of the prophyll from the coleoptile occurred (Counce et al., 2000). Rice were then dried to 12 ± 0.5% moisture content and stored at 4°C.

**Milling Properties**

Dried germinated rough rice of 150 g was dehulled by passing through a Satake dehusker (THU-35, Satake Corp., Hiroshima, Japan) twice because one dehulling pass was inadequate to remove most hulls. Dehulled rice weight was recorded, and head rice was separated from broken kernels using a double-tray sizing machine (GrainMan Machinery, Miami, FL). Breakens (%) was calculated by the weight of rice fragments less than three quarters of a whole kernel divided by the weight of dehulled rice from an original 150 g of rough rice. Premature, chalky, or defected rice were sorted and removed from whole kernels.

Kernel weights were recorded by randomly selecting 10 whole kernels from each germination duration used for proximate analysis. For chemical and physicochemical analyses, whole rice kernels were ground into flour using a UDY cyclone sample mill (UDY, Ft. Collins, CO, USA) fitted with a 0.50-mm sieve.

**Proximate Composition**

The total starch content was determined by an amyloglucosidase/α-amylase assay (Megazyme; Wicklow; Ireland) in accordance to Approved Method 79-13 (AACC, 2000). Soluble sugar from the rice flour was extracted with 80% ethanol at 75°C for 10 min with
stirring and then centrifuged at 1500 ×g for 10 min, and the extraction was repeated twice. The total sugar content was estimated using the phenol-sulfuric acid method (Dubois et al., 1956). Crude protein was measured by a micro-Kjeldahl method according to Approved Method 46-13, (AACC, 2000) using the conversion factor of 5.95 to convert nitrogen content to crude protein content. Crude fat was measured according to Approved Method 30-20 (AACC, 2000) using a Soxtec apparatus (Avanti 2055, Foss North America, Eden Prairie, MN) and petroleum ether as the solvent. Total Ash content was measured according to Approved Method 08–01 (AACC, 2000) by ashing approximately 2 g of ground brown rice flour at 550°C for 6 hr.

**Physicochemical Properties**

The apparent amylose content of the rice flour was determined by the colorimetric method of Juliano et al. (1981).

Gamma-aminobutyric acid (GABA) was measured using the colorimetric method of Kitaoka and Nakanom (1969) with modifications. Brown rice flour (0.15 g) and 80% ethanol (1.5 mL) were weighed into 2-mL microcentrifuge tubes, vortexed, and then shaken in a water bath at 150 strokes/min (OLS200, Grant Instruments, Cambridge, UK) and 25°C for 1 hr. The tubes were then centrifuged (Microcentrifuge 5415D, Eppendorf, Hauppauge, NY) at 9300 ×g for 10 min. One mL of the supernatant was transferred into 15-mL tubes before 0.2 mL of 0.2 M borate buffer (pH 9) and 1 mL of 6% phenol were added while submerged in an ice bath under constant stirring. Tubes were then vortexed and left to stir for 5 min before 0.4 mL of NaOCl (7.5% Cl) was added, vortexed, and left to stir in the ice bath for an additional 5 min. Tubes were then submerged in a boiling water bath for 10 min with constant stirring, followed by cooling in an ice bath for 5 min. Readings were taken at λ = 630 nm with a spectrophotometer (s40014,
Genesys 20, Thermo Fisher Scientific, Waltham, MA). The standard curve was prepared with GABA standard (A5835, Sigma-Aldrich Co., St. Louis, MO) at 10, 30, 50, 70, 100 μg/L.

Thermal properties were measured using a differential scanning calorimeter (DSC, model Diamond, Perkin-Elmer Co., Norwalk, CT). Approximately 4 mg of ground rice flour was weighed into an aluminum DSC pan with 8 μL of deionized water added via a microsyringe. The pan was sealed and equilibrated at room temperature for 1 hr prior to heating from 25°C to 120°C at 10°C/min. An empty pan was used as a reference. Onset, peak, and conclusion temperatures and enthalpy were calculated.

Pasting properties were determined using a Rapid ViscoAnalyser (RVA, Newport Scientific Pty. Ltd, Warriewood NSW, Australia). Rice slurry was prepared by mixing ~3.0 g of rice flour (12% moisture basis) with ~25.0 mL of deionized water or 0.50 mM silver nitrate into a RVA canister. The slurry was rapidly heated to 50°C, heated from 50°C to 95°C at 5°C/min, held at 95°C for 5 min, cooled from 95°C to 50°C at 5°C/min, and then held at 50°C at for 5 min. Peak, breakdown, setback, and final viscosities (Cp) were recorded.

**Starch Isolation and Characterization**

The molecular size distribution of starch in germinated rice was analyzed by high performance size-exclusion chromatography (HPSEC) according to the method of Kasemsuwan et al (1995) with modifications by Wang and Wang (2000). Starch was extracted from 1 g of flour (combining 0.5 g from both replicates due to limited sample size) by adding 10 mL of extraction solution comprised of 1% (v/v) sodium dodecyl sulfate and 0.5% (v/v) β-mercaptoethanol into a 15-mL centrifuge tube. The tube was vortexed and then placed on a rotator (Rotisserie Rotator, Labquake, Barnstead Thermolyne, Dubuque, IA) for 1 hr prior to
centrifugation at 3820 ×g for 10 min. Supernatant was discarded, and the extraction process was repeated again with 10 mL of the extraction solution. The centrifugation and decanting process was repeated three times using deionized water, and the gray protein layer was scrapped off after each water extraction step, followed by a single extraction of 10 mL of methanol and then acetone. Samples were then dried at 40°C overnight before ground into flour.

For HPSEC analysis, 10 mg of isolated starch and 2.5 mL of 90% DMSO were placed in a 25-mL test tube, boiled for 1 hr with stirring, and stirred at room temperature overnight prior to filtering through a 5-µm nylon membrane filter (National Scientific F2500-50). The HPSEC system (Waters Corporate, Milford, MA) consisted of a 100-µL sample loop, two columns (Shodex OHpak KB-802 and KB-804) maintained at 60°C, and a 2414 refractive index detector maintained at 40°C. A solution of 0.1 M sodium nitrate with 0.02% (w/v) sodium azide was eluted at a flow rate of 0.6 mL/min.

Texture Analysis

Germinated brown rice samples were cooked according to Perez and Juliano (1979) using a consumer rice cooker (ARC-914B, Aroma, Aroma Housewares Co, San Diego, CA). Five grams of whole kernels were soaked in deionized water in a 100-mL beaker for 30 min with a fixed water-to-rice ratio of 2.1:1 for Wells and 1.9:1 for Jupiter. Six 100-mL beakers containing different soaked rice were placed on a metal rack placed within the cooking bowl holding 250 g deionized water. Cooking duration was determined by removing 10 kernels every 5 min after cooking for 30 min until a minimum of 9 kernels showed no starchy cores when compressed between two glass plates, indicating cooking completion (Ranghino, 1966). Cooked rice was
gently mixed, transferred to an airtight zip-lock bag, placed in a thermo insulator, and was used within 30 min for texture analysis.

Texture analysis was conducted with a 50-kg load cell and an aluminum plate of 10 cm in diameter and 0.6 cm in thickness using a TA. XT Plus Texture Analyzer (Texture Technologies Corp., Hamilton, MA). A compression test mode was performed with 10 whole rice kernels at a speed of 5 mm/s, compressed to 0.3 mm, held for 5.0 s, and returned at 0.5 mm/s. The maximum compression force (peak force, N) and adhesiveness (negative peak force area, N × s) was recorded as cooked rice hardness and stickiness, respectively (Saleh and Meullenet, 2007). Measurements were repeated six times for each replicate sample.

Statistical Analysis

Four replications of the experimental treatment conditions were performed for each property. The treatment structure was a 2×6 factorial arrangement with two cultivars (Wells and Jupiter) and six germination durations (with two controls BR and 0 hours along with the four additional durations). The experimental design was a Completely Randomized Design with 12 treatment combinations and four replications that were assigned independently to the experimental units. The analysis model for the design was fitted in the Fit Model platform of JMP PRO Ver. 11.2.1 (SAS Software Institute, Cary, NC) with the main effects and interaction. Tukey’s HSD multiple comparisons test (α = 0.05) was used to identify significant differences of the dozen treatment LSmeans including the two controls.

RESULTS AND DISCUSSION

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Milling Properties

Wells had a significantly higher (P < 0.001) percentage of brokens for brown rice and all germination durations, and soaking alone significantly increased brokens percentage (P < 0.0001) (Table 1). The increase of brokens from the soaking may be due to the formation of moisture gradients and consequently fissures upon drying (Siebenmorgen et al., 1998). During germination, the percentage of brokens remained relatively unchanged for Jupiter, but increased significantly after 26 hr for Wells. The significant increase in broken kernels at the later germination durations of Wells suggests that advanced germination greatly weakens Wells kernel structure. The shorter, rounder shape of Jupiter, a medium-grain cultivar, may provide more structural support upon dehulling than Wells, a long-grain cultivar, even if the kernel structure was weakened from germination. This finding agrees with previous studies, which reported increased fissured kernels in germinated Jasmine rice after 20 hr (Cheevitsopon, and Noomhorm, 2011) and 36 hr of germination (Srisang et al., 2011). However these studies used severe drying conditions, including hot air and superheated steam, which may also contribute to their increases in broken kernels.

Overall, there was little change in rice kernel weight for Jupiter during germination, but there was a significant decrease in kernel weight at the last germination duration of Wells at 34 hr (Table 1). The kernel weight had a negative correlation with the percentage of brokens, implying that loss of kernel mass may weaken structural integrity and increase kernel breakage.

Chemical Composition

Jupiter and Wells cultivars shared a similar chemical composition prior to germination, but were affected differently by the soaking and germination (Table 2). Soaking significantly
decreased the starch content and increased the crude fat and ash contents in Jupiter, while Wells remained unaffected. Once germinated the starch content of both cultivars significantly increased, which was proposed to be primarily due to the hydrolysis of the other components in the bran layer such as lipids, phytin, and hemicellulose (Barber and De Barber, 1991; Greml and Juliano, 1970; Palmiano and Juliano, 1973) to result in its relative increase. With the progression of germination Jupiter and Wells showed a gradual decrease in starch content, but only the decrease in Wells was statistically significant at the last germination duration. The decrease in the starch content of Wells after 34 hr of germination may contribute to its decreased kernel weight and consequently increased broken (Table 1).

Wells, a long-grain cultivar, had a significantly higher apparent amylose content than Jupiter, and both displayed a significant increase in apparent amylose content once germinated (P < 0.0001). The increase in apparent amylose content may be due to the relative increase in starch content from the hydrolysis of bran components or possible disruption of amylose-lipid complexes, allowing for better measurement. The apparent amylose content in both cultivars remained unchanged with germination progression, suggesting that amylose was not significantly degraded during germination and was still capable of complexing with iodine.

The soluble sugars in germinated rice flour were significantly higher in Jupiter than in Wells and gradually increased with germination for both cultivars (P < 0.0001). The inverse relation between soluble sugars and starch content was more evident for Wells than for Jupiter. Their differences in soluble sugars content may be attributed to their different amylopectin/amylose ratios. Previous studies have observed a negative relationship between amylose content and susceptibility to α-amylase degradation (Cone and Wolters, 1990; Riley et al, 2004). The change in soluble sugars suggests that more starch is degraded at the later
developments of germination and different rice cultivars show different patterns of degrading starch.

Both Jupiter and Wells had a similar protein content, and there was no change in their crude protein contents in the germination process. Although proteins may be hydrolyzed into free amino acids over the course of germination, they were not distinguished and were included in the crude protein analysis. This finding agrees with Xu et al. (2012), but some studies reported an increase in crude protein content during germination (Lee et al., 2007; Moongngarm and Saetung, 2010).

Germination had an overall significant effect on crude fat content ($P < 0.0001$) where both cultivars showed a slight decrease in crude fat during germination, which correlated with the decrease in starch. However the impact of germination on crude fat content was not the same for both cultivars because Jupiter displayed a significant decrease by the second germination duration, while Wells showed a significant decrease at the last germination duration. The ash content remained relatively unchanged during germination for both cultivars.

The GABA content in Jupiter was consistently and significantly higher than that in Wells ($P < 0.001$) during germination, although their brown rice had a similar GABA content (Table 2). Once germinated, the GABA content in Jupiter significantly increased, and then remained at a similar level over the duration of germination. In contrast, the increase in GABA content was not significant for Wells. Many studies reported that GABA increased with germination; however the rice cultivars investigated were of primarily aromatic, short-, or medium-grain backgrounds (Banchuen et al., 2009; Kayahara and Tsukahara, 2000; Kim et al., 2012; Maisont and Narkrugsa, 2010; Varanyond et al., 2005). Therefore, more work is needed to confirm if the
change of GABA from germination is cultivar specific. Differences between the two cultivars in GABA content increase could also be affected by the differences in required germination durations, since extending germination time increases GABA content (Jannoey et al., 2010).

**Gelatinization Properties**

There was no significant change in onset and peak gelatinization temperature between germination durations within each Jupiter or Well cultivar (Table 3). However, when considering the overall impact of germination on both cultivars together, germination significantly increased both onset and peak gelatinization temperatures ($P < 0.05$). Xu et al. (2012) reported a decrease in gelatinization temperature and enthalpy after germination. The difference may be attributed to cultivar effect and/or brown rice, instead of rough rice, used in Xu et al. (2012), which germinates at a faster rate than rough rice.

Gelatinization enthalpy was significantly influenced over the course of germination in both cultivars ($P = 0.0001$), and there was a significant cultivar and germination duration interaction ($P = 0.0054$). Although enthalpy did not significantly change from brown rice to different germination durations for both cultivars, there were significant differences when comparing different germination durations within each cultivar. The gelatinization enthalpy of Wells significantly increased from 10 hr to 34 hr of germination, whereas that of Jupiter increased at 32 hr and then decreased. These differences in enthalpy between cultivars and between germination durations may be related to the extent of starch hydrolysis. It has been proposed that there is an inverse relationship between $\alpha$-amylase activity and gelatinization enthalpy in starch granules (Wolters and Cone, 1992). Hydrolysis of the amorphous lamellae may increase gelatinization enthalpy in Wells and Jupiter at the beginning of germination.
Moreover, hydrolysis of crystalline lamellae upon further germination may result in reduced enthalpy in Jupiter.

**Pasting Properties**

The pasting profiles of brown rice and germinated brown rice from both cultivars at different germination durations in water as well as in 50 mM silver nitrate are shown in Figure 2. Silver nitrate was used to inhibit enzyme activities during RVA measurement (Collado and Corke, 1999). For brown rice flour in water, Jupiter had a higher peak viscosity, a greater breakdown, and a lower final viscosity compared with Wells (Figure 2A and B) because of its lower amylose content. The peak viscosity of Jupiter dramatically decreased from 2653 cP to ~900 cP at 24 and 32 hr of germination and then to ~ 200 cP at 40 and 48 hr of germination. In contrast, the change in pasting profile was more gradual for Wells. The slight increase in final viscosity of the soaked samples from both cultivars was ascribed to the annealing effect that strengthened starch granule integrity through perfecting starch crystalline structure.

When the pasting properties were conducted in silver nitrate, there was little change in pasting profiles between brown rice and germinated samples for both cultivars (Figure 1C and D). The differences in pasting profiles between water and silver nitrate indicate that starch was not hydrolyzed substantially during germination, which support the gelatinization results (Table 3), although α-amylase activity increased with the progression of germination. Therefore viscosity changes of the germinated rice investigated with water reflected α-amylase activity that occurred during RVA analysis because silver nitrate inhibits α-amylase activity (Collado and Corke, 1999). The lower peak and final viscosities analyzed with water compared to silver nitrate...
for both cultivars imply that α-amylase activity is also reactivated with water during RVA analysis in brown rice before germination.

The more rapid decrease in the water pasting profiles of Jupiter (Figure 2A) suggests that amyllopectin was rapidly hydrolyzed by α-amylase, which was attributed to its lower amylose content and higher amyllopectin content compared with Wells. By the last two durations of germination, the pasting profiles of Jupiter were almost not visible, which confirms that α-amylase is the primary enzyme responsible for changes in pasting properties in water. Nevertheless, other enzymes such as protease and lipases could also contribute the decrease by disrupting or degrading protein network and lipid complexes to allow for more extensive hydrolysis of starch by α-amylase.

**Starch Characterization**

The molecular size distribution as characterized by HPSEC was divided into three fractions: Fraction I (amylopectin), Fraction II (intermediate materials) and Fraction III (amylose). The molecular size distribution of Jupiter showed a gradual decrease of amyllopectin and a gradual increase of intermediate materials over the progression of germination (Figure 3A), indicating that amyllopectin was gradually hydrolyzed to a smaller molecular size. Changes in amylose were not significant, and therefore differences in properties observed over the course of germination for Jupiter may be attributed to changes in amyllopectin. The molecular size distribution of Wells significantly changed upon germination (Figure 3B). The relative proportion of amyllopectin (Fr. I) significantly increased while that of intermediate materials and amylose (Fr. II and III) decreased once germination initiated in Wells. The lack of substantial changes in starch profiles during germination correlated with the silver nitrate pasting profiles
for both cultivars, where there was no significant influence of germination on pasting viscosities (Figure 2C, D). The gradual decrease of amylopectin in Jupiter and increase in amylopectin ratio in Wells after germination from HPSEC analysis were not significant enough to affect the overall pasting profiles of rice flour.

**Texture Analysis**

Overall Wells, both brown and germinated, had significantly higher hardness values (P < 0.0001) than Jupiter when cooked (Table 4) because of its higher amylose content. Cooked rice hardness had been associated with amylose and/or long amylopectin chains (Ong and Blanshard, 1995; Radhika et al., 1993; Ramesh et al., 1999). Although germination had an overall effect of decreasing cooked rice hardness (P = 0.0001) for both cultivars, only Wells exhibited a significant decrease in hardness at the last germination time (34 hr). The similar hardness values for Jupiter during different germination durations may be a result of low amylose content and insignificant hydrolysis of amylose. The present study suggests that germination had more impact on the hardness of long-grain rice than medium-grain rice due to its higher amylose and long amylopectin chain content. Previous studies reporting significant decreases in hardness of germinated brown rice were based on Jasmine rice cultivars after 6-20 hr of germination at room temperature or 35°C (Jiamyangyuen and Ooraikul, 2008; Cheevitsopon and Noomhorm, 2010; 2014). Their reported decreased hardness may be due to more advanced germination with the utilization of brown rice instead of rough rice.

Jupiter generally had greater stickiness values (P < 0.0001) than Wells because of its higher proportion of amylopectin, and germination had an overall significant effect on reducing stickiness when compared with the brown rice after soaking (P < 0.0001); however the effect is
not the same for both cultivars. There was a significant interaction effect between cultivars and germination time (P = 0.0002). The initial increased stickiness for both Jupiter and Wells from soaking may be attributed to the disruption of protein di-sulfide bonds and starch-granule associated proteins complexes from protease activity. Previous studies have found that disrupting these protein networks during cooking increased cooked rice stickiness (Derycke et al., 2005; Hamaker et al., 1991; Xie et al., 2008). The wax component on the bran (Champagne et al., 2004) may also have been hydrolyzed or removed during the soaking process, allowing for through lipid extraction at subsequent germinations. Once germinated, the stickiness of Wells did not change, which may be attributed to its high amylose content or longer amylopectin chains interacting with other components such as protein, thus restricting protein disruption (Ong and Blanshard, 1995). Jupiter became less sticky by the last germination hour compared to earlier germination times probably due to its more degradation of amylopectin as suggested from the HPSEC results (Figure 3A).

A significant interaction effect was observed between Jupiter and Wells cultivars throughout different germination durations for brokens (P < 0.0001), soluble sugars (P = 0.0008), crude fat content (P = 0.008), gelatinization enthalpy (P = 0.0054) and cooked rice stickiness (P =0.0002). The overall germination effect was significant on starch content where both cultivars significantly decreased in starch content from germination (P < 0.0001) despite Wells having an overall higher content than Jupiter (P = 0.002). A cultivar effect was more significant in cooked rice hardness and stickiness. Cooked rice hardness was significantly higher for Wells than Jupiter, while stickiness was higher in Jupiter than Wells; but there were no significant interaction.
CONCLUSION

Jupiter and Wells showed differences in milling, composition, gelatinization, pasting, and textural properties during the course of germination. Wells was more susceptible to kernel breakage and kernel weight decrease after germination than Jupiter. Soluble sugar, ash, and GABA increased as germination progressed with Jupiter consistently higher than Wells. Although both amylose and amyllopectin were hydrolyzed during the germination, their extents of hydrolysis were not significant enough to change gelatinization temperature and pasting properties. Germination had more impact on cooked rice hardness for Wells, a long-grain cultivar, and on cooked rice stickiness for Jupiter, a medium-rice cultivar. The different properties between germinated Jupiter and Wells imply that the changes from germination may be grain-type specific, possibly because of their different chemical composition and inherent enzyme activities. Therefore germination practices and characteristics of one grain type may not directly relate to another grain type.
REFERENCES


Table 1. Milling properties of brown rice and germinated brown rice at varying germination durations for Jupiter and Wells\textsuperscript{a}

<table>
<thead>
<tr>
<th>Rice Cultivar</th>
<th>Germination Duration (hr)</th>
<th>Brokens (%)</th>
<th>Kernel Weight (g) \textsuperscript{c}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>Brown Rice \textsuperscript{b}</td>
<td>3.16 ± 0.08g</td>
<td>0.20 ± 0.01ab</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>5.56 ± 0.66f</td>
<td>0.20 ± 0.00ab</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>6.23 ± 0.76ef</td>
<td>0.20 ± 0.01ab</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>7.24 ± 0.46e</td>
<td>0.20 ± 0.01ab</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>6.63 ± 0.45ef</td>
<td>0.20 ± 0.01ab</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>7.06 ± 0.47e</td>
<td>0.20 ± 0.01ab</td>
</tr>
<tr>
<td>Wells</td>
<td>Brown Rice</td>
<td>13.23 ± 1.00cd</td>
<td>0.20 ± 0.00ab</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>16.55 ± 0.71b</td>
<td>0.21 ± 0.01a</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>15.71 ± 0.33b-d</td>
<td>0.21 ± 0.01ab</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>16.56 ± 1.38bc</td>
<td>0.21 ± 0.01ab</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>20.81 ± 1.23a</td>
<td>0.19 ± 0.00bc</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>19.60 ± 3.13a</td>
<td>0.17 ± 0.02c</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Mean values in a column followed by the same letter are not significantly different based on Tukey’s honestly significant difference test (\(\alpha = 0.05\)).

\textsuperscript{b}Brown rice without the soaking step.

\textsuperscript{c}Weight of 10 randomly selected kernels.

\textsuperscript{d}HSD value of the log of broken kernels (%).
Table 2. Chemical composition (dry basis) of brown rice and germinated brown rice at varying germination durations for Jupiter and Wells\(^a\)

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Germination Duration (hr)</th>
<th>Starch (%)</th>
<th>Apparent Amylose (%)</th>
<th>Soluble Sugars (%)</th>
<th>Crude Protein (%)</th>
<th>Crude Fat (%)</th>
<th>Ash (%)</th>
<th>GABA (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>Brown rice(^b)</td>
<td>76.03±0.86e</td>
<td>15.7±0.6ef</td>
<td>8.60±0.16a</td>
<td>2.58±0.04a</td>
<td>1.52±0.11ab</td>
<td>43.0±0.8b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>76.75±0.47d</td>
<td>15.1±0.1f</td>
<td>8.55±0.20a</td>
<td>2.05±0.05d</td>
<td>1.24±0.01c</td>
<td>35.3±0.4bc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>83.97±0.57a-c</td>
<td>17.6±0.2de</td>
<td>8.10±0.34a</td>
<td>2.61±0.01a</td>
<td>1.59±0.02ab</td>
<td>52.9±1.3a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>84.03±0.93a-c</td>
<td>17.7±0.3d-f</td>
<td>8.37±0.12a</td>
<td>2.42±0.06cd</td>
<td>1.42±0.16bc</td>
<td>54.3±2.7a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>83.23±1.03bc</td>
<td>17.9±0.6d</td>
<td>8.28±0.65a</td>
<td>2.44±0.04cd</td>
<td>1.40±0.11bc</td>
<td>54.1±4.2a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>82.59±0.46c</td>
<td>17.2±0.3d-f</td>
<td>8.33±0.38a</td>
<td>2.37±0.06a-c</td>
<td>1.55±0.09ab</td>
<td>56.8±2.0a</td>
<td></td>
</tr>
<tr>
<td>Wells</td>
<td>Brown rice</td>
<td>78.15 ± 0.34d</td>
<td>24.0 ± 1.0c</td>
<td>8.10 ± 0.13a</td>
<td>2.52 ± 0.04ab</td>
<td>1.58 ± 0.09ab</td>
<td>34.3±2.0c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>78.68 ± 0.12d</td>
<td>24.8 ± 0.1bc</td>
<td>8.24 ± 0.05a</td>
<td>2.34 ± 0.01a-d</td>
<td>1.42 ± 0.00a-c</td>
<td>31.9±0.3c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>84.84 ± 0.69a</td>
<td>27.4 ± 0.3a</td>
<td>7.85 ± 0.22a</td>
<td>2.57 ± 0.03a</td>
<td>1.56 ± 0.01ab</td>
<td>38.7±2.8bc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>84.72 ± 0.80ab</td>
<td>26.7 ± 0.5ab</td>
<td>8.25 ± 0.12a</td>
<td>2.44 ± 0.01a-c</td>
<td>1.53 ± 0.09ab</td>
<td>36.0±3.6c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>83.84 ± 0.63a-c</td>
<td>27.1 ± 0.6ab</td>
<td>7.82 ± 0.62a</td>
<td>2.40 ± 0.02a-c</td>
<td>1.52 ± 0.05ab</td>
<td>36.4±3.2c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>82.87 ± 0.59c</td>
<td>27.1 ± 0.1a</td>
<td>8.17 ± 0.13a</td>
<td>2.27 ± 0.07b-d</td>
<td>1.64±0.09a</td>
<td>38.3±2.4bc</td>
<td></td>
</tr>
<tr>
<td>HSD value</td>
<td></td>
<td>2.17</td>
<td>1.88</td>
<td>0.11</td>
<td>1.04</td>
<td>0.34</td>
<td>0.27</td>
<td>10.43</td>
</tr>
</tbody>
</table>

\(^a\)Mean values in a column followed by the same letter are not significantly different based on Tukey’s honestly significant difference test (\(\alpha = 0.05\)).

\(^b\)Brown rice without the soaking step.
Table 3. Gelatinization properties of brown rice and germinated brown rice at varying germination durations for Jupiter and Wells\textsuperscript{a}

<table>
<thead>
<tr>
<th>Rice Cultivar</th>
<th>Germination Duration (hr)</th>
<th>Gelatinization Temperature (°C)</th>
<th>Enthalpy (J/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Onset</td>
<td>Peak</td>
</tr>
<tr>
<td>Jupiter</td>
<td>Brown rice\textsuperscript{b}</td>
<td>69.0bc</td>
<td>74.7b</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>70.3b</td>
<td>76.7b</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>69.9b</td>
<td>76.4b</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>68.7c</td>
<td>75.3b</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>70.0b</td>
<td>76.4b</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>69.9b</td>
<td>76.3b</td>
</tr>
<tr>
<td>Wells</td>
<td>Brown rice</td>
<td>75.8a</td>
<td>80.4a</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>77.2a</td>
<td>81.6a</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>76.7a</td>
<td>81.7a</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>76.7a</td>
<td>81.4a</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>76.9a</td>
<td>81.8a</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>76.8a</td>
<td>81.5a</td>
</tr>
<tr>
<td>HSD value</td>
<td></td>
<td>1.54</td>
<td>1.67</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Mean values in a column followed by the same letter are not significantly different based on Tukey’s honestly significant difference test (\(\alpha = 0.05\)).

\textsuperscript{b}Brown rice without the soaking step.
Table 4. Hardness and stickiness of cooked brown rice and germinated brown rice at varying germination durations for Jupiter and Wells

<table>
<thead>
<tr>
<th>Rice Cultivar</th>
<th>Germination Duration (hr)</th>
<th>Hardness (Peak Force, N)</th>
<th>Stickiness (Negative Force Area, N × s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>Brown Rice (^b)</td>
<td>52.58 ± 2.6b-d</td>
<td>2.13 ± 0.46b-d</td>
</tr>
<tr>
<td>(MG)</td>
<td>0</td>
<td>46.89 ± 3.69d</td>
<td>3.65 ± 0.49a</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>52.94 ± 3.74cd</td>
<td>2.04 ± 0.34bc</td>
</tr>
<tr>
<td></td>
<td>32</td>
<td>50.29 ± 4.41cd</td>
<td>2.60 ± 0.34b</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>49.27 ± 3.8 cd</td>
<td>2.08 ± 0.48bc</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>49.77 ± 4.85 cd</td>
<td>1.95 ± 0.41cd</td>
</tr>
<tr>
<td>Wells</td>
<td>Brown Rice</td>
<td>62.36 ± 9.9ab</td>
<td>1.26 ± 0.33d-f</td>
</tr>
<tr>
<td>(LG)</td>
<td>0</td>
<td>54.15 ± 3.91a-c</td>
<td>1.45 ± 0.30c-e</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>61.76 ± 5.37a</td>
<td>1.23 ± 0.41ef</td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>54.38 ± 9.12bc</td>
<td>1.07 ± 0.31f</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>55.52 ± 3.61a-c</td>
<td>1.16 ± 0.27ef</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>53.34 ± 4.66c</td>
<td>0.89 ± 0.22f</td>
</tr>
<tr>
<td>HSD value</td>
<td></td>
<td>8.98</td>
<td>0.76</td>
</tr>
</tbody>
</table>

\(^a\)Mean values in a column followed by the same letter are not significantly different based on Tukey’s honestly significant difference test (\(\alpha = 0.05\)).

\(^b\)Brown rice without the soaking step.

\(^c\)Negative values expressed as absolute value.
Figure 1. Wells and Jupiter rice at four germination durations at their respective germination hours.
Figure 2. Pasting profiles of brown rice (BR) and germinated brown rice at varying germination durations (hr) for Jupiter and Wells using water and silver nitrate.
Figure 3. Normalized high performance size-exclusion chromatograms of brown rice (BR) and germinated brown rice at varying germination durations (hr) for Jupiter and Wells.
IV. Effect of Parboiling on Milling, Physicochemical, and Textural Properties of Medium- and Long-grain Germinated Brown Rice

ABSTRACT

Germinated brown rice is considered as a more nutritious and palatable cooked product than conventional brown rice. However germination usually decreases rice milling yield and alters some physicochemical properties. Parboiling is commonly used to increase milling yield and retain nutrients, but it also changes rice color and texture. The objective of this study was to investigate the effect of parboiling on milling, physicochemical, and textural properties of a medium- and a long-grain rice after germination at varying durations. Germinated rice samples of three germination durations were prepared with one germination time before 70% of rice revealed hull protrusion (optimum time), the optimum time, and one time after, at 8-hr increments. Germinated rice was then immediately parboiled at 120°C for 20 min, and then immediately dried. Parboiling significantly decreased the percentage of brokens and whiteness but increased gamma-aminobutyric acid content (GABA) for both cultivars. Parboiling reduced pasting viscosities for both cultivars, but Jupiter still exhibited higher pasting viscosities than Wells. Cooked parboiled germinated rice was overall softer than non-parboiled rice due to kernel splitting, but Wells remained harder and less sticky than Jupiter. It is beneficial to combine parboiling with germination to enhance nutritional values and milling properties without affecting desired textural properties for both rice cultivars.
INTRODUCTION

Germinated brown rice (GBR) is a functional food popular in Asia for its high gamma-aminobutyric acid content (GABA). GABA is primarily an inhibitory neurotransmitter linked to numerous health benefits such as reducing blood pressure, improving sleeplessness, cardiovascular diseases and diabetes regulation, and may also limit weight gain (Kayahara et al., 2001; Oh et al., 2004; Roohinejad et al., 2009). Germination also activates enzymes such as α-amylase, protease, phytase, and lipase to result in a softer and sweeter cooked brown rice (Jiamyangyuen and Ooraikul, 2008). Because rice bran contributes to a hard, chewy texture usually not favored by some consumers, increasing softness is an important attribute in eating quality of cooked GBR (Matz, 1991; Roberts, 1979).

Parboiling is a hydrothermal treatment that involves soaking, heating, and drying of rough rice. This practice is commonly used to increase head rice yield and better retain nutrients such as water-soluble vitamins and minerals due to steam pressure applied to the kernels (Choudhury, 1991). Soaking is required to increase the moisture content of rough rice to around 30-35% for proper germination and effective parboiling (Bhattacharya, 1985). When under heat and pressure, starch gelatinization and amylose-lipid complexation occur, followed by starch retrogradation upon cooling and drying of the rice kernels. The extents of starch retrogradation and complexation with lipids increase with parboiling severity, which consequently could increase cooked rice hardness (Derycke et al., 2005a; Lamberts et al. 2009). The formation and strengthening of protein barriers from disulfide cross-linking during parboiling may restrict water absorption of rice during cooking (Derycke et al., 2005b). The changes of starch, lipids and proteins during parboiling contribute to harder and less sticky cooked rice texture (Kato et al., 1983).
Germinated brown rice became darker, more yellow, and had a higher reducing sugar content but a lower crude protein content after parboiling (Panchan and Naivikul, 2009; Rattanadee and Naivikul, 2011). Komatsuzaki et al. (2007) reported an increase in GABA content after germinated brown rice was steamed. Cheevitsopon and Noomhorm (2014) reported a reduction in fissured kernels, GABA content, and total solids loss of GBR after parboiling. Cheevitsopon and Noomhorm (2011) found an increase in overall cooked rice hardness when rice was steamed and then dried with a fluidized bed dryer at high temperatures (110-150°C). However, recently Cheevitsopon and Noomhorm (2014) observed no change in cooked rice hardness when simultaneous parboiling and drying using superheated steam with a fluidized bed dryer. It was found that overall pasting viscosity increased in parboiled germinated brown rice (PGBR) compared with GBR (Cheevitsopon and Noomhorm; 2011, 2014). These results may be attributed to increased degrees of starch gelatinization with increasing drying temperature from the fluidized bed drier. Panchan and Naivikul (2009) and Rattanadee and Naivikul (2011) dried PGBR at 45°C ± 10°C and reported a significant decrease in pasting viscosity after parboiling of germinated rice compared with brown rice. Most of these studies used aromatic rice to study the effect of parboiling on germinated rice, except Rattanadee and Naivikul (2011) who used a high amylose, non-aromatic rice.

Because of limited information and contradictory results, there is a need for further understanding the effects of parboiling on GBR with relation to grain type and germination duration. Different grain types may differ in germination properties and subsequently parboiling properties because of their different physical characteristics and compositions. Miyoshi and Sato (1997) reported different responses to germination stimulant treatments between japonica and indica rice cultivars. Therefore the objective of this study was to compare the effects of
parboiling on the milling, physicochemical and texture properties of germinated long-grain and medium-grain rice at varying germination durations compared with their respective germinated brown rice counterparts.

MATERIAL AND METHODS

Materials
Rough rice of two cultivars, Wells of long-grain and Jupiter of medium-grain, from the 2012 crop were provided by the University of Arkansas Rice Research and Extension Center in Stuttgart, AR.

Germination

Rough rice (400 g) of each cultivar was soaked in 1.25% NaClO at 25°C for 30 min for disinfecting (Yang et al., 2001). The sample was rinsed three times under tap water prior to a final rinse with deionized water, and then soaked in excess water in a 9×13×2 inch stainless steel pan at 25°C in a water bath (OLS200, Grant Instruments, Cambridge, UK). The minimum soaking time to reach equilibrium moisture content was determined by establishing the water absorption curve for each cultivar. Rice samples were removed every 10 min for the first hour, then every hour up to 24 hr, pat dried, and weighed. The moisture content of soaked rice was calculated based on the initial moisture content by using the equation below. All treated rice samples were soaked until the time when moisture content approached equilibrium.

\[
\text{Moisture Content (\%) = 100 \times \left(\frac{\text{Final wet weight} - \text{Initial dry weight}}{\text{Initial dry weight}}\right)}
\]

After the soaking, the rice sample was rinsed again with deionized water prior to the germination procedure. For germination, approximately 240 g of soaked rice was each placed on
top of two damp cheese cloths on metal racks, which were situated in two 9×13×2 inch stainless steel pans with deionized water filled up to one inch height of the pan. Aluminum foil and masking tape were used to insulate and seal the pan and rice before placed in an incubator (APT.line BF, Binder, Tuttlingen, Germany) at 30-34°C. Twenty random whole kernels were removed from the cheese cloths regularly to determine the germination degree by counting the number of kernels showing protrusion through the hull and the embryonic growth length (cm). The optimum germination time was determined when 70% of the rice population displayed hull protrusion (Duration 2) as either S1 or S2 stages (Counce et al., 2000). Two additional germination times were selected: one prior to and one following the optimum time (Duration 1 and Duration 3, respectively). The germination durations were 10, 26 (optimum), and 34 hr for Wells, and 24, 40 (optimum), and 48 hr for Jupiter. One control soaked for 12 hr without incubation (0 hr) was used for each cultivar. The control and germinated samples were replicated twice.

**Parboiling**

After soaking and germination, rough rice was transferred and evenly spread onto a perforated rack placed into an autoclave (Tuttnauer Brinkman 2340E, Westbury NY). Soaked or germinated rice samples were immediately parboiled under steaming pressure (18 psi) and temperature (120°C) for 20 min. After autoclaving, rough rice was dried to 12 ± 0.5% moisture content in an Equilibrium Moisture Content (EMC) chamber (dry bulb 26°C, wet bulb 13.5°C) and stored at 4°C.

**Milling Properties**
Parboiled and dried germinated rough rice of 150 g were dehulled by passing through a Satake dehusker (THU-35, Satake Corp., Hiroshima, Japan) twice because one dehulling pass was inadequate to remove most hulls. Dehulled rice weight was recorded, and head brown rice was separated from broken kernels using a double-tray sizing machine (GrainMan Machinery, Miami, FL). Premature, chalky, or defected rice was removed from whole kernels. The percentage of broken (%) was calculated by the weight of rice fragments less than three quarters of a whole kernel divided by the original 150 g of rough rice. For physicochemical analyses, whole rice kernels were ground into flour using a UDY cyclone sample mill (UDY, Ft. Collins, CO, USA) fitted with a 0.50-mm sieve.

The color of dehulled brown rice kernels was measured using a Minolta colorimeter (CR 400, Minolta, Osaka, Japan), and whiteness (*L) and yellowness (*b) values were recorded. The colorimetric meter was calibrated with the reference white plates provided and two readings were taken for each replicate sample.

**GABA Content**

Gamma-aminobutyric acid (GABA) was measured using the colorimetric method of Kitaoka and Nakanom (1969) with modifications. Brown rice flour (0.15 g) and 80% ethanol (1.5 mL) were weighed into 2-mL microcentrifuge tubes, vortexed, and then shaken in a water bath at 150 strokes/min (OLS200, Grant Instruments, Cambridge, UK) at 25 °C for 1 hr. The tubes were then centrifuged (Microcentrifuge 5415D, Eppendorf, Hauppauge, NY) at 9300g for 10 min. One mL of the supernatant was transferred into 15-mL test tubes before 0.2 mL of 0.2 M borate buffer (pH 9) and 1 mL of 6% phenol were added while submerged in an ice bath under constant stirring. Tubes were then vortexed and left to stir for 5 min before 0.4 mL of NaOCl
reagent (7.5% Cl) was added, vortexed, and left to stir in the ice bath for another 5 min. Tubes were then submerged in a boiling water bath for 10 min with constant stirring, followed by cooling in an ice bath for a remaining 5 min. Readings were taken with a spectrophotometer (40014, Genesys 20, Thermo Fisher Scientific, Waltham, MA) at a wavelength of 630 nm. The standard curve was prepared with ethanol and GABA (A5835, Sigma-Aldrich Co., St. Louis, MO) at 10, 30, 50, 70, and 100 µL/mL concentrations.

**Physicochemical Properties**

Thermal properties were measured using a differential scanning calorimeter (DSC, model Diamond, Perkin-Elmer Co., Norwalk, CT). Approximately 8 mg of ground parboiled rice flour were weighed into a stainless steel pan with a 16 µL of deionized water added via a microsyringe. The pan was sealed and equilibrated at room temperature for 24 hr prior to heating from 25°C to 150°C at 10°C/min. A respective empty pan was used as a reference. Onset, peak, and conclusion temperatures (°C) and enthalpy (J/g) were calculated.

Pasting properties were determined using a Rapid ViscoAnalyser (RVA, Newport Scientific Pty. Ltd, Warriewood NSW, Australia) according to AACC Method 61-02. Rice slurry was prepared by mixing ~3.0 g of rice flour (12% moisture basis) with ~25.0 mL of deionized water (12% moisture basis) into a RVA canister. The slurry was rapidly heated to 50°C then heated from 50°C to 95°C at 5°C/min, held at 95°C for 5 min, cooled from 95°C to 50°C at 5°C/min, and then held at 50°C at for 5 min. Peak, breakdown, setback, and final viscosities (Cp) were recorded.

**Texture Analysis**
Parboiled germinated brown rice and parboiled soaked brown rice were cooked according to Perez and Juliano (1979) using a consumer rice cooker (ARC-914B, Aroma, Aroma Housewares Co, San Diego, CA). Five grams of whole kernels were soaked in deionized water in a 100-mL beaker for 30 min with a fixed water-to-rice ratio of 2.1:1 for Wells and 1.9:1 for Jupiter. Six beakers containing the soaked rice were placed on a metal rack placed within the cooking bowl holding 250 g deionized water. Cooking duration was determined by removing 10 kernels every 5 min after cooking for 30 min until a minimum of 9 kernels showed no starchy cores when compressed between two glass plates, indicating cooking completion (Ranghino, 1966). Cooked rice was gently mixed, transferred to an airtight zip-lock bag, placed in a thermo insulator and was used within 30 min for texture analysis.

Texture analysis was performed with a 50-kg load cell and an aluminum plate of 10 cm in diameter and 0.6 cm in thickness using a TA. XT Plus Texture Analyzer (Texture Technologies Corp., Hamilton, MA). A compression test mode was performed with 10 whole rice kernels at a speed at 5 mm/s, compressed to 0.3 mm, held for 5.0 s, and returned at 0.5 mm/s. The maximum compression force (peak force, N) and adhesiveness (area of negative force, N × s) was recorded as cooked rice hardness and stickiness, respectively (Saleh and Meullenet, 2007). Measurements were repeated six times for each replicate sample.

Four replications of the experimental treatment conditions were performed for each property. The treatment structure was a $2 \times 2 \times 4$ factorial arrangement with two cultivars (Wells and Jupiter), two processing treatments (Non-parboiled and Parboiled) and three germination durations (with the 0 hours control along with the three additional durations). The experimental design was a Completely Randomized Design with 16 treatment combinations and four replications that were assigned independently to the experimental units. The analysis model for
the design was fitted in the Fit Model platform of JMP PRO Ver. 11.2.1 (SAS Software Institute, Cary, NC) with the main effects and interaction. Tukey’s HSD multiple comparisons test (α = 0.05) was used to identify significant differences of the dozen treatment LSmeans including the control.

RESULTS AND DISCUSSION

Milling Properties

Parboiling significantly decreased the percentage of brokens in germinated brown rice for both Jupiter and Wells cultivars (P < 0.0001) (Table 1), which was also reported by Cheevitsopon and Noomhorm (2011). This reduction in brokens was primarily attributed to starch gelatinization that sealed fissures present naturally and from soaking and germination. (Bhattacharya, 2004). The brokens was decreased by 12-17 % in Wells, with the largest decrease for the longest germination time, and was decreased approximately 4 % in Jupiter. Therefore, parboiling is an effective way of reducing brokens after germination.

There were no differences in whiteness (L-value) among non-parboiled germinated rice for the same cultivar, approximately 52 for Jupiter and 61 for Wells. Upon parboiling the whiteness significantly decreased for both cultivars (P < 0.001), but their difference still remained with Wells having higher whiteness values than Jupiter (Table 1). This finding agrees with Bhattacharya (1996) who reported decreasing whiteness with increasing parboiling time and pressure. The lower whiteness values in Jupiter samples were correlated with their higher soluble sugars contents (Han et al., 2015). Parboiled rice becomes discolored as a result of Maillard reaction and the diffusion of hull and bran pigments into the endosperm during soaking.
(Bhattacharya 2004; Lamberts et al., 2006; Houston et al., 1956; Parnsahkorn and Langkapin, 2013; Rordprapat et al. 2005). The results suggest that Maillard reaction was the main contributor to the discoloring of parboiled rice, and germination duration had little impact on the whiteness of the resultant parboiled rice. Wells was more yellow than Jupiter (P < 0.0001), and parboiling overall increased yellowness of germinated Wells samples but not that of germinated Jupiter samples when compared with their respective non-parboiled counterpart. Cheevitsopon and Noomhorm (2011, 2014) attributed increased yellowness from parboiling on germinated Jasmine brown rice to the Maillard reaction. However, the present results suggest that Maillard reaction has a strong negative effect on the whiteness of parboiled germinated rice, but its impact on yellowness was not significant.

**GABA Content**

After parboiling, the GABA content of both germinated Jupiter and Wells cultivars significantly increased (P < 0.0001), and their differences diminished (Table 1). Inconsistent results in terms of parboiling effects on GABA content of germinated rice have been reported. Chungcharoen et al. (2014), Komatsuzaki et al. (2007), and Srisang et al. (2010; 2011) reported that germinated rice contained unchanged or significantly increased GABA content after steaming and drying; however, Cheevitsopon and Noomhorm (2011, 2014) reported up to 50% reduction in GABA after parboiling with drying. The significant increase in GABA content in this study after parboiling was attributed to degradation of protein into amino acids that were also detected by the spectrophotometric method used in this study as compared with the HPLC method used in previously studies (Chungcharoen et al., 2014; Komatsuzaki et al., 2007; Srisang et al., 2010; 2011). This may also explain the similar GABA contents in Jupiter and Wells after parboiling.
Physicochemical Properties

There were two endothermic transitions in parboiled germinated rice for both cultivars (Table 2): retrograded amylopectin melting at a lower temperature and amylose-lipid complex melting at a higher temperature. Both cultivars had similar melting temperatures and enthalpies for both transitions, except that Wells had significant higher retrogradation end temperatures and enthalpies, which was ascribed to a greater proportion of amylose and amylopectin long branch chains in long-grain Wells cultivar than in medium-grain Jupiter cultivar (Fan and Marks, 1998; Lu et al., 1997; Inouchi et al., 2000; Jane et al., 1999; Patindol and Wang, 2003; Patindol et al., 2005). The greater proportion of amylopectin long branch chains in Wells not only contributed to its higher gelatinization temperatures but also was responsible for its increased retrogradation extent. The lack of significant changes between germination durations for amylopectin retrogradation properties in both cultivars support the previous study (Han et al., 2015) that germination did not significantly change amylopectin structure to result in different amounts and structures of retrograded crystallites.

The amylose-lipid complexes were not present in non-parboiled germinated samples (Han et al., 2015) because they were formed during the heating process of parboiling (Priestly, 1976). Kato et al. (1983) reported an increase in lipids bound to starch and protein after parboiling. After gelatinization, amylose and lipids may form an inclusion complex, and Type-II amylose-lipid complex is more thermodynamically favored and the preferred form at high crystallization temperatures with peak melting temperatures of 110–120°C (Biliaderis and Galloway, 1989; Biliaderis et al., 1993) when processed under high temperatures as observed in this study. The specific temperatures to form amylose-lipid complexes are dependent on lipid characteristics (Tufvesson et al., 2003). The enthalpy values of amylose-lipid complex were
similar to Newton et al. (2011). The lack of significant differences in amylose-lipid complex melting between germination durations for both cultivars agrees with the previous study (Han et al., 2015) and suggests that germination did not sufficiently alter amylose molecular size to change its interaction with lipids.

Jupiter had an overall higher pasting profile than Wells (Figure 1) because of its higher amylopectin content (Chung et al., 2008). The pasting viscosities were significantly decreased after parboiling when compared with their germinated counterparts (Han et al., 2015) due to reduced starch water-binding capacity after gelatinization, retrogradation, and interaction with protein and lipids, thereby decreasing swelling ability (Ali and Bhattacharya, 1980; Rao and Juliano, 1970; Patiindol et al., 2008; Soponronnarit et al., 2006). Within each cultivar, there were little differences in pasting profiles between germination durations after parboiling. These results support the previous study, in which a similar pasting profile was found in germinated rice from the same cultivar at different germination durations when conducted in silver nitrate.

**Texture Analysis**

Before parboiling, germinated brown rice samples from Wells were generally higher in hardness and lower in stickiness than those from Jupiter when cooked (Han et al., 2015). Parboiling resulted in a decrease in hardness for both cultivars, but had different influences on stickiness. All parboiled germinated rice samples split after cooking; therefore the decreased hardness for both cultivars was presumably due to kernel splitting. Similar to germinated rice, parboiled germinated Wells had significantly higher hardness and lower stickiness values than Jupiter (P < 0.0001) (Table 3). Parboiling resulted in a greater difference in hardness and stickiness between Wells and Jupiter, which was attributed to their different amylose contents and consequently different amounts of amylose-lipid complex after parboiling. Amylose content,
amylose-lipid complexes, and long amylopectin chains have been found to be associated with cooked rice hardness (Biliaderis et al., 1993; Ong and Blanshard, 1995; Radhika et al., 1993; Ramesh et al., 1999). As shown previously, amylose-lipid complex was formed during parboiling. It is possible that these newly formed complexes may be more concentrated on the endosperm-bran interface where lipids and proteins are more abundant and contribute to kernel splitting by constricting swelling on the kernel surface while the endosperm swelled during cooking. Despite both cultivars splitting after cooking, the differences in decreased hardness between the two cultivars after parboiling were still present, where germination had an overall effect of decreasing cooked rice hardness ($P = 0.001$) for both cultivars, more so than their non-parboiled germinated counterparts (Han et al., 2015). Therefore parboiling did change the hardness of cooked germinated brown rice, however the inherent difference in germinated rice still remained after parboiling.

The differences in stickiness between cultivars were greater after parboiling with parboiled germinated Wells significantly less sticky than its non-parboiled cooked rice (Han et al., 2015) (Table 3). Parboiled germinated Jupiter showed a significant decrease in stickiness once germinated but overall had similar stickiness as non-parboiled germinated rice (Han et al., 2015). The lack of overall differences between parboiled and non-parboiled Jupiter samples implies that splitting of the cooked kernels did not influence stickiness because non-parboiled Jupiter did not split. Cooked rice hardness usually increased, whereas cooked rice stickiness decreased as a result of parboiling (Kato et al., 1983; Islam et al., 2000; Patindol et al., 2008). This may be a result of increased protein-starch complexes formed from parboiling, which were found to be negatively correlated with cooked rice stickiness (Hamaker et al., 1991; Kato et al., 1983). For Jupiter, more amylopectin might be hydrolyzed with increasing germination (Han et
al., 2015), and thereby resulting in decreased protein-starch complex formation upon parboiling. However for parboiled Wells the similar stickiness values across germination durations and its overall decreased stickiness compared with its non-parboiled germinated rice (Han et al., 2015) suggest that amylose content may play a more important role in affecting cooked rice stickiness than protein complexes as suggested by Hamaker et al. (1991) and Kumar et al. (1976).

A significant three-way interaction was observed between rice cultivars, germination durations, and parboiling treatment for brokens, whiteness, and GABA content (P = 0.0291, 0.0131, and 0.0090, respectively) (Figure 2). This implies that these three properties were impacted not only by parboiling treatment, but also through a combined effect of the type of germinating rice at a certain germination times. Compared to the parboiled non-germinated counterparts, the parboiled germinated Wells had significantly less brokens at the last germination duration while parboiling significantly decreased brokens for Jupiter at first germination duration. The whiteness values for parboiled germinated Wells significantly decreased at the second germination duration while parboiled germinated Jupiter significantly increased at the last germination duration. The GABA content significantly increased after parboiling for germinated Wells at the second duration, while Jupiter significantly increased at the last parboiled germinated duration.

CONCLUSION

Parboiling significantly changed the milling, physicochemical, and textural properties of germinated medium-grain, Jupiter, and long-grain, Wells rice. Parboiling significantly decreased the percentage of brokens and whiteness values for both cultivars, but only increased yellowness
in Wells. The GABA content significantly increased after parboiling for both cultivars. After parboiling, germinated rice from both cultivars had significantly lower pasting viscosities, although Jupiter remained overall higher in pasting viscosity than Wells. Both cooked germinated rice cultivars became softer after parboiling due to cooked kernel splitting and continued to soften with progressed germination time. The results demonstrate that some desired characteristics of germinated rice such as GABA content and cooked rice softness were enhanced after parboiling compared with non-germinated parboiled rice for both rice types. However parboiled germinated medium- and long-grain rice still exhibited inherently different color, pasting, and textural properties after parboiling.
REFERENCES


Table 1. The percentage of brokens, color, and γ-aminobutyric acid (GABA) content of parboiled brown rice and germinated brown rice at varying germination durations for Jupiter and Wells.a

<table>
<thead>
<tr>
<th>Rice Cultivar</th>
<th>Treatment</th>
<th>Germination Duration (hr)</th>
<th>Brokens (%)</th>
<th>L-value</th>
<th>b-value</th>
<th>GABA (mg/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>Non-parboiled</td>
<td>0′</td>
<td>5.56 ± 0.66b-d</td>
<td>52.93b</td>
<td>16.74a-f</td>
<td>43.0±0.8h</td>
</tr>
<tr>
<td></td>
<td></td>
<td>24</td>
<td>6.23 ± 0.76bc</td>
<td>52.28b</td>
<td>15.43e-g</td>
<td>52.9±1.3g</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40</td>
<td>6.63 ± 0.45bc</td>
<td>52.49b</td>
<td>15.60fg</td>
<td>54.1±4.2fg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>48</td>
<td>7.06 ± 0.47b</td>
<td>52.71b</td>
<td>15.24g</td>
<td>56.8±2.0e-g</td>
</tr>
<tr>
<td>Parboiled</td>
<td>0′</td>
<td>5.11 ± 1.20cd</td>
<td>40.97e</td>
<td>15.73c-g</td>
<td>62.50 ± 0.54c-e</td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>2.53 ± 0.25fg</td>
<td>41.04e</td>
<td>15.74b-g</td>
<td>64.27 ± 2.33b-d</td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>2.36 ± 0.55g</td>
<td>40.92e</td>
<td>15.36fg</td>
<td>67.77 ± 1.06a-c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>2.42 ± 0.12fg</td>
<td>42.71d</td>
<td>15.44e-g</td>
<td>70.75 ± 1.46a</td>
<td></td>
</tr>
<tr>
<td>Wells</td>
<td>Non-parboiled</td>
<td>16.55 ± 0.71a</td>
<td>61.45a</td>
<td>16.78a-e</td>
<td>34.3±2.0i</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>15.71 ± 0.33a</td>
<td>60.16a</td>
<td>16.23a-g</td>
<td>38.7±2.8hi</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>20.81 ± 1.23a</td>
<td>60.95a</td>
<td>16.96a-c</td>
<td>36.4±3.2i</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>19.60 ± 3.13a</td>
<td>60.72a</td>
<td>15.68c-g</td>
<td>38.3±2.4hi</td>
<td></td>
</tr>
<tr>
<td>Parboiled</td>
<td>0′</td>
<td>4.46 ± 0.67de</td>
<td>45.59c</td>
<td>16.85a-d</td>
<td>59.56 ± 0.93d-f</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3.19 ± 0.08e-g</td>
<td>45.53c</td>
<td>17.16ab</td>
<td>61.74 ± 0.66c-e</td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>3.23 ± 0.19e-g</td>
<td>43.29d</td>
<td>16.85a-d</td>
<td>65.99 ± 0.42a-c</td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>2.43 ± 0.50fg</td>
<td>46.64c</td>
<td>17.50a</td>
<td>69.01 ± 1.84ab</td>
<td></td>
</tr>
<tr>
<td>HSD value</td>
<td></td>
<td>0.33d</td>
<td>0.0007e</td>
<td>0.18f</td>
<td>6.20</td>
<td></td>
</tr>
</tbody>
</table>

aMean values in a column followed by the same letter are not significantly different based on Tukey’s honestly significant difference test (α = 0.05).

bSoaked brown rice.

cParboiled soaked brown rice.

d-fHSD values of the log of broken kernels (%), reciprocal of L-values, and square root of b-values, respectively.
Table 2. Thermal properties of parboiled brown rice and germinated brown rice at varying germination durations for Jupiter and Wells\textsuperscript{a}

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Germination Duration (hr)</th>
<th>Retrograded Amylopectin</th>
<th>Amylose-lipid complex</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Onset Temp (°C)</td>
<td>Peak Temp (°C)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Onset Temp (°C)</td>
<td>Peak Temp (°C)</td>
</tr>
<tr>
<td>Jupiter</td>
<td>0\textsuperscript{b}</td>
<td>52.1a 61.7a 67.1b 1.1b</td>
<td>107.1a 115.3a 122.8a</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>51.6a 61.1a 66.8b 1.0b</td>
<td>106.2a 114.4a-c 122.4a</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>51.8a 61.1a 66.1b 1.0b</td>
<td>106.4a 113.8bc 121.8a</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>50.6a 61.0a 67.1b 1.2b</td>
<td>105.8a 113.5c 123.7a</td>
</tr>
<tr>
<td>Wells</td>
<td>0\textsuperscript{b}</td>
<td>50.8a 60.8a 68.7a 2.9a</td>
<td>107.3a 114.8ab 122.5a</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>51.4a 61.1a 69.3a 3.2a</td>
<td>107.1a 114.7a-c 121.9a</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>52.7a 61.2a 69.8a 3.4a</td>
<td>107.0a 115.0a 122.6a</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>52.4a 61.1a 69.9a 3.7a</td>
<td>107.3a 114.9ab 121.8a</td>
</tr>
<tr>
<td>HSD value</td>
<td></td>
<td>0.05 0.02 0.02 0.26</td>
<td>2.33 1.19 2.00</td>
</tr>
</tbody>
</table>

\textsuperscript{a}Mean values in a column followed by the same letter are not significantly different based on Tukey’s honestly significant difference test (\(\alpha = 0.05\)).

\textsuperscript{b}Parboiled brown rice.
**Table 3.** Hardness and stickiness of cooked parboiled brown rice and germinated brown rice at varying germination durations for Jupiter and Wells

<table>
<thead>
<tr>
<th>Rice Cultivar</th>
<th>Germination Duration (hr)</th>
<th>Hardness (Peak Force, N)</th>
<th>Stickiness (Negative Force Area, N × s)(^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jupiter</td>
<td>0(^b)</td>
<td>41.33 ± 3.55d</td>
<td>2.26 ± 0.31a</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>39.81 ± 3.77de</td>
<td>1.62 ± 0.24c</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>38.10 ± 2.43de</td>
<td>2.09 ± 0.26ab</td>
</tr>
<tr>
<td></td>
<td>48</td>
<td>34.23 ± 1.84e</td>
<td>1.86 ± 0.16bc</td>
</tr>
<tr>
<td>Wells</td>
<td>0(^b)</td>
<td>56.90 ± 4.90ab</td>
<td>0.07 ± 0.08d</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>58.27 ± 2.91a</td>
<td>0.13 ± 0.12d</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>51.28 ± 3.90c</td>
<td>0.18 ± 0.12d</td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>52.05 ± 4.50bc</td>
<td>0.14 ± 0.07d</td>
</tr>
<tr>
<td>HSD value</td>
<td></td>
<td>5.33</td>
<td>0.28</td>
</tr>
</tbody>
</table>

\(^a\)Mean values in a column followed by the same letter are not significantly different based on Tukey’s honestly significant difference test (\(\alpha = 0.05\)).

\(^b\)Parboiled soaked brown rice.

\(^c\)Negative values expressed as absolute value.
Figure 1. Pasting profiles of parboiled brown rice and germinated brown rice at varying germination durations for Jupiter and Wells.
Figure 2. Statistical three-way interactions for Brokens, L-value (whiteness), and GABA content based on Least Squares Means (LS Means) of parboiled brown rice and germinated brown rice at varying germination durations for Jupiter and Wells.
Figure 1. Wells and Jupiter rice at three germination durations at their respective germination hours.
V. Final Conclusion

This study demonstrates that milling, physicochemical and textural properties of germinated rice and parboiled germinated rice were affected by germination duration and grain type. Both soaking and germination significantly increased brokens, whereas parboiling effectively reduced brokens through gelatinization of starch. Although both amylose and amylopectin were hydrolyzed during germination, the hydrolysis was not significant to change starch gelatinization temperatures and pasting properties for both cultivars. The sugar and GABA contents were higher in Jupiter than in Wells, and parboiling further increased GABA content in both rice to comparable quantities. Germination decreased cooked rice hardness more for Wells and decreased cooked rice stickiness more for Jupiter; parboiling accentuated their differences in cooked rice hardness and stickiness. Germination practices and characteristics of one grain type may not directly relate to another grain type, and inherent differences remain between different rice types. Germination and parboiling can be combined to enhance nutritional value while maintaining desired milling and functional properties of different types of rice cultivars.