Journal of Cereal Science 69 (2016) 283–289

Contents lists available at ScienceDirect

Journal of Cereal Science

journal homepage: www.elsevier.com/locate/jcs

Impacts of parboiling conditions on quality characteristics of parboiled commingled rice

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ARTICLE INFO

Article history:
Received 21 December 2015
Received in revised form
4 April 2016
Accepted 7 April 2016
Available online 8 April 2016

Keywords:
Parboiling
Commingled rice
Onset gelatinization temperature
Head rice yield

ABSTRACT

Commingling of rice cultivars with a wide range of onset gelatinization temperatures (T_o) could occur during harvesting, drying, storage, and distribution, and consequently impact parboiled rice properties. This study investigated the effects of commingling, soaking temperature and steaming duration on parboiled commingled rice properties. Rough rice of pureline (Taggart and CL151) and hybrid (XL753 and CL XL745) cultivars were mixed at 1:1 weight ratio to obtain 3 commingled rice lots with a difference in T_o of 1.2, 3.9, and 6 °C. Rough rice was soaked at 65°, 70°, or 75 °C for 3 h, and steamed at 112 °C for 10, 15, or 20 min prior to drying. The effects of soaking temperature and steaming duration were found to vary with commingled rice. Soaking temperature exerted more influence on commingled rice comprising low T_o cultivars. Commingled rice comprising high T_o cultivars was less affected by soaking temperature and steaming duration in terms of head rice yield, deformed kernels and pasting viscosities. Both the difference in T_o among commingled rice cultivars and the T_o relative to the soaking temperature were important in parboiled commingled rice properties. Commingled rice with a wide range of T_o tended to result in parboiled rice with less desirable properties.

1. Introduction

Parboiled rice consumption has been primarily of cultural preferences in countries like India, Pakistan, Bangladesh, and Nigeria, and has become popular in many countries in Europe, North and South America (Bhattacharya, 2011). Parboiled rice finds many applications in the food industry such as instant rice, frozen entrees, canned goods, and ready-to-eat meals because of its heat stability and retained nutrients (Luh and Mickus, 1991). The parboiling process includes soaking, steaming, and drying, which all have impacts on the quality of parboiled rice. Parboiling decreases breakage susceptibility of rice during the dehulling and milling processes, resulting in greater head rice yield. However, unfavorable characteristics may develop if rice is not properly parboiled, for example discoloration, off-odor and flavor, deformation, white core, and unsatisfactory sensory attributes (Bhattacharya, 2011).

The effects of parboiling conditions on the qualities of parboiled rice have been extensively investigated. Parboiling resulted in an increase in head rice yield and a decrease in overall pasting profile, swelling and amylose leaching of parboiled rice (Raghavendra Rao and Juliano, 1970; Ali and Bhattacharya, 1980; Islam et al., 2001; Patindol et al., 2008; Gunaratne et al., 2013; Graham-Acquaah et al., 2015). Bhattacharya and Subba Rao (1966a) found that the intensity of parboiled rice color was affected by the severity of the parboiling process, including soaking temperature, soaking duration, steaming pressure as well as steaming duration. Pillaiyar and Mohandoss (1981) reported a decrease in hardness of cooked rice kernels with increasing soaking temperature, whereas longer steaming durations increased the hardness of cooked rice (Kar et al., 1999; Saif et al., 2004). Patindol et al. (2008) reported head rice yield of brown rice was 89.6 and 62.6% when steamed at 100 °C and 120 °C for 20 min, respectively. Longer steaming time reduced the chalkiness and pasting viscosities as well as increased the hardness of cooked parboiled rice. Buggenhout et al. (2013, 2014) suggested that the degree of starch gelatinization, which was affected by severity of parboiling conditions, played an important role in breakage susceptibility of parboiled rice. The presence of white belly and fissured kernels decreased head rice yield because of their tendency to breakage during milling, which was supported

Abbreviations: T_o, onset gelatinization temperature; MC, moisture content; RH, relative humidity; HRY, head rice yield.

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http://dx.doi.org/10.1016/j.jcs.2016.04.003

by their lower bending forces compared with the transparent, non-fissured parboiled rice kernels.

Because of a significant increase in rice cultivars, particularly the development of hybrid cultivars in the U.S., an intermingling between rice cultivars with pureline and hybrid and with a wide range of gelatinization temperatures could occur during harvesting, drying, storage, and distribution. Bhattacharya and Subba Rao (1966a) noted the differences in hydration rate of rough rice during soaking and milling yield of parboiled rice as affected by varietal differences, particularly in terms of starch gelatinization temperature. Basutkar et al. (2014) reported significant effects of commingled rice on milled rice yield, head rice yield, and chalkiness of milled rice. However, the effects of commingling on whiteness and yellowness was insignificant. Basutkar et al. (2015) proposed that a large variation in starch onset gelatinization temperature (T_o) of the rice cultivars in commingles may cause inconsistent quality of products because the T_o of commingled rice was determined by cultivars with the lower T_o.

Besides gelatinization temperature, milling characteristics differ among cultivars, which could affect hydration rate and consequently rice quality after parboiling. The bran layer of hybrid rice cultivars was found to be thinner than that of pureline cultivars; therefore, hybrid rice required a shorter milling duration to reach the same degree of milling as pureline (Siebenmorgen et al., 2006; Lanning and Siebenmorgen, 2011; Siebenmorgen et al., 2012). Varietal differences also had an influence on color and cooking quality of parboiled rice (Bhattacharya and Subba Rao, 1966b). Raghavendra Rao and Juliano (1970) attributed changes in pasting characteristics among different rice cultivars from parboiling to the differences in amylose content of individual rice cultivars. Patindol et al. (2008) found that milling, physicochemical, pasting, thermal, and cooking properties of parboiled rice were affected by cultivars in terms of chemical composition and gelatinization temperature.

Because of the aforementioned differences in rice properties among cultivars, the goal of this study was to investigate the impacts of parboiling conditions on the quality of parboiled rice when using commingled rough rice as a feedstock.

2. Materials and methods

2.1. Materials

Long-grain pureline (Taggart and CL151) and hybrid (CL XL745 and XL753) rice cultivars from the 2012 crop year were used in this study and obtained from the University of Arkansas Rice Processing Program (Fayetteville, Arkansas). These cultivars were selected because they had the lowest T_o and the highest T_o among pureline and hybrid cultivars available from the 2012 crop year, as determined by a differential scanning calorimeter, of 72.1, 74.2, 73.3, and 78.1 °C for Taggart, CL151, CL XL745, and XL753, respectively. Three combinations of commingled rice samples were prepared using a 1:1 ratio based on rough rice weight (approximately at 12.5% moisture content, MC). Taggart/CL XL745, CL151/XL753, and Taggart/XL753 represented Low T_o/Low T_o (L/L), High T_o/High T_o (H/H), and Low T_o/High T_o (L/H) commingles with T_o differences of 1.2, 3.9, and 6.0 °C, respectively. The rough rice was accurately weighed and mixed 5 times, 2 min each time, using a rotary rice grader (TRG, Satake, Tokyo, Japan).

2.2. Parboiling conditions

A partially-automated, pilot-scale parboiling unit fabricated by the University of Arkansas Rice Processing Program was used to parboil rice samples. Soaking temperatures, soaking durations, steaming pressure and steaming durations were set before starting the process. Rough rice was soaked at 65, 70, or 75 °C for 3 h prior to steaming at 69 kPa (10 psi, 112 °C) for 10, 15 or 20 min. The selected soaking temperatures were set approximately 3–7 °C below T_o of rice samples. After steaming, rice was dried in an equilibrium moisture content (EMC) chamber at 26 °C and 65% RH for 3 days to reach 12% MC.

2.3. Milling properties

Dried parboiled rice was dehulled using a Satake THU-35 dehusker (THU-35, Satake Corp., Hiroshima, Japan) and milled for 60 s with a McGill No. 2 mill (PRAPSCO, Brookshire, TX) which had a 1.5 kg mass placed on the lever arm at 15 cm from the center of the milling chamber. The head rice kernels were separated from broken kernels by a double-tray sizing device (Seedburo Equipment Co., Chicago, IL). Head rice yield (HRY) was expressed as a percentage of head parboiled rice mass to dried parboiled rough rice mass.

2.4. Color

The whiteness (L^*) and yellowness (b^*) of parboiled rice was measured using a Hunter lab digital colorimeter (Colorflex EZ, Hunterlab, Reston, VA) and determined by CIE color scales. The colorimeter was standardized using a white blank (Illuminant D65 10° Observer, x = 79.88, y = 84.72, z = 89.47) with a 31.8-mm aperture. Approximately 30 g of head parboiled rice was filled in a clear, flat-bottom dish and placed at the center of the sample port. The cup was rotated 180° for the second reading.

2.5. White core

The percentage of white core was determined using an image analysis system (Winseedle™ Pro 2005a Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Several white core and translucent parboiled kernels were scanned and used as references for the system to classify the white core and translucent area based on number of pixels. One hundred random rice kernels were placed in a tray made from a 2-mm thick clear acrylic sheet (Plexiglass) with no grain touching each other, and then imaged with a scanner (Epson Perfection V700 Photo, Model# J221A, Seiko Epson Corp., Japan) (Fig. 1). The system measured the number of pixels and classified them according to the pre-set criteria. White core was expressed as the percentage of the number of pixels as white core area over the number of pixels in total kernel projected area.

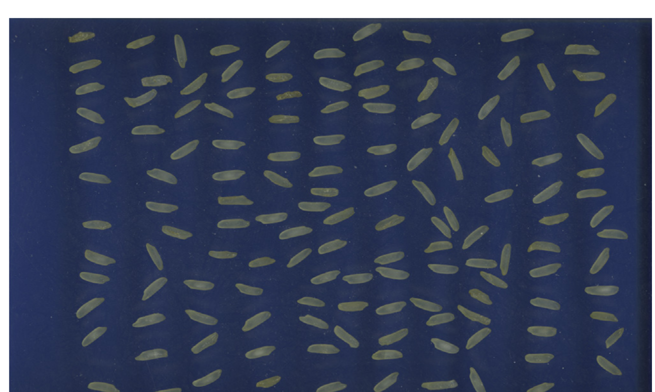

Fig. 1. The scanned image of parboiled rice kernels by using Winseedle for determining the percentage of white core.

2.6. Deformed kernels

Parboiled rice kernels were visually inspected from 50 g of head parboiled rice. Parboiled rice kernels with an abnormal shape were considered as deformed kernels, which were then collected and weighed. Deformed kernels was expressed as percentage of the mass of deformed kernels over the mass of parboiled rice sample. Deformed kernels are considered as defects and need to be removed, thus resulting in reduced yields.

2.7. Pasting properties

Parboiled head rice kernels were ground into flour using a UDY cyclone sample mill (UDY Corp., Ft. Collins, CO) fitted with a 0.50-mm sieve. The pasting properties of parboiled rice flour were characterized using a Rapid ViscoAnalyser (Newport Scientific Pty. Ltd, Warriewood, NSW, Australia). Rice slurry was prepared by mixing 3.0 g of parboiled rice flour (12% moisture basis) with 25.0 mL of water, heated from 50 °C to 95 °C at 4 °C/min, held at 95 °C for 5 min, cooled to 50 °C at 4 °C/min and then held at 50 °C for 2 min. Data were collected using RVA software – Thermocline for Windows.

2.8. Statistical analysis

This experiment was performed using a full factorial design (3 × 3 × 3) with three main factors (T_o difference, soaking temperature, and steaming duration) and three levels in each factor. Experimental data were conducted in triplicate and analyzed with JMP 12.0.0 (SAS Software Institute, Cary, NC). Analysis of variance (ANOVA) with a significant level at 0.05 was used to determine the effects of T_o difference, soaking temperature, steaming duration, and their interactions on the quality characteristics of parboiled rice. Mean differences were evaluated by using Tukey's HSD test.

3. Results and discussions

3.1. Head rice yield

HRY was comparable among most samples (Table 1). The effect of soaking temperature and steaming duration varied among commingled samples with L/L affected by both, L/H affected only by soaking temperature, and H/H not affected. The effect of steaming duration was only observed in L/L at the soaking temperature of 75 °C.

The preceding study that investigated the impact of soaking temperature alone on rice properties reported an increase in head brown rice yield of commingled rice with increasing soaking temperature (Leethanapanich et al., 2016). The maximum head brown rice yield of T/CLXL (i.e. L/L), CL/XL (i.e. H/H), and T/XL (i.e. L/H) was obtained when the soaking temperature was 75 °C. Similar results, particularly among L/L and L/H samples, were observed in the present study. It is hypothesized that higher soaking temperatures accelerated hydration rates as well as reduced chalkiness and fissures as a result of concurrently swelling and rearrangement of starch granules and protein denaturation. The decrease in chalkiness and fissures may increase kernel resistance to breakage during milling. It is worth noting that the soaking temperature of 75 °C, which was above the T_o of low T_o cultivars, resulted in the greatest HRY for both L/L and L/H, which was different from the findings obtained from single rice cultivars, in which soaking temperatures below, but close to, T_o yielded the greatest head brown rice yield (Leethanapanich et al., 2016). It is hypothesized that annealing from soaking, which caused a reduction in gelatinization temperature range and an increase in T_o, may allow for soaking temperature for commingled rice to be slightly above their T_o.

There was little difference in terms of steaming duration on HRY in all commingled rice, except that the HRY of L/L declined with increasing steaming duration at the soaking temperature of 75 °C, which presumably was too severe for L/L. The high soaking temperature of 75 °C was above the T_o of L/L, and thus some starch may already swell and gelatinize during the soaking step. Therefore, when soaking at 75 °C was combined with a steaming duration of 20 min for L/L, starchy endosperm may be disrupted, causing hull splitting and reduced HRY. In addition, the leached starch from excessive swelling may adhere to the hull, causing the separation of hull from the endosperm difficult and more likely to break during dehulling. Steaming was reported to increase the hardness of the rice kernels after parboiling as a result of starch gelatinization, thus increasing the HRY (Soponronnarit et al., 2005). This study shows that soaking temperature may play a more dominant role in affecting HRY than did steaming duration, particularly for commingled rice with lower T_o, and therefore attention should be paid to selecting an appropriate soaking temperature according to the T_o of the rice cultivar.

3.2. Color

In general, L^* values decreased and b^* values increased with increasing soaking temperature and steaming duration; however, the response to soaking temperature and steaming duration varied among commingled rice (Table 1). For L/L, yellowness (b^*) increased at 70 °C of soaking or steaming duration increased from 10 to 15 min; whiteness (L^*) was not affected by soaking temperature but it decreased after steaming for 15 min at 65 and 70 °C, and for 20 min at 75 °C. For L/H, the changes in yellowness as affected by soaking temperature were only observed when soaking temperature increased from 65 to 70 °C at steaming duration of 10 min; whiteness decreased with increasing soaking temperature and increasing steaming duration from 10 to 20 min, but no effect of steaming duration was observed at soaking temperature of 75 °C. For H/H, whiteness decreased after soaking at 75 °C and yellowness increased after soaking at 70 °C.

The change in color after parboiling has been reported (Ali and Bhattacharya, 1980; Lamberts et al., 2006, 2008). Lamberts et al. (2006) suggested that an increase in yellowness and a decrease in whiteness of the rice after soaking were resulted from the pigment migration from the bran to the endosperm during soaking. In contrast, Maillard reaction played a major role in color changes during steaming, and the intensity of the changes increased with severity of steaming. It is possible that greater soaking temperatures increased the amount of dissolved pigments, rate of pigment migration and water diffusion; whereas longer steaming durations facilitated higher rates of Maillard reaction and pigment migration. However, the present results further suggest that differences in color of parboiled commingled rice may be primarily attributed to variation in kernel and chemical compositions of individual rice cultivars as shown from the greater increase in yellowness with increasing soaking temperature in H/H compared with L/L. Oli et al. (2016) also observed the variety effect on color change during soaking. Therefore, commingling of rice cultivars with different susceptibility to temperature may result in color disparity after parboiling.

3.3. White core

The occurrence of white core indicates incomplete starch gelatinization during parboiling, which can be either from insufficient soaking that leads to uneven moisture distribution inside the

Table 1
Milling and physical qualities of parboiled commingled rice as affected by commingling, soaking temperature, and steaming duration[1]

Sample	Soaking temperature (°C)	Steaming duration (min)	HRY (%)	Whiteness (L^*)	Yellowness (b^*)	White core (%)	Deformed kernels (%)
L/L	65	10	$71.2^{b,A}$	$60.1^{a,A}$	$23.3^{b,B}$	$4.6^{a,A}$	$1.5^{a,C}$
		15	$70.5^{a,A}$	$57.3^{a,B}$	$24.6^{b,A}$	$2.6^{a,B}$	$3.4^{b,B}$
		20	$70.2^{b,A}$	$55.9^{a,B}$	$24.7^{b,A}$	$0.0^{a,C}$	$6.1^{c,A}$
	70	10	$70.4^{c,A}$	$59.6^{a,A}$	$23.9^{ab,B}$	$3.9^{b,A}$	$1.3^{a,C}$
		15	$70.4^{a,A}$	$57.7^{a,B}$	$25.8^{a,A}$	$2.1^{a,B}$	$6.8^{a,B}$
		20	$71.1^{a,A}$	$56.3^{a,B}$	$25.9^{a,A}$	$0.0^{a,C}$	$13.8^{b,A}$
	75	10	$72.2^{a,A}$	$58.2^{a,A}$	$24.1^{a,B}$	$3.9^{b,A}$	$0.9^{a,C}$
		15	$71.5^{a,AB}$	$56.5^{a, AB}$	$25.3^{ab,A}$	$0.0^{b,B}$	$6.7^{a,B}$
		20	$70.3^{b,B}$	$55.4^{a,B}$	$25.9^{a,A}$	$0.0^{a,B}$	$18.9^{a,A}$
H/H	65	10	$70.2^{a,A}$	$59.3^{a,A}$	$23.7^{b,B}$	$5.7^{a,A}$	$1.7^{a,B}$
		15	$70.2^{a,A}$	$57.1^{a,B}$	$24.5^{c, AB}$	$4.8^{a,A}$	$3.1^{a,A}$
		20	$71.3^{a,A}$	$55.9^{a,B}$	$25.6^{a,A}$	$1.1^{a,B}$	$3.7^{a,A}$
	70	10	$71.3^{a,A}$	$58.1^{a,A}$	$25.3^{a,B}$	$3.4^{b,A}$	$1.2^{a,B}$
		15	$70.7^{a,A}$	$56.1^{ab, AB}$	$25.6^{b,B}$	$1.5^{b,AB}$	$2.9^{a,A}$
		20	$69.5^{a,A}$	$54.9^{a,B}$	$26.7^{a,A}$	$1.0^{a,B}$	$3.4^{a,A}$
	75	10	$71.3^{a,A}$	$55.0^{b,A}$	$26.4^{a,A}$	$2.3^{b,A}$	$1.1^{a,B}$
		15	$71.3^{a,A}$	$53.3^{b,B}$	$26.8^{a,A}$	$0.8^{b,B}$	$2.5^{a,B}$
		20	$70.7^{a,A}$	$52.1^{b,B}$	$26.0^{a,A}$	$0.7^{a,B}$	$3.9^{a,A}$
L/H	65	10	$69.5^{b,A}$	$60.1^{a,A}$	$24.4^{b,C}$	$5.6^{a,A}$	$3.1^{a,B}$
		15	$68.4^{a,A}$	$59.0^{a, AB}$	$26.6^{a,B}$	$2.0^{a,B}$	$4.8^{b,B}$
		20	$69.3^{a,A}$	$58.4^{a,B}$	$27.2^{a,A}$	$1.7^{a,B}$	$9.9^{b,A}$
	70	10	$70.9^{ab,A}$	$60.1^{a,A}$	$25.5^{a,B}$	$3.2^{b,A}$	$4.9^{a,B}$
		15	$68.8^{a,A}$	$56.7^{b,B}$	$26.4^{a, AB}$	$0.3^{b,B}$	$5.5^{b,B}$
		20	$70.0^{a,A}$	$56.4^{b,B}$	$27.4^{a,A}$	$0.4^{b,B}$	$11.3^{b,A}$
	75	10	$71.4^{a,A}$	$54.2^{b,A}$	$26.0^{a,B}$	$1.8^{c,A}$	$3.8^{a,B}$
		15	$70.8^{a,A}$	$54.0^{c,A}$	$26.2^{a,B}$	$0.8^{b,AB}$	$14.8^{a,A}$
		20	$70.9^{a,A}$	$53.4^{c,A}$	$27.2^{a,A}$	$0.4^{b,B}$	$15.6^{a,A}$
HSD[2]			2.9	2.6	1.2	1.5	5.5

[1] Mean values in a column followed by the same letter in each sample are not significantly different based on Tukey's HSD test; small and capital letters compared values at different soaking temperatures and different steaming durations, respectively.
[2] Mean differences greater than the HSD suggest significant differences among those two means.

kernels or from inadequate steaming duration (Buggenhout et al., 2014). For all commingled samples, white core diminished with higher soaking temperatures and longer steaming durations, but steaming duration clearly played a major role in reducing white

Table 2
Pasting viscosity of parboiled commingled rice as affected by commingling, soaking temperature, and steaming duration[1].

Sample	Soaking temperature (°C)	Steaming duration (min)	Peak viscosity (cP)	Final viscosity (cP)	Setback viscosity (cP)
L/L	65	10	$1426^{a,A}$	$2268^{a,A}$	$840^{a,A}$
		15	$1309^{a,B}$	$1839^{a,B}$	$531^{a,B}$
		20	$956^{a,C}$	$1301^{b,C}$	$345^{b,C}$
	70	10	$1429^{a,A}$	$2250^{a,A}$	$821^{a,A}$
		15	$1161^{b,B}$	$1720^{b,B}$	$559^{a,B}$
		20	$937^{b,C}$	$1327^{ab,C}$	$390^{a,C}$
	75	10	$1287^{b,A}$	$2055^{b,A}$	$768^{a,A}$
		15	$1149^{b,B}$	$1651^{c,B}$	$502^{a,B}$
		20	$891^{b,C}$	$1214^{a,C}$	$323^{b,B}$
H/H	65	10	$1297^{a,A}$	$1844^{a,A}$	$547^{a,A}$
		15	$1227^{a,B}$	$1750^{a,B}$	$523^{a,A}$
		20	$1083^{a,C}$	$1430^{b,C}$	$430^{a,B}$
	70	10	$1185^{b,A}$	$1804^{b,A}$	$620^{a,A}$
		15	$1154^{b,AB}$	$1706^{b,B}$	$552^{a,A}$
		20	$1000^{b,B}$	$1477^{a,C}$	$395^{b,B}$
	75	10	$1193^{b,B}$	$1759^{c,A}$	$567^{a,A}$
		15	$1220^{a,A}$	$1599^{b,A}$	$379^{b,B}$
		20	$919^{c,C}$	$1281^{c,B}$	$362^{c,C}$
L/H	65	10	$1244^{a,A}$	$1891^{a,A}$	$648^{a,A}$
		15	$1145^{a,B}$	$1491^{a,C}$	$347^{a,C}$
		20	$1190^{a,B}$	$1617^{a,B}$	$427^{a,B}$
	70	10	$1235^{a,A}$	$1728^{b,A}$	$494^{b,A}$
		15	$1162^{a,A}$	$1520^{a,B}$	$358^{a,B}$
		20	$1024^{b,B}$	$1354^{b,C}$	$331^{b,B}$
	75	10	$992^{b,A}$	$1532^{c,A}$	$540^{ab,A}$
		15	$938^{b,B}$	$1303^{b,B}$	$365^{a,B}$
		20	$894^{c,C}$	$1228^{c,C}$	$334^{b,B}$
HSD[2]			84	78	111

[1] Mean values in a column followed by the same letter in each sample are not significantly different based on Tukey's HSD test; small and capital letters compared values at different soaking temperatures and different steaming durations, respectively.
[2] Mean differences greater than the HSD suggest significant differences among those two means.

core. White core was lower in L/L and L/H than in H/H at 65 °C of soaking and 15 min of steaming, presumably because the lower T_o cultivars would require a shorter steaming duration to fully gelatinize starch (Table 1).

3.4. Deformed kernels

Deformed kernels were formed as a result of husk splitting during soaking and/or steaming. Soaking temperature and steaming duration had different impacts on deformed kernels in commingled rice (Table 1). H/H showed significantly lower percentages of deformed kernels when soaked at 70 or 75 °C and steamed for 20 min compared with L/H and L/L because of their higher T_o. There was no significant difference in deformed kernels in H/H among all soaking temperatures for the same steaming duration, whereas a significant increase in deformed kernels was observed in L/L and L/H, particularly after soaking at 75 °C, because of their lower T_o cultivars.

Deformed kernels increased with longer steaming duration. For H/H, at lower soaking temperatures like 65 and 70 °C, the effect of steaming duration was pronounced at 15 and 20 min but at 75 °C, the effect was observed for 20 min steaming. This might be due to the effect of annealing during soaking at higher temperature like 75 °C, which caused an increase in T_o; therefore, longer steaming duration would be required to cause deformed kernels. The deformed kernels increased in L/H when rice was soaked at 65 or 70 °C and steamed for 20 min as well as when rice was soaked at 75 °C and steamed for 15 min and 20 min. This implies that steaming duration had more impacts on deformed kernels when soaking temperature was below T_o; whereas deformed kernels were affected by both soaking temperature and steaming duration when soaking temperature was higher than T_o. As the soaking temperature and steaming duration increased, the white core decreased but the deformed kernels increased. This inverse relationship highlights the importance of identifying parboiling conditions to simultaneously achieve minimum deformed kernels and white core.

3.5. Pasting properties

A decrease in peak, final, and setback viscosity was observed after parboiling for all commingled rice (Table 2 & Fig. 2). The effect of soaking temperature on the peak viscosity differed from the results in the preceding study (Leethanapanich et al., 2016). The preceding study investigated the soaking temperature effect alone and reported lowered peak viscosities when commingled rice samples containing low T_o cultivars were soaked at 75 °C. However, the present study showed that L/H soaked at 75 °C and steamed for 10 min had lower peak viscosity than L/L under the same condition, indicating that steaming exerted more significant impacts on pasting viscosities, particularly on peak viscosity, likely through starch-protein interaction. At 20 min of steaming, peak viscosity of all commingled samples decreased with increasing soaking temperature. However, at 10 and 15 min of steaming, the change in peak viscosity with increasing soaking temperature varied. For example, at 15 min of steaming, the peak viscosity of L/L and H/H decreased when soaked at 70 °C, whereas that of L/H decreased when soaked at 75 °C. These results show that the trend of soaking was not followed when steaming was combined, and more reactions were involved in the steaming step of parboiling.

The peak viscosity of L/L was slightly higher than those of H/H and L/H at the same parboiling condition, possibly because of their lower lipid and protein contents after milling. The decreased peak viscosity of parboiled rice was reported to be the interaction of protein and starch that restricts the starch swelling (Derycke et al., 2005; Newton et al., 2011). Lipid that is concentrated in the bran layer also restricted starch swelling through inclusion complexation (Gray and Schoch, 1962). The bran layer of individual cultivar in L/L may be thinner than others; therefore, at the same milling duration, the greater amount of lipid and protein may be removed.

The reduction in setback and final viscosities after parboiling for all samples indicates less disruption of starch granules and a small amount of leached amylose during cooking of parboiled rice because of restricted swelling from interaction between starch and protein or lipid (Gray and Schoch, 1962; Derycke et al., 2005; Newton et al., 2011). The extent of reduction in final and setback viscosities varied among commingled rice. H/H exhibited a smaller reduction in final and setback viscosities from 10 to 20 min for all soaking temperatures, whereas L/L and L/H showed a greater reduction, suggesting that under the same parboiling condition, starch in H/H was less disrupted than those in L/L and L/H because H/H had higher T_o.

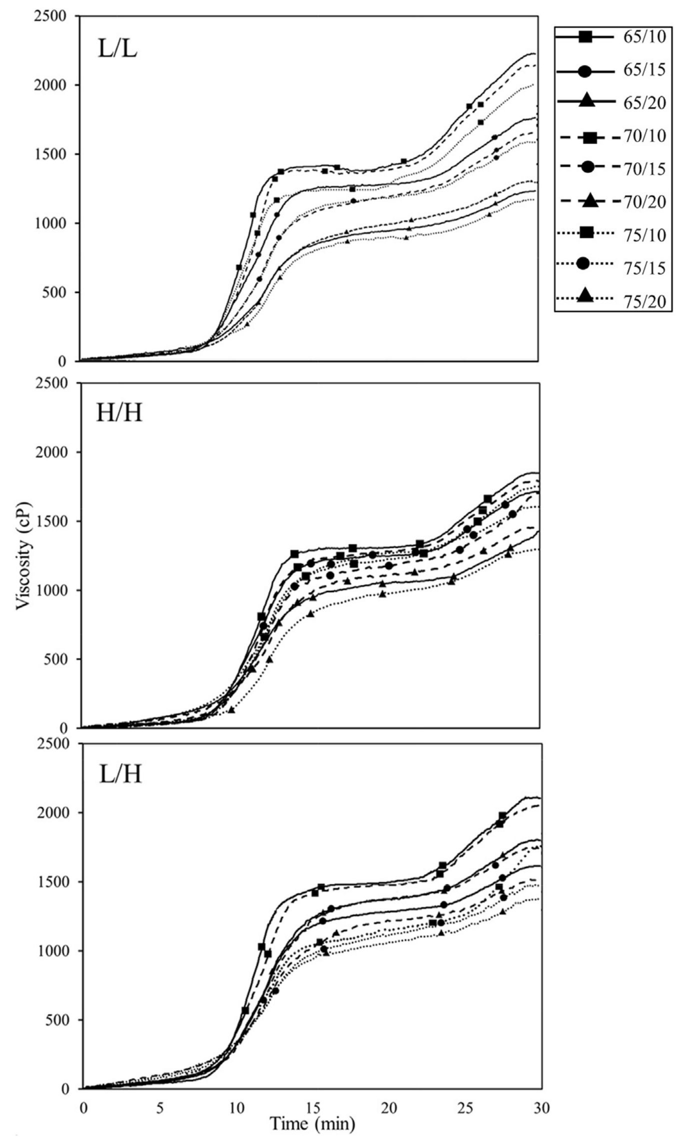

Fig. 2. Pasting profiles of parboiled commingled rice as affected by commingling, soaking temperature, and steaming duration [soaking temperature (°C)/steaming duration (min)].

3.6. Relative importance of factors

Commingling, soaking temperature, steaming duration, and their interactions all had impacts on parboiled commingled rice properties, but their impacts varied with properties. In Table 3, sum of square indicates how much each factor affected the quality characteristics of parboiled rice. HRY was strongly affected by soaking temperature, followed by commingling and steaming duration, but not affected by their interactions. Steaming duration was the most influential factor affecting white core, deformed kernels and pasting viscosities. Leethanapanich et al. (2016) reported that T_o difference from commingling had more impact on head brown rice yield than soaking temperature when rice was soaked only without the steaming step. However, in the present study, soaking temperature had more influence on HRY than commingling. It is possible that soaking alone increased the resistance to breakage of individual cultivars, but the extent of the soaking temperature effect varied with cultivars. Nevertheless, the commingling effect on HRY diminished when soaking was combined with steaming because starch gelatinization occurring in the steaming step hardened the rice kernels and might reduce the difference in breakage susceptibility among cultivars. This implies that soaking at high temperatures followed by steaming could reduce the difference in breakage susceptibility of commingled rice.

Besides HRY, the presence of white core and deformed kernels are also important to the quality of parboiled rice because they are removed after parboiling, thus lowering the final HRY. Therefore, prediction profiler was prepared by considering HRY, white core, and deformed kernel, and the desirability scores from 0 to 1 were set for each quality characteristics. The best parboiling conditions would result in maximum HRY and minimum white core and deformed kernels, and an example is depicted in Fig. 3. The

Table 3
Analysis of variance (ANOVA) of parboiled commingled rice quality as affected by commingling, soaking temperature, steaming duration, and their interactions.

Quality characteristics	Sum of squares						
	Commingling (C)	Soaking temperature (T)	Steaming duration (t)	C × T	C × t	T × t	C × T × t
HRY	12 (*)[1]	17 (***)	7 (*)	6 (NS)	3 (NS)	4 (NS)	11(NS)
Whiteness (L^*)	40 (***)	175 (***)	116 (***)	42 (***)	5 (***)	5 (NS)	7 (NS)
Yellowness (b^*)	30 (***)	17 (***)	34 (***)	5 (***)	4 (***)	3 (**)	6 (***)
White core	5 (***)	52 (***)	147 (***)	8 (***)	10 (***)	13 (***)	14 (***)
Deformed kernels	459 (***)	151 (***)	737 (***)	120 (***)	227 (***)	96 (***)	147 (***)
Peak viscosity	119869 (***)	239877 (***)	880219 (***)	124357 (***)	225838 (***)	15582 (**)	138241 (***)
Final viscosity	740791 (***)	478569 (***)	3779681 (***)	113453 (***)	893664 (***)	10751 (**)	163086 (***)
Setback viscosity	266506 (***)	41197 (***)	1084359 (***)	38694 (***)	237502 (***)	11469 (NS)	49104 (***)

[1] Sum of squares (P-value), the levels of statistical significance of the mean values are *≤0.05, **≤0.01,*** ≤0.001, and NS = not significant.

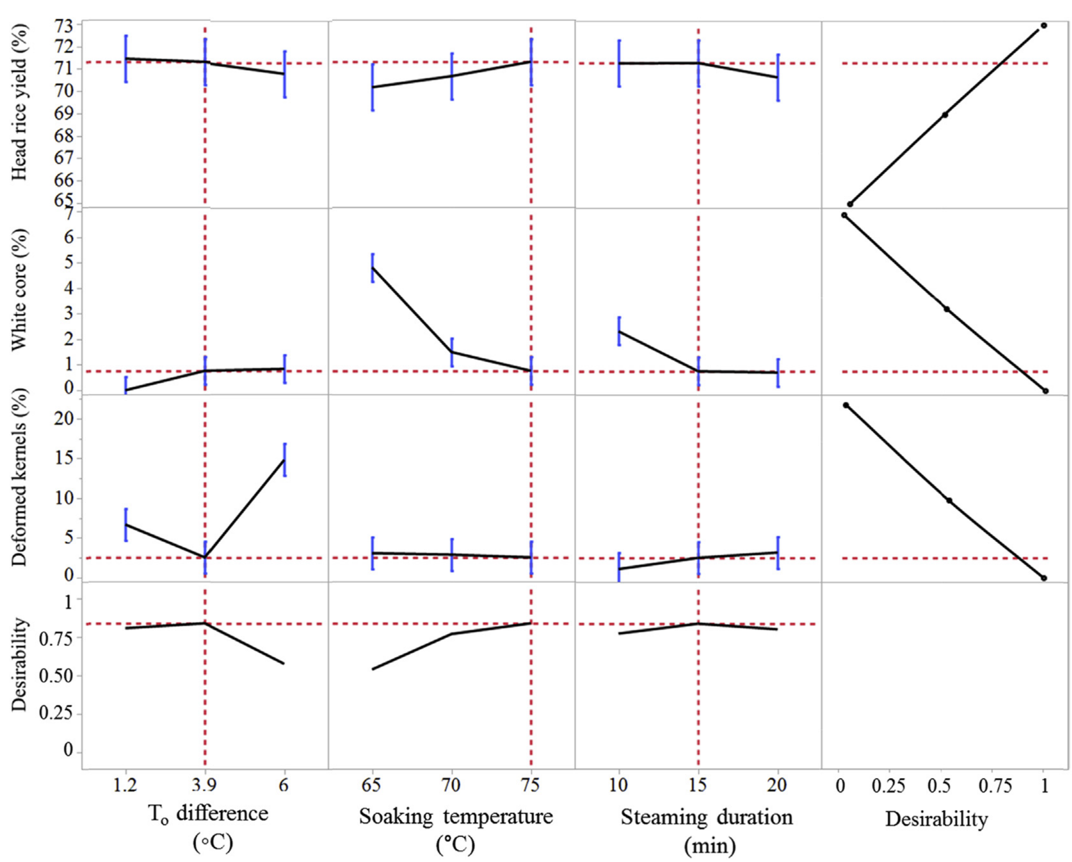

Fig. 3. Prediction profiler represents obtained values from each sample at different condition. This figure only show the results based on the condition that gave maximum desirability score (dash line) when the highest desirability score was set at maximum head rice yield and minimum white core and deformed kernels.

condition that would render the highest desirability score of 0.84 was from H/H when soaked at 75 °C for 3 h and steamed at 112 °C for 15 min, which resulted in 71.3% HRY, 0.8% white core, and 2.5% deformed kernels based on the present results. This result agrees with our previous study (Leethanapanich et al., 2016) that soaking temperatures close to but below T_o would give the highest HRY. The parboiling condition that would produce the highest score for L/L (0.81) was soaking at 75 °C for 3 h and steaming at 112 °C for 15 min to give 71.5% HRY, 0% white core and 6.7% deformed kernels. For L/H, soaking at 75 °C for 3 h and steaming at 112 °C for 10 min gave the highest desirability score (0.78) with 71.4% HRY, 1.8% white core, and 3.8% deformed kernels. At the given highest desirability score, the percentage of deformed kernels in L/L and the percentages of white core and deformed kernels in L/H were higher than those in H/H. Furthermore, it can be seen that the highest desirability score was obtained from H/H (T_o difference of 3.9 °C), followed by L/L (T_o difference of 1.2 °C) and then L/H (T_o difference of 6.0 °C), suggesting that although T_o difference is important in parboiling when using commingled rice, the T_o of commingles relative to the soaking temperature is also important. Therefore, the soaking temperature for commingled rice can be close to or even slightly above it T_o without affecting the resultant parboiled rice quality.

4. Conclusions

Commingling, soaking temperature, steaming duration, and their interactions were all important in parboiled commingled rice properties, but their impacts varied with properties. Commingled rice with a great T_o difference from individual cultivars tended to yield less desirable properties. When commingling of rice with low T_o, the commingled rice was more susceptible to high soaking temperatures and long steaming durations, and consequently exhibited a decrease in HRY, white core, and pasting viscosities but increased deformed kernels. Soaking at high temperatures followed by steaming could reduce the difference in breakage susceptibility of commingled rice. Commingling of rice could also resulted in parboiled rice with uneven color because color change was found to be more cultivar dependent. The T_o of commingles relative to the soaking temperature was important in optimizing the parboiled commingled rice properties.

Acknowledgments

This research was financially supported by the Royal Thai Government. Samples and research facilities were provided by the University of Arkansas Rice Processing Program.

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