Journal of Cereal Science 69 (2016) 267–274

Contents lists available at ScienceDirect

Journal of Cereal Science

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

Effect of soaking temperature on commingled rice properties

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ARTICLE INFO

Article history:
Received 21 December 2015
Received in revised form
4 April 2016
Accepted 6 April 2016
Available online 7 April 2016

Keywords:
Commingled rice
Soaking temperature
Chalkiness
Head brown rice yield

ABSTRACT

Parboiling involves soaking, steaming, and drying, and soaking is important in achieving desired parboiled rice properties. This study investigated the effects of soaking temperature and commingling on rice properties prior to steaming. Rough rice of four cultivars (Taggart, CL151, XL753, and CL XL745) and their combinations at 1:1 wt ratio were soaked at 65, 70 or 75 °C for 3 h, and dried. Both soaking temperature and difference in onset gelatinization temperature (T_o) of individual cultivars in commingled rice affected milling and physicochemical properties. The head brown rice yield was greater when the soaking temperature was below but close to the T_o for individual rice cultivars, but became difficult to predict for commingled rice. Commingled rice consisting of high T_o rice cultivars required higher soaking temperatures to reduce chalkiness during soaking. The color attributes of commingled rice was predominately affected by the cultivar that exhibited the most change. The gelatinization properties were governed by the low-T_o cultivar, whereas the pasting properties were more influenced by the high-T_o cultivar for the commingled rice. Therefore, using commingled rice with a wide range of gelatinization temperature as a feedstock may lead to inconsistent quality of parboiled rice.

1. Introduction

Parboiled rice has been used in many applications such as canned rice, instant rice, ready-to-eat meals, and puffed cereals because of its ease of cooking and improved heat stability. Parboiling is a hydrothermal process involving soaking, steaming, and drying steps. Rough rice or brown rice is first soaked in excess water to become hydrated to allow starch gelatinization in the following steaming step. Drying is followed to dehydrate the rice kernels to approximately 12% moisture content (MC) for safe storage and good milling quality. The changes in rice properties after parboiling such as milling, physicochemical, cooking, and eating qualities are primarily attributed to the changes in starch as a result of gelatinization and retrogradation, although minor compositions like proteins and lipids also have influences on parboiled rice properties (Bhattacharya, 2004).

Soaking is an important step in the parboiling process. Rough rice is required to absorb water and reach equilibrium moisture content of approximately 30% for proper hydration (Gariboldi, 1974). The amount of absorbed water is dependent on soaking temperature and soaking duration. Bakshi and Singh (1980) reported that soaking at high temperatures increased diffusion coefficients, which leads to an increase in hydration as well as a reduction in soaking duration, thus preventing enzymatic reaction and microbial fermentation that could cause discoloration and off-flavor in parboiled rice. Bhattacharya and Subba Rao (1966) suggested that maximum milling yields and minimum breakages were obtained if rice kernels absorbed sufficient water during the soaking step. Chung et al. (1990) found an increase in head rice yield of parboiled rice with increasing soaking temperature of 50, 60, or 70 °C for 5, 4, or 3.5 h, respectively. Sareepuang et al. (2008) also observed the same trend when soaking rice at 40, 50, or 60 °C for 3 h.

Recently, the development of rice breeding program causes a drastic increase in the number of rice cultivars in the U.S., particularly hybrid cultivars. Studies have shown differences in milling characteristics between hybrid and pureline cultivars. Siebenmorgen et al. (2006) found that for the same milling duration, hybrids (XL7 and XL8) were milled to lower surface lipid contents than pureline cultivars (Cocodrie, Cypress, and Lemont), which was proposed to be due to a thinner bran layer in hybrid cultivars. Lanning and Siebenmorgen (2011) noted differences in

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Abbreviations: T_o, onset gelatinization temperature; T_p, peak gelatinization temperature; T_c, conclusion gelatinization temperature; ΔH, enthalpy; MC, moisture content; RH, relative humidity; HBRY, head brown rice yield.

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http://dx.doi.org/10.1016/j.jcs.2016.04.002
0733-5210/

milling characteristics between two pureline cultivars (Wells and Francis) and four hybrid cultivars (XL723, CL XL729, CL XL730, and CL XL745). Siebenmorgan et al. (2012) showed that hybrid cultivars required shorter milling durations than pureline cultivars to obtain the same degree of milling.

Basutkar et al. (2014) studied the effects of commingling (pureline/pureline, pureline/hybrid, and hybrid/hybrid) on milling properties of long-grain rice cultivars by mixing the rice cultivars into varying ratios (0:100, 10:90, 25:75, 50:50, 75:25, 90:10, and 100:0). They found that the milling duration to reach the same degree of milling (0.4% surface lipid content) for each commingled sample varied with the ratio of individual cultivar in a commingled sample. The whiteness and yellowness of milled rice were not significantly affected by commingling. Commingling, however, had an influence on the milled rice yield, head rice yield, and chalkiness, which could be predicted by calculating the weight average of the individual cultivar for each property. Basutkar et al. (2015) suggested that commingling of rice may cause inconsistent quality of products especially when there was a great difference in onset gelatinization temperature (T_o) of the rice cultivars in commingles. The T_o of commingled rice was governed by the rice cultivar with the lower T_o. The pasting viscosities of commingled rice changed proportionally according to the mass percentage of each cultivar in commingles.

It was hypothesized that using commingled rice with different T_o as a feedstock for parboiling may cause inconsistent quality of parboiled rice. Because soaking is the first step of parboiling where rice is subjected to heat, this study aimed at investigating the impacts of varying soaking temperatures on the milling and physiochemical properties of commingled rice.

2. Materials and methods

2.1. Materials

Rough rice of long-grain pureline (Taggart and CL151) and hybrid (CL XL745 and XL753) cultivars from the 2012 crop year were used in this study and obtained from the University of Arkansas Rice Processing Program (Fayetteville, AR). These cultivars were selected because they had the least and the greatest T_o among pureline and hybrid cultivars available from the 2012 crop year, as measured by a differential scanning calorimeter, of 72.1, 74.2, 73.3, and 78.1 °C for Taggart (T), CL151 (CL), CL XL745 (CLXL), and XL753 (XL), respectively. Six possible combinations of commingled rice samples were prepared using a 1:1 ratio based on rough rice weight (approximately at 12.5% MC). The rough rice was accurately weighed and mixed 5 times, 2 min each time, using a rotary rice grader (TRG, Satake, Tokyo, Japan). The 1:1 ratio of the individual rice cultivars was selected to prepare the comingled rice because it represents the most extreme situation that could result in the most impacts on rice properties when the two rice cultivars with the most difference in T_o according to Basutkar et al. (2014), in which the commingled rice properties such as peak viscosity increased or decreased proportionally according to the ratio of individual rice cultivars in commingles.

2.2. Soaking conditions

Soaking temperatures were chosen at 3–5 °C below T_o of individual and commingled rice samples. Rough rice (100 g) was soaked in 250 mL of deionized water in a water bath at 65°, 70°, or 75 °C for 3 h in order to reach a minimum 30% MC. The soaked rice was then dried at room temperature overnight and afterwards at an equilibrium moisture content (EMC) chamber at 26 °C and 65% RH for 2 days to reach ~12% MC.

2.3. Head brown rice yield

Dried rough rice was dehulled using a Satake THU-35 dehusker (THU-35, Satake Corp., Hiroshima, Japan). The broken brown rice kernels were separated by a double-tray sizing device (Seedburo Equipment Co., Chicago, IL). Head brown rice yield was expressed as a percentage of head brown rice mass to dried rough rice mass.

2.4. Physical properties

The color attributes of whiteness (L^*) and yellowness (b^*) of rice before and after soaking were 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 (Iluminat D65 10° Observer, $x = 79.88$, $y = 84.72$, $z = 89.47$) with a 31.8-mm aperture. Approximately 30 g of head brown rice was filled in a clear, flat-bottom dish and placed at the center of the sample port for the measurement. The cup was rotated 180° for the second reading.

The chalkiness was measured by an image analysis system (Winseedle™ Pro 2005a Regent Instruments Inc., Sainte-Foy, Quebec, Canada). Several chalky and translucent kernels were scanned and used as references for the system to classify the chalk and translucent area based on number of pixels. To determine the chalkiness, one hundred random rice kernels were placed in a tray made from a 2-mm thick clear acrylic sheet (Plexiglass) with no kernel touching another, and then imaged with a scanner (Epson Perfection V700 Photo, Model# J221A, Seiko Epson Corp., Japan). The system measured the number of pixels and classify them according to the pre-set criteria. Chalkiness was expressed as percentage of the number of pixels in chalky area over the number of pixels in total kernel projected area.

2.5. Gelatinization properties

Brown rice was ground into flour using a UDY cyclone sample mill (UDY Corp., Ft. Collins, CO) fitted with a 0.50-mm sieve. The gelatinization properties of rice samples were determined using a differential scanning calorimeter (DSC, Diamond, Perkin-Elmer Co., Norwalk, CT). Approximately 4 mg of brown rice flour was measured into an aluminum sample pan and added with 8 μL of deionized water. The sample pans were then sealed and kept at room temperature for 1 h prior to scanning from 25 °C to 120 °C at 10.0 °C/min. Onset (T_o), peak (T_p), and conclusion (T_c) temperature as well as gelatinization enthalpy (ΔH) were determined.

2.6. Pasting properties

The pasting properties of brown 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 rice flour (12% moisture basis) with 25.0 mL of water, and heated from 50 °C to 95 °C at 4 °C/min, held at 95 °C for 5 min, and then cooled to 50 °C at 4 °C/min and held at 50 °C for 2 min. Data were collected using the RVA software – Thermocline for Windows.

2.7. Statistical analysis

Experiments were conducted in triplicate. The differences in mean values of each rice properties among samples were evaluated using one-way ANOVA with Tukey's HSD. The effects of soaking temperatures and T_o difference including their interactions and relative importance of both factors were examined using two-way ANOVA. All statistical analyses were carried out at $\alpha = 0.05$ using JMP software version 12.0.0 (SAS Software Institute, Cary, NC) using at $\alpha = 0.05$.

3. Results and discussion

3.1. Physical properties

3.1.1. Head brown rice yield

The effects of soaking temperature on head brown rice yield (HBRY) varied with cultivars and commingles (Table 1). In the present study, HBRY, instead of head milled rice yield, was used to represent the milling yield of rice after soaking in order to avoid the influence of chalky kernels that tend to break during milling. The rough rice that was not subjected to soaking was used as a control. The HBRY of all individual rice cultivars, except XL753 (XL), increased after soaking and with increasing soaking temperature, and the greatest HBRY was obtained when the soaking temperature was closer to but still below the T_o.

The increase in HBRY is proposed to result from a reduction of fissured kernels that may break during milling (Cnossen et al., 2003). Recently, Buggenhout et al. (2014) proposed that fissures initially developed and thereafter gradually disappeared over the course of soaking. The fissures were visually inspected, and kernels with at least one visible fissure were considered as fissured. They observed that during the initial period of soaking (5–15 min), fissures increased up to more than 90% based on brown rice mass, remained steady, and then decreased when MC reached a certain level. This MC level varied with soaking temperature, for example, 28% MC for 55 or 65 °C and 31% MC for 40 °C. A drastic reduction of fissures was observed when MC reached equilibrium at approximately 33%. They also suggested that higher soaking temperatures effected a greater extent of water absorption and starch swelling, leading to a greater fissure reduction, which is supported by the present results of increasing HBRY with increasing soaking temperature close to but not above T_o. The reduced HBRY obtained after soaking at above T_o may be ascribed to excessive swelling of starch after gelatinization, leading to husk splitting (Bhattacharya and Subba Rao, 1966).

Unlike other single cultivars, the HBRY of XL was significantly reduced at 65 °C (13 °C below T_o), but was only close to and not greater than that of its control even when soaked at 75 °C (3 °C below T_o). These results indicate the importance of soaking temperature relative to the T_o in terms of rice kernel moisture distribution and fissure reduction. The soaking temperature and moisture gradient between the kernel surface and the core play a key role in the rate of hydration and water diffusion of rice kernels (Engles et al., 1986). When soaked above the glass transition

Table 1
Head brown rice yield, (HBRY) chalkiness, whiteness, and yellowness of Taggart, CL151, CL XL745, XL753, and their commingles after soaking at 65, 70, or 75 °C for 3 h prior to drying to 12% MC, and their controls of no soaking.[1]

Cultivar/Commingles	Soaking temperature (°C)	HBRY (%)	Chalkiness (%)	Whiteness (L*)	Yellowness (b*)
Taggart (T)	control	87.2 ± 0.1^{c}	2.5 ± 0.1^{a}	59.6 ± 0.0^{a}	22.1 ± 0.2^{c}
(72.1 °C)[2]	65	90.8 ± 0.7^{b}	1.1 ± 0.2^{b}	59.8 ± 0.9^{a}	22.4 ± 0.9^{bc}
	70	92.6 ± 0.6^{a}	0.2 ± 0.1^{c}	58.7 ± 0.1^{a}	23.6 ± 0.1^{b}
	75	90.7 ± 0.4^{b}	0.1 ± 0.1^{c}	54.1 ± 0.0^{b}	25.0 ± 0.6^{a}
CL151 (CL)	control	95.5 ± 0.1^{c}	4.3 ± 0.1^{a}	60.2 ± 0.0^{a}	21.1 ± 0.1^{c}
(74.2 °C)	65	96.3 ± 0.4^{b}	1.9 ± 0.3^{b}	58.6 ± 0.5^{b}	21.3 ± 0.4^{c}
	70	97.4 ± 0.3^{a}	0.5 ± 0.1^{c}	56.3 ± 0.1^{c}	22.2 ± 0.6^{b}
	75	96.6 ± 0.4^{b}	0.0 ± 0.0^{c}	52.8 ± 0.1^{d}	23.4 ± 0.4^{a}
CL XL745 (CLXL)	control	93.4 ± 0.3^{c}	2.1 ± 0.1^{a}	57.9 ± 0.1^{a}	20.7 ± 0.4^{b}
(73.3 °C)	65	97.0 ± 0.9^{a}	0.4 ± 0.2^{b}	56.4 ± 0.0^{b}	21.9 ± 0.0^{a}
	70	96.6 ± 0.1^{a}	0.0 ± 0.0^{c}	53.1 ± 0.2^{c}	22.3 ± 0.7^{a}
	75	94.4 ± 0.7^{b}	0.0 ± 0.0^{c}	51.8 ± 0.8^{d}	22.5 ± 0.6^{a}
XL753 (XL)	control	92.6 ± 0.4^{a}	6.6 ± 0.1^{a}	62.7 ± 0.3^{a}	21.6 ± 0.2^{d}
(78.1 °C)	65	79.3 ± 0.8^{c}	6.8 ± 0.4^{a}	62.3 ± 0.0^{a}	22.3 ± 0.1^{c}
	70	88.5 ± 0.1^{b}	2.0 ± 0.5^{b}	59.8 ± 0.9^{b}	23.3 ± 0.1^{b}
	75	92.0 ± 0.2^{a}	0.5 ± 0.1^{c}	57.1 ± 0.8^{c}	25.2 ± 0.2^{a}
T/CL	control	91.4 ± 0.1^{b}	3.4 ± 0.1^{a}	59.9 ± 0.1^{a}	21.6 ± 0.1^{c}
(72.5 °C)	65	94.6 ± 0.1^{a}	1.6 ± 0.1^{b}	58.3 ± 0.1^{b}	21.9 ± 0.7^{c}
	70	94.7 ± 0.3^{a}	1.4 ± 0.3^{b}	58.9 ± 0.6^{ab}	23.0 ± 0.2^{b}
	75	94.4 ± 0.3^{a}	0.0 ± 0.0^{c}	54.1 ± 0.1^{c}	24.2 ± 0.0^{a}
T/CLXL	control	90.3 ± 0.1^{c}	2.3 ± 0.1^{a}	58.8 ± 0.1^{a}	21.4 ± 0.1^{c}
(72.3 °C)	65	93.6 ± 0.7^{b}	0.8 ± 0.0^{b}	57.8 ± 0.8^{b}	22.4 ± 0.1^{b}
	70	94.0 ± 0.6^{b}	0.2 ± 0.1^{c}	56.2 ± 0.2^{c}	23.0 ± 0.6^{a}
	75	95.4 ± 0.6^{a}	0.0 ± 0.0^{d}	52.7 ± 0.3^{d}	23.3 ± 0.1^{a}
T/XL	control	89.9 ± 0.2^{c}	4.4 ± 0.3^{a}	61.2 ± 0.0^{a}	21.9 ± 0.1^{c}
(72.8 °C)	65	88.7 ± 0.0^{d}	3.2 ± 0.2^{b}	60.6 ± 0.4^{ab}	22.4 ± 0.3^{bc}
	70	91.3 ± 0.5^{b}	2.0 ± 0.1^{c}	60.4 ± 0.4^{b}	23.3 ± 0.2^{ab}
	75	93.0 ± 0.6^{a}	0.1 ± 0.0^{d}	55.6 ± 0.5^{c}	24.2 ± 0.9^{a}
CL/CLXL	control	94.5 ± 0.4^{c}	3.2 ± 0.1^{a}	59.1 ± 0.1^{a}	20.9 ± 0.1^{c}
(73.3 °C)	65	97.2 ± 0.2^{a}	1.4 ± 0.2^{b}	56.9 ± 0.2^{b}	22.3 ± 0.0^{b}
	70	97.0 ± 0.2^{a}	0.7 ± 0.1^{c}	55.4 ± 0.9^{c}	22.2 ± 0.3^{b}
	75	96.5 ± 0.1^{b}	0.0 ± 0.0^{d}	53.5 ± 0.3^{d}	23.1 ± 0.3^{a}
CL/XL	control	94.1 ± 0.2^{a}	5.5 ± 0.0^{a}	61.5 ± 0.1^{a}	21.4 ± 0.1^{b}
(74.9 °C)	65	91.8 ± 0.6^{b}	2.7 ± 0.2^{b}	59.9 ± 0.4^{b}	21.7 ± 0.8^{b}
	70	94.7 ± 0.7^{a}	1.1 ± 0.2^{c}	57.6 ± 0.7^{c}	23.5 ± 0.0^{a}
	75	95.0 ± 0.3^{a}	1.0 ± 0.3^{c}	58.1 ± 0.2^{c}	23.4 ± 0.8^{a}
CLXL/XL	control	93.2 ± 0.3^{c}	4.4 ± 0.0^{a}	60.6 ± 0.4^{a}	21.2 ± 0.1^{c}
(74.7 °C)	65	92.3 ± 0.5^{c}	3.4 ± 0.6^{b}	61.0 ± 0.8^{a}	22.1 ± 0.5^{b}
	70	94.5 ± 0.4^{b}	1.9 ± 0.2^{c}	59.0 ± 0.5^{b}	23.1 ± 0.7^{a}
	75	95.8 ± 0.5^{a}	0.0 ± 0.0^{d}	54.4 ± 0.2^{c}	23.8 ± 0.4^{a}
HSD		1.2	0.7	1.3	1.1

[1] Mean values ± SD followed by the same letter in the same column within the same sample are not significantly different based on Tukey's HSD test.
[2] Onset gelatinization temperature measured by differential scanning calorimetry.

temperature but below T_o, the starch granule changes from a glassy state to a rubbery state, leading to an increase in specific water diffusivity. With increasing soaking temperature, still at below T_o, the hydration rate slowly increases before reaching moisture equilibrium, whereas at above T_o, it exponentially increases (Bhattacharya and Subba Rao, 1966). Therefore, it is hypothesized that the greater difference between the soaking temperature (at 65 and 70 °C) and T_o of XL (78 °C) resulted in a slower rate of water absorption and subsequently fissure healing, and thus XL may need a longer soaking duration or a higher soaking temperature in order to reach moisture equilibrium throughout the kernel to make the fissures disappear. When the difference between the soaking temperature and the T_o of XL decreased, the rate of fissure healing increased.

Most commingled rice samples showed an increase in HBRY with increasing soaking temperatures, except that T/CL had a similar HBRY at 65, 70, and 75 °C, and CL/CLXL had a slightly lower HBRY at 75 °C than at 70 °C. Moreover, the HBRY characteristic of individual rice cultivars can be observed in the commingles, for example, the decreased HBRY at soaking temperature of 65 °C was also found in commingled rice containing XL.

The difference in T_o between the two rice cultivars in commingled rice samples was 2.1, 1.2, 6.0, 0.9, 3.9, and 4.8 °C for T/CL, T/CLXL, T/XL, CL/CLXL, CL/XL, and CLXL/XL, respectively. They can be divided into two groups according to T_o difference: 1) T/CL, T/CLXL, and CL/CLXL with 1–2 °C difference, and 2) T/XL, XLCL, and XL/CLXL with 4–6 °C difference. When the differences in HBRY between the measured values and the calculated value based on weighted average were plotted against the different soaking temperatures (Fig. 1A), the group with a smaller T_o difference better predicted HBRY. Therefore, using commingled rice with large T_o difference would be more difficult to predict and manage to achieve the targeted properties.

3.1.2. Chalkiness

Chalkiness varied among cultivars with XL showing the highest chalkiness. Chalkiness decreased with an increase in soaking temperature, and was almost completely eliminated in individual rice cultivars when soaked at 75 °C for 3 h (Table 2). The chalkiness of T, CL, and CLXL was reduced by 50–80% after soaking at 65 °C for 3 h, but that of XL did not change until 70 °C. These results show that soaking at temperatures close to or above T_o were more effective in removing chalkiness. The change in chalkiness of commingled rice followed a similar trend as the individual cultivars. Commingled rice consisting of high T_o rice cultivars, such as CL and XL, required higher soaking temperatures to reduce chalkiness, and soaking at 75 °C almost completely removed all chalkiness. The change in chalkiness of commingled rice samples was more accurately predicted by using weighted average chalkiness than HBRY (Fig. 1B).

Raghavendra Rao and Juliano (1970) proposed that the decrease in chalkiness after parboiling was caused by gelatinization of starch and disruption of protein bodies from the steaming step. However,

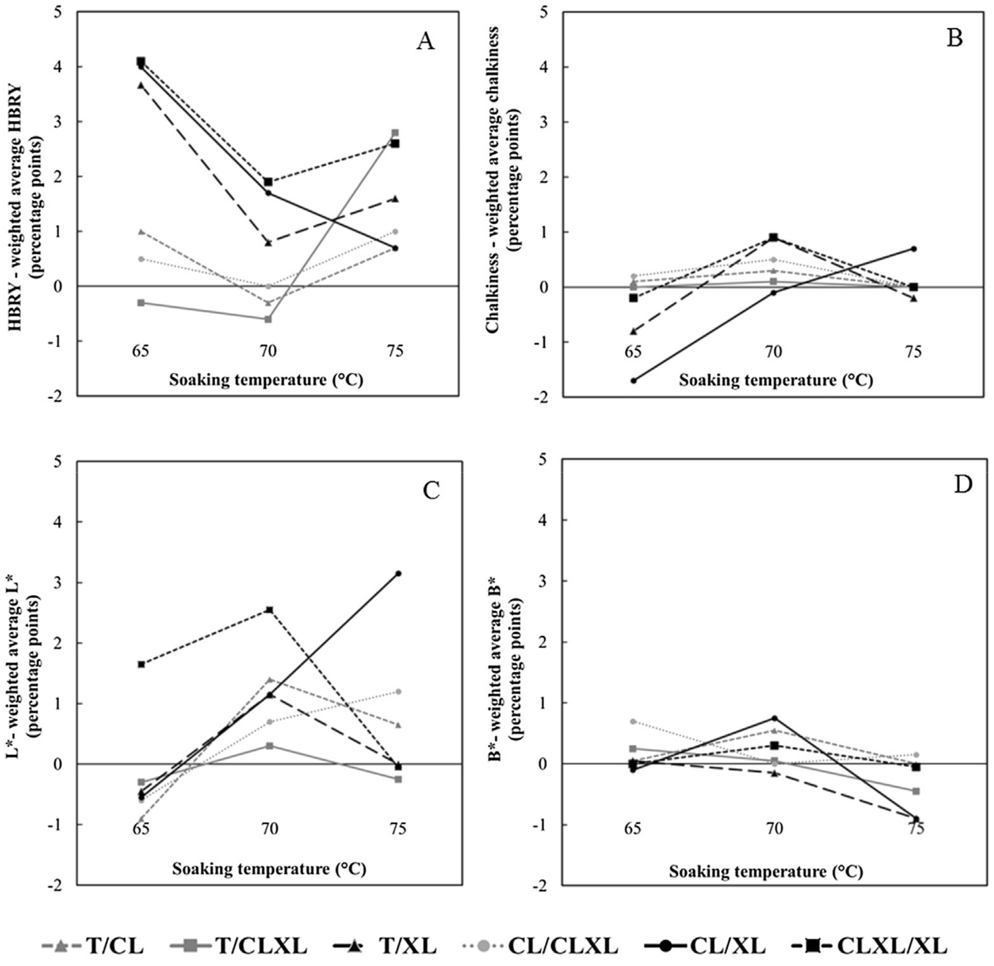

Fig. 1. Differences between head brown rice yield (A), chalkiness (B), whiteness (C), and yellowness (D), and their weighted average for each commingled rice after soaking at 65, 70, or 75 °C for 3 h. Weighted average for each commingle was calculated using the mass ratio of 1:1.

Table 2
Gelatinization properties of Taggart, CL151, CL XL745, XL753, and their commingles after soaking at 65, 70, or 75 °C for 3 h, and their controls of no soaking.[1]

Cultivar/Commingles	Soaking temperature (°C)	Gelatinization temperature (°C)				ΔH (J/g)
		T_o	T_p	T_c	T_c-T_o	
Taggart	control	72.1 ± 0.6^{c}	78.0 ± 1.0^{c}	84.0 ± 1.6^{b}	11.9 ± 1.0^{a}	9.2 ± 0.9^{a}
(T)	65	73.3 ± 1.0^{bc}	78.8 ± 1.0^{bc}	84.5 ± 1.4^{b}	11.2 ± 0.7^{a}	9.2 ± 0.5^{a}
	70	75.2 ± 0.3^{b}	80.6 ± 0.4^{b}	87.1 ± 0.6^{ab}	11.9 ± 0.5^{a}	8.5 ± 0.3^{a}
	75	79.9 ± 0.9^{a}	84.8 ± 1.0^{a}	90.3 ± 1.0^{a}	10.4 ± 0.3^{a}	7.8 ± 0.5^{a}
CL151	control	74.2 ± 0.3^{d}	80.1 ± 0.3^{c}	84.9 ± 1.1^{c}	10.4 ± 1.3^{a}	9.3 ± 0.3^{a}
(CL)	65	75.8 ± 0.4^{c}	80.6 ± 0.4^{c}	85.8 ± 0.6^{c}	10.0 ± 0.2^{a}	9.7 ± 0.6^{a}
	70	78.8 ± 0.2^{b}	83.0 ± 0.7^{b}	88.5 ± 0.9^{b}	9.7 ± 0.8^{a}	9.0 ± 0.2^{ab}
	75	81.3 ± 0.2^{a}	85.7 ± 0.3^{a}	91.8 ± 0.6^{a}	10.6 ± 0.4^{a}	8.2 ± 0.0^{b}
CL XL745	control	73.3 ± 0.2^{d}	78.7 ± 0.0^{b}	85.0 ± 1.2^{c}	11.7 ± 1.0^{a}	10.3 ± 0.1^{a}
(CLXL)	65	75.0 ± 0.6^{c}	80.2 ± 1.0^{b}	86.5 ± 1.9^{bc}	11.5 ± 1.3^{a}	10.7 ± 1.0^{a}
	70	78.3 ± 0.4^{b}	82.7 ± 0.3^{a}	88.6 ± 0.4^{ab}	10.2 ± 0.5^{a}	8.8 ± 0.9^{a}
	75	80.2 ± 0.5^{a}	84.3 ± 0.5^{a}	90.2 ± 0.7^{a}	10.0 ± 0.2^{a}	8.6 ± 0.9^{a}
XL753	control	78.1 ± 0.7^{c}	83.2 ± 0.9^{b}	89.0 ± 1.1^{b}	10.9 ± 0.4^{a}	10.7 ± 0.4^{a}
(XL)	65	78.0 ± 0.9^{c}	83.0 ± 0.9^{b}	88.5 ± 1.4^{b}	10.6 ± 0.4^{a}	10.4 ± 0.7^{a}
	70	79.8 ± 0.1^{b}	84.6 ± 0.3^{ab}	90.1 ± 0.6^{ab}	10.3 ± 0.4^{a}	9.9 ± 0.6^{a}
	75	81.5 ± 0.2^{a}	86.4 ± 0.3^{a}	92.2 ± 0.5^{a}	10.7 ± 0.3^{a}	10.7 ± 0.1^{a}
T/CL	control	72.5 ± 0.3^{c}	79.1 ± 0.3^{b}	85.4 ± 0.3^{b}	12.9 ± 0.1^{a}	9.8 ± 0.8^{a}
	65	74.3 ± 0.1^{b}	80.0 ± 1.0^{b}	86.3 ± 1.1^{b}	11.9 ± 0.2^{b}	9.7 ± 0.8^{a}
	70	74.1 ± 0.1^{bc}	79.7 ± 0.2^{b}	86.2 ± 0.1^{b}	12.1 ± 0.2^{ab}	9.6 ± 0.6^{a}
	75	79.0 ± 0.1^{a}	83.9 ± 0.1^{a}	89.6 ± 0.2^{a}	10.6 ± 0.2^{c}	8.1 ± 0.2^{a}
T/CLXL	control	72.3 ± 0.8^{c}	78.5 ± 0.8^{c}	84.9 ± 1.1^{b}	12.6 ± 0.4^{a}	10.8 ± 0.2^{a}
	65	74.4 ± 0.9^{b}	79.5 ± 0.1^{bc}	85.6 ± 1.1^{b}	11.2 ± 0.1^{b}	9.1 ± 0.3^{b}
	70	75.8 ± 0.8^{b}	81.0 ± 0.8^{b}	87.1 ± 0.8^{ab}	11.3 ± 0.2^{b}	8.9 ± 0.3^{b}
	75	79.4 ± 0.6^{a}	83.8 ± 0.8^{a}	89.4 ± 0.2^{a}	10.0 ± 0.4^{c}	8.4 ± 0.6^{b}
T/XL	control	72.8 ± 0.2^{c}	82.5 ± 0.7^{b}	88.8 ± 0.2^{c}	16.0 ± 0.0^{a}	9.6 ± 0.4^{a}
	65	75.3 ± 0.5^{b}	84.2 ± 0.2^{a}	91.3 ± 0.0^{b}	16.0 ± 0.5^{a}	9.6 ± 0.0^{a}
	70	74.8 ± 0.7^{b}	81.2 ± 1.0^{b}	89.3 ± 0.9^{c}	14.5 ± 0.2^{b}	9.2 ± 0.3^{a}
	75	78.6 ± 0.1^{a}	85.7 ± 0.3^{a}	93.1 ± 0.2^{a}	14.5 ± 0.2^{b}	9.7 ± 0.9^{a}
CL/CLXL	control	73.3 ± 0.3^{d}	79.9 ± 0.2^{c}	85.9 ± 0.3^{c}	12.6 ± 0.6^{a}	9.9 ± 0.2^{a}
	65	76.2 ± 0.7^{c}	81.0 ± 0.6^{bc}	86.9 ± 0.7^{bc}	10.8 ± 0.0^{b}	9.9 ± 0.4^{a}
	70	77.7 ± 0.2^{b}	82.2 ± 0.2^{b}	87.7 ± 0.2^{b}	10.1 ± 0.3^{b}	8.6 ± 0.5^{a}
	75	80.5 ± 0.2^{a}	84.6 ± 0.6^{a}	90.6 ± 0.9^{a}	10.1 ± 0.4^{b}	8.8 ± 0.8^{a}
CL/XL	control	74.9 ± 0.2^{c}	81.1 ± 0.2^{c}	88.0 ± 0.2^{b}	13.1 ± 0.2^{a}	10.1 ± 0.0^{a}
	65	76.8 ± 1.0^{b}	82.2 ± 0.8^{bc}	90.4 ± 1.1^{a}	13.6 ± 0.2^{a}	10.0 ± 0.6^{a}
	70	78.0 ± 0.5^{ab}	82.9 ± 0.4^{ab}	89.7 ± 0.7^{ab}	11.8 ± 0.2^{b}	9.9 ± 0.6^{a}
	75	79.0 ± 0.5^{a}	84.0 ± 0.6^{a}	91.2 ± 0.6^{a}	12.2 ± 0.2^{b}	10.1 ± 0.1^{a}
CLXL/XL	control	74.7 ± 0.6^{b}	80.1 ± 0.5^{b}	89.0 ± 0.8^{b}	14.3 ± 0.4^{a}	9.2 ± 0.5^{a}
	65	75.6 ± 0.9^{b}	81.7 ± 1.0^{b}	89.4 ± 1.2^{b}	13.8 ± 0.4^{a}	10.2 ± 0.2^{a}
	70	76.5 ± 0.9^{b}	82.8 ± 1.0^{b}	88.9 ± 1.3^{b}	12.4 ± 0.5^{b}	9.6 ± 0.6^{a}
	75	81.1 ± 0.9^{a}	86.5 ± 0.9^{a}	93.6 ± 1.1^{a}	12.6 ± 0.3^{b}	9.4 ± 0.2^{a}
HSD		2.1	2.5	3.1	1.7	2.0

[1] Mean values ± SD followed by the same letter in the same column within the same sample are not significantly different based on Tukey's HSD test.

the present results demonstrate that chalkiness was also removed by soaking alone. Recently, Leethanapanich and Wang (2016) observed that during soaking starch granules swelled and protein bodies rearranged to a more packed structure and filled void spaces, thus lowering chalkiness in rice. Adebiyi et al. (2009) reported that glutenin, the predominant protein in rice, had a denaturation temperature of 74 °C, Therefore, the high soaking temperature of 75 °C would have more influence on glutenin and consequently on chalkiness removal.

The reduction in chalkiness might be partially responsible for the increase in HBRY of most rice samples after soaking at 65 and 70 °C because chalky kernels tend to break during milling (Bautista et al., 2009). However, it was noted that even though almost all chalkiness was removed after soaking at 75 °C, the HBRY dropped for T, CL, CLXL, and CL/CLXL. As previously mentioned, soaking at temperatures above T_o resulted in husk splitting and deformed kernels, which could break and result in reduced HBRY during milling.

3.1.3. Color

The color of brown rice samples became darker with lower L* values and yellower with higher b* values when soaking temperature increased (Table 1). Chung et al. (1990), Sareepuang et al. (2008), and Mir and Bosco (2013) observed a similar trend. The decrease in whiteness and increase in yellowness of parboiled rice have been ascribed to a result of migration of bran components into the endosperm and Maillard reaction between free amino acids and reducing sugars during soaking (Ali and Bhattacharya, 1980; Kimura et al., 1993; Lambert et al., 2008).

Nevertheless, the effect of soaking temperature on the extent of change in whiteness and yellowness varied among cultivars and commingles. In all commingled samples, the change in color was dominated by the cultivar that exhibited the most change. The whiteness of commingles with a large difference in color between the individual cultivars, such as CL/XL and CLXL/XL, tended to deviate from their weighted average (Fig. 1C). However, the predicted b* of all samples appeared to be close to the actual values (Fig. 1D), possibly because of a small difference in b* among individual rice cultivars. It is important to take the difference in color of individual rice cultivars into consideration when using commingled rice because a greater difference might result in inconsistent color in the finished products.

3.2. Gelatinization properties

Gelatinization temperatures (T_o, T_p, and T_c) increased with

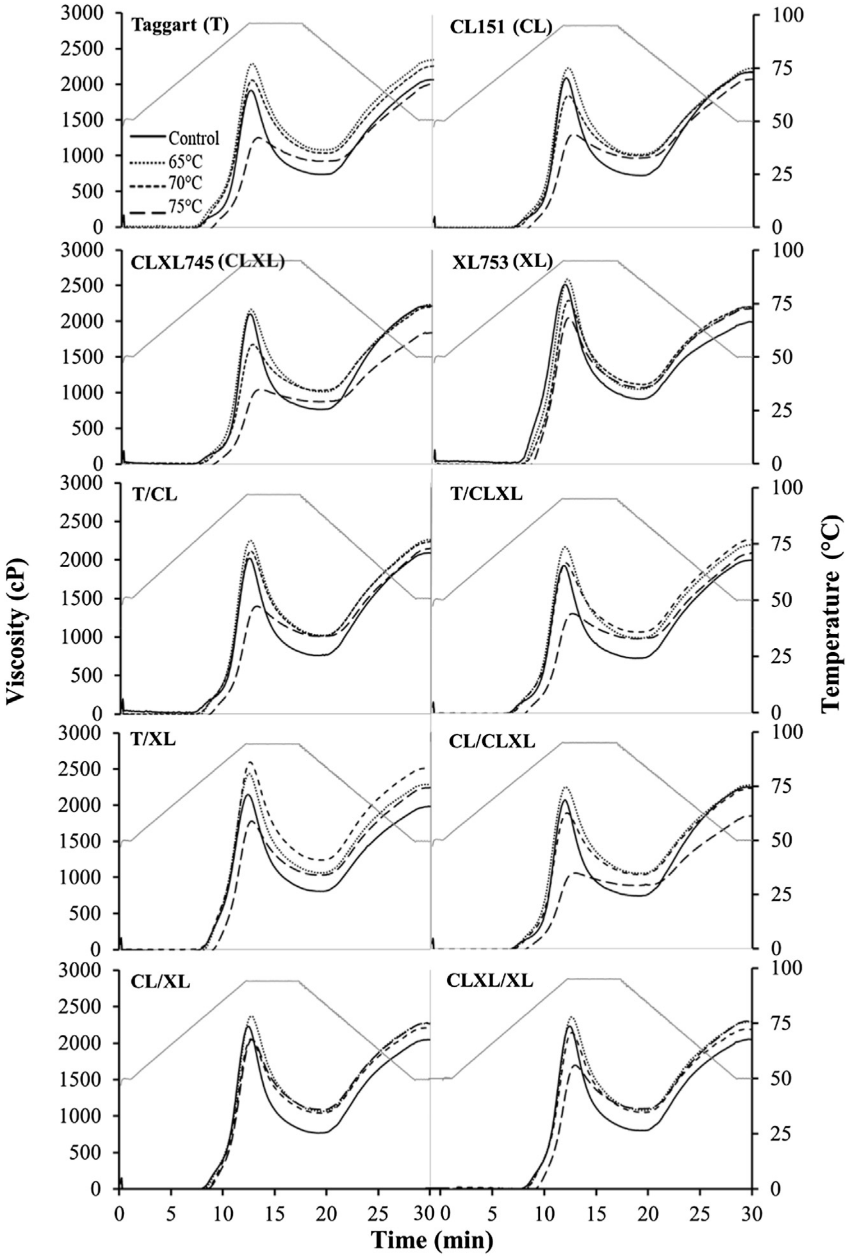

Fig. 2. Pasting profiles of Taggart, CL151, CL XL745, XL753, and their commingles after soaking at 65, 70, or 75 °C for 3 h and their controls of no soaking.

increasing soaking temperature for all individual and commingled rice samples, and the increase became greater when the soaking temperature was close to T_o (Table 2). The increase in gelatinization temperature was attributed to an increase in starch crystallinity (Tester and Debon, 2000; Waduge et al., 2006), and the interactions of amylose-amylose and amylose-amylopectin during soaking from annealing (Adebowale et al., 2005).

For T/XL, the T_p and T_c were higher at 65 °C than at 70 °C, a trend that was different from the other samples and was attributed to inhomogeneous physical mixing of the two cultivars. Basutkar et al. (2015) proposed that the T_o of commingled rice was determined by the rice cultivar with a lower T_o, and commingled rice with a great difference in T_o may cause inconsistent quality of products. The present results support their findings and further demonstrate that this relationship remained after soaking at 65, 70, and 75 °C for 3 h. For example, the T_o of T/CL (72.5 °C), T/CLXL (72.3 °C), and T/XL (72.8 °C) were close to the T_o of T (72.1 °C), and their increase in T_o at increasing soaking temperature was similar to that of T.

Soaking temperature had little influence on gelatinization temperature range (T_c-T_o) of individual rice cultivars because T_o and T_c increased concurrently. The (T_c-T_o) was significantly larger in commingled rice than in individual rice because of the greater difference in T_o and T_c between the two individual rice cultivars. Nevertheless, the (T_c-T_o) decreased with increasing soaking temperature, and the impact of soaking temperature on (T_c-T_o) was affected by its range. Commingles with a large (T_c-T_o) required a higher soaking temperature to reduce (T_c-T_o) than those with a small (T_c-T_o). For example, the (T_c-T_o) of T/CL, T/CLXL, and CL/CLXL decreased after soaking at 65 °C, whereas those of T/XL, CL/XL, and CLXL/XL did not change until soaking at 70 °C. The present results imply that soaking reduced the difference in (T_c-T_o) in commingled rice, thus potentially minimize the varietal difference in commingled rice.

The ΔH of all rice samples, except CL and T/CLXL, remained

Table 3
Analysis of variance (ANOVA) of soaked commingled rice properties as affected by onset gelatinization temperature (T_o) difference, soaking temperature and their interactions.

Quality characteristics	Sum of squares			Root mean square error (RMSE)	R^2
	Soaking temperature	T_o difference	Interaction		
HBRY (%)	37***	160***	35***	0.39	0.98
Chalkiness (%)	34***	17***	10***	0.22	0.97
L*	184***	106***	43***	0.39	0.98
b*	21***	3**	4**	0.35	0.86
T_o (°C)	177***	43***	21**	0.69	0.93
T_p (°C)	124***	52***	32***	0.77	0.91
T_c (°C)	109***	138***	23*	0.89	0.90
T_c-T_o (°C)	14***	128***	7***	0.31	0.98
ΔH (J/g)	4**	9**	6^{NS}	0.54	0.64
Peak viscosity (cP)	5166607***	1450843***	661154***	29.61	1.00
Final viscosity (cP)	71613***	91837***	121037***	18.69	0.96
Breakdown viscosity (cP)	4855536***	964574***	487148***	19.65	1.00
Setback viscosity (cP)	4070041***	912248***	366037***	18.28	1.00

* represents the level of statistical significance, *≤0.05, **≤0.01,*** ≤0.001.
NS = not significant.

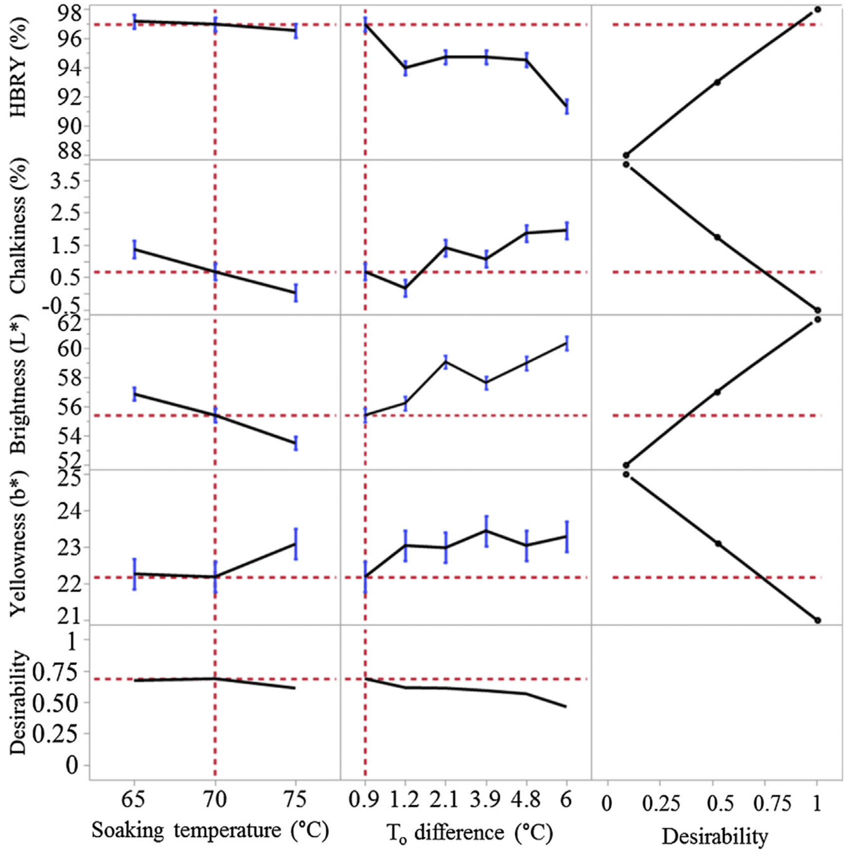

Fig. 3. Prediction profile of optimum soaking temperature and T_o difference for maximizing desirability score. Vertical dash line represents the soaking temperature and T_o difference whereas horizontal dash line represents values obtained at condition that result in the highest desirability score.

unchanged after soaking at different temperatures, although gelatinization temperatures increased during soaking from annealing. Lan et al. (2008) also found no change in ΔH of wheat starches after annealing because no new double helices were formed. It is also possible that some starch was gelatinized after soaking at temperatures above T_o, thus lowering ΔH, but the decreased ΔH was offset by the increased ΔH from annealing.

3.3. Pasting properties

The peak viscosity slightly increased at lower soaking temperatures, but decreased at 75 °C for most rice samples (Fig. 2). The profiles of commingled rice samples were similar to those of individual rice cultivars, and strongly affected by the rice cultivars with high T_o, particularly XL753, as evidenced by the less significant decrease of peak viscosity at 75 °C when XL753 was present in the commingled rice samples.

The reduced peak viscosity was proposed to mainly result from the interaction of denatured protein bodies with starch, which limited starch swelling, and to a less extent by the damage of starch granules (Derycke et al., 2005). The slight increase in peak viscosity at 65 or 70 °C was proposed to be the result of annealing. Jacobs et al. (1996) observed an increase in peak and final viscosity of annealed rice starch. They proposed that annealing permitted amylopectin molecules that were not perfectly ordered to rearrange into a more ordered structure. Therefore, annealed starch granules could swell to a larger volume than the native granules before disruption, thus increasing the peak viscosity. Dias et al. (2010) observed similar results from medium-amylose rice starch annealed at 45 and 50 °C.

3.4. Relative importance of factors

The contributions of soaking temperature, T_o difference, and their interactions on quality of commingled brown rice were analyzed by analysis of variance (Table 3). Rice properties including HBRY, chalkiness, whiteness, yellowness, gelatinization temperatures, and pasting viscosities, were strongly affected by both soaking temperature and T_o difference of individual rice cultivars in commingled rice, and their interaction. Nevertheless, the relative impacts of soaking temperature and T_o difference on soaked rice properties were not the same as shown from different sum of square values that indicate the influence of each factor. Soaking temperature exerted more impacts on overall quality than did T_o difference and their interaction. Chalkiness, L*, b*, T_o, T_p, and pasting viscosities were more influenced by soaking temperature, whereas HBRY, T_c, (T_c-T_o), and ΔH were more influenced by T_o difference. The influence of T_o difference on HBRY was shown from the different effects of soaking temperature on different samples. In addition, breakage susceptibility was cultivar dependent and varied with the level of fissures, chalkiness, immaturity and kernel dimensions (Bhattacharya, 1969).

The prediction profile (Fig. 3) was created in order to illustrate the relationship of soaking temperature and T_o difference with desirable properties. The highest desirability score was set for the condition that would give the highest HBRY, lowest percentage of chalkiness, lightest color, and least yellowness. Based on the present results, commingled rice with T_o difference of 0.9 °C had the highest desirability score at 0.69 when soaked at 70 °C; commingled rice with T_o difference of 6 °C showed the highest desirability score at 0.49 when soaked at 75 °C. This result indicates that using commingled rice with a greater T_o difference was more likely to result in the parboiled rice with less desirable quality.

4. Conclusions

Soaking temperature relative to the T_o and T_o difference between individual rice cultivars in commingled rice significantly affected overall properties of commingled rice. Soaking rice at a temperature close to T_o increased HRY and reduce chalkiness but also yielded a darker and more yellow rice. Using commingled rice with a great T_o difference as a feedstock for parboiling can lead to undesirable quality characteristics. Increasing soaking temperature minimized the varietal difference of commingled rice; however, potential gelatinization of low-T_o cultivars at high soaking temperatures changed the pasting profile when combined with high-T_o cultivars.

Acknowledgments

The authors acknowledge the financial support from the Royal Thai Government and research facilities from the University of Arkansas Rice Processing Program.

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