Erratum

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[F: Table 2]

Applicability of Dry Flours Produced from a Table Potato Variety (*Solanum tuberosum* L. cv. May Queen) in Bread Making

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Table 2. Dough properties and bread making qualities of dough and breads made with untreated, B and BR potato flours.

Formulation	Water absorption of dough (%)	GRD (mL)	GP (mL)			SLV (mL/g)	Moisture content of bread (%)
			1 h	2 h	3 h		
Control	67.5	110.0 ± 5.0 b	28.3 ± 0.4 a	64.3 ± 2.0 a	97.7 ± 3.3 c	4.70 ± 0.14 b	44.3 ± 0.3 b
C + Untreated	65.0	95.0 ± 0.0 d	26.3 ± 0.2 c	62.8 ± 0.5 b	108.2 ± 0.8 b	4.00 ± 0.07 cd	43.6 ± 0.1 c
C + 10B	72.0	96.7 ± 2.9 cd	28.0 ± 0.2 ab	67.5 ± 0.4 a	112.0 ± 0.8 a	3.74 ± 0.23 d	45.7 ± 0.3 a
C + 30B	72.5	101.7 ± 2.9 cd	26.5 ± 0.1 c	60.0 ± 0.3 c	99.4 ± 0.8 c	3.76 ± 0.06 d	45.7 ± 0.2 a
C + 10BR	70.5	103.3 ± 2.9 bc	25.8 ± 0.3 d	61.1 ± 1.0 c	102.2 ± 2.5 c	4.11 ± 0.05 cd	44.8 ± 0.0 b
C + 30BR	72.0	96.7 ± 2.9 cd	24.5 ± 0.1 e	58.8 ± 0.6 c	99.1 ± 0.9 cd	3.95 ± 0.05 cd	45.5 ± 0.3 a
Y	69.0	130.0 ± 0.0 a	27.6 ± 0.2 b	63.5 ± 0.5 b	96.7 ± 0.7 d	5.16 ± 0.24 a	44.8 ± 0.2 b
Y + 10BR	72.0	110.0 ± 0.0 b	26.1 ± 0.2 cd	63.7 ± 0.6 b	106.3 ± 0.8 b	4.20 ± 0.13 c	45.6 ± 0.2 a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

Abbreviations: GRD, Gas retention of dough; GP, Total gassing power; SLV, Specific loaf volume

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Table 2. Properties of doughs and breads made from 8 different formulations of test flours.

Formulation	Water absorption of dough (%)	GRD (ml)	GP (ml)		SLV (ml/g)	Moisture content of bread (%)
			1 h	2 h		
Control	67.5	110.0 ± 5.0 b	28.3 ± 0.4 a	62.6 ± 0.4 bc	4.70 ± 0.14 b	44.3 ± 0.3 b
S + D	65.0	95.0 ± 0.0 d	26.3 ± 0.2 c	62.8 ± 0.5 bc	4.00 ± 0.07 cd	43.6 ± 0.1 c
S + 10B	72.0	96.7 ± 2.9 cd	28.0 ± 0.2 ab	67.5 ± 0.4 a	3.74 ± 0.23 d	45.7 ± 0.3 a
S + 30B	72.5	101.7 ± 2.9 cd	26.5 ± 0.1 c	60.0 ± 0.3 d	3.76 ± 0.06 d	45.7 ± 0.2 a
S + 10BR	70.5	103.3 ± 2.9 bc	25.8 ± 0.3 d	62.0 ± 0.2 c	4.11 ± 0.05 cd	44.8 ± 0.0 b
S + 30BR	72.0	96.7 ± 2.9 cd	24.5 ± 0.1 e	58.8 ± 0.6 d	3.95 ± 0.05 cd	45.5 ± 0.3 a
ES	69.0	130.0 ± 0.0 a	27.6 ± 0.2 b	63.5 ± 0.5 b	5.16 ± 0.24 a	44.8 ± 0.2 b
ES + 10BR	72.0	110.0 ± 0.0 b	26.1 ± 0.2 cd	63.7 ± 0.6 b	4.31 ± 0.13 c	45.6 ± 0.2 a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

Abbreviations: GRD, Gas retention of dough; GP, Total gassing power; SLV, Specific loaf volume

Original paper

Applicability of Dry Flours Produced from a Table Potato Variety (*Solanum tuberosum* L. cv. May Queen) in Bread Making

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Five different potato flours were prepared from the table potato variety, May Queen, by drying potato slices without boiling or refrigeration (D), with boiling for 10 or 30 min (10B, 30B) and with boiling for 10 or 30 min, followed by refrigeration (10BR, 30BR), and their applicability to bread making was evaluated. When 10% potato flour was added to strong wheat flour (S), B and BR increased the water absorption of dough and lowered the gas retention of dough (GRD) and specific loaf volume (SLV). However, the highest GRD and SLV were observed in a combination of S with 10BR among the tested flour blends. Furthermore, GRD and SLV were improved by replacing S with extra-strong wheat flour (ES). The bread made from ES and 10BR maintained significantly higher softness of crumb compared to control during 3 days of storage at 20°C ($p < 0.05$).

Keywords: potato flour, table potato, bread making quality, boiling, refrigeration

Introduction

Potato (*Solanum tuberosum* L.) is one of the major global crops, and has the highest quantity of production among all root and tuber crops in the world and Japan (FAOⁱ). In Japan, the major potato varieties produced are classified into three-groups: table, processing, and starch extraction potatoes (Ministry of Agriculture, Forestry and Fisheries of Japanⁱⁱ). For table potatoes, external injury such as scuffing and bruising of the tuber negatively affects their market acceptability; and even though these potatoes are still safe to eat (Burton, 1989), they are typically diverted for starch extraction in Japan.

Aina *et al.*, (2009) reported that the production of dry flour from sweet potato could help to reduce food losses, add value and increase earnings for farmers. Thus, the production of potato flour would be a better alternative for utilization of externally injured

table potatoes than starch extraction. Potato flour is generally produced by blanching or cooking, drying, grinding and sieving of potato tubers (Kim and Kim, 2014). It has been recognized that physicochemical properties of potato flours are influenced by treatments such as heating (Yadav *et al.*, 2006) and pectinase treatment (Kim and Kim, 2014). In addition, the application of potato flours to food products such as extruded puff (Faller and Heymann, 1996), cookies (Singh *et al.*, 2003), and breads (Ijah *et al.*, 2014) has been widely studied. In regards to bread making, however, it has been reported that non-wheat flours, such as cassava, corn, potato, rice, rye, soy and sweet potato flour, used to replace wheat flour wholly or partially lead to lower bread making qualities such as specific loaf volume (SLV), gas retention of dough (GRD) and acceptability compared to wheat flour breads (He and Hosney, 1991; Eddy *et al.*, 2007; Sabanis and Tzia, 2009; Ijah

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et al., 2014; Trejo-González *et al.*, 2014). Ijah *et al.* (2014) further reported that partial replacement of wheat flour with 10% dehydrated uncooked potato flour resulted in a significant decrease in acceptability compared to wheat flour bread ($p < 0.05$). On the other hand, the addition of extra-strong wheat flour was reported to improve SLV and GRD of bread and dough made from medium-strong wheat flour that is typically not suitable for bread making (Yamauchi *et al.*, 1999; Yamauchi *et al.*, 2003), and thus, extra-strong wheat flour can potentially improve bread quality because of its high gluten content (Hung *et al.*, 2005).

Therefore, the objectives of the present study were to evaluate the applicability of 5 different potato flours produced from the table potato variety, May Queen, in bread making and assess the effect of introducing extra-strong wheat flour on bread making quality.

Materials and Methods

Raw materials A commercial table potato variety (*Solanum tuberosum* L. cv. May Queen) was purchased from a local market and used for preparation of potato flours.

Preparation of dry potato flour (D) Potato tubers were peeled, sliced to 1 cm thickness and dried in a hot air oven (WFO-700, TOKYO RIKAKIKI Co., Ltd., Tokyo, Japan) at 50°C for 48 h. Dried slices were milled by a blender (New Power Mill PM-2005, OSAKA CHEMICAL Co., Ltd., Osaka, Japan) and sifted through a 300 µm aperture sieve. The sample was stored at 4°C until use.

Preparation of boiled potato flours (B) Potato tubers were peeled, boiled in tap water for 10 or 30 min and then sliced, dried, milled and sieved in the same manner as above. Potato flours with boiling for 10 or 30 min were coded as 10B and 30B, respectively and stored at 4°C until use.

Preparation of boiled and refrigerated potato flours (BR) Potato tubers were peeled, boiled in tap water for 10 or 30 min and then refrigerated in a polyethylene bag at 5°C for 5 days. The boiled and refrigerated potato tubers were sliced, dried, milled and sieved in the same manner as above. Potato flours with boiling for 10 or 30 min followed by refrigeration (10BR and 30BR) were stored at 4°C until use.

Wheat flours Commercial strong wheat flour (S), Camellia, and extra-strong wheat flour (ES), Tsukinomahou, made from *Triticum aestivum* L. cv. Yumehikara, were purchased from Nisshin Flour Milling Co., Ltd. (Tokyo, Japan) and Yamamoto Tadanobu Shoten KK. (Hokkaido, Japan), respectively. Protein and ash contents of S and ES were 12.2 and 13.9%, and 0.39 and 0.53%, respectively (w/w, 13.5% moisture base).

Analytical determination of physicochemical properties of potato flours Moisture content was determined by the method of the Association of Official Analytical Chemists (AOAC) (2000). Damaged starch content was determined by a Megazyme assay kit based on the method of Gibson *et al.* (1991) (Megazyme International Co., Ltd., Bray, Ireland). Particle size distribution was

determined by a compact laser diffraction particle size analyzer (Helos & Rodos, Sympatec GmbH, Clausthal-Zellerfeld, Germany). L^* , a^* and b^* as color properties were determined by a color difference meter (CR410, Konica Minolta, Inc., Tokyo, Japan).

Bread making The no-time method was used for bread making with the standard white bread formulation as the control, consisting of 200 g of S, 10 g of sugar, 10 g of shortening (Snowlight, Kaneka Corp., Osaka, Japan), 4 g of salt, 4 g of wet yeast (Regular yeast, Nippon Beet Sugar Mfg. Co., Ltd., Tokyo, Japan), 20 mg of L-ascorbic acid and a suitable quantity of water. The dough was mixed to just beyond peak development, divided into 100 g pieces, rounded and allowed to rest for 20 min at 30°C and 75% humidity as bench time. The pieces were panned, proofed at 38°C and 85% humidity for 70 min and then baked at 200°C for 18 min. (Yamauchi *et al.*, 1992; Yamauchi *et al.*, 2001). The optimal water absorption of dough was determined by a Farinograph at 500 BU, according to the AACC method (1991). For preparing breads from S with potato flours, 10% S was partially replaced with potato flours. In addition, S was replaced by ES.

Analytical determination of dough properties Twenty gram of dough after proofing was used for measuring the gas retention of dough (GRD) by the method of Yamauchi *et al.* (2000). Maximum volume of dough in a cylinder under low pressure was used for evaluation of GRD. The total gassing power (GP) with 20 g of dough after bench time was measured at 30°C for 2 h with a Fermograph II (ATTO Co., Ltd., Tokyo, Japan).

Analytical determination of bread properties Specific loaf volume (SLV) of bread was measured by the rapeseed displacement method after cooling the bread at room temperature for 1 h after baking. Bread crumbs (2 cm × 3 cm × 3 cm) were dried for 3 h at 135°C for determining moisture content (AOAC, 2000). Images of breads were obtained using a digital camera (EX-H15, Casio Computer Co., Ltd., Tokyo, Japan), while images of individual slices from breads were photocopied using a scanner (GT-9800F, Seiko Epson Corp., Nagano, Japan). L^* , a^* and b^* as color properties were determined using a color difference meter (CR410, Konica Minolta, Inc., Tokyo, Japan) at the center of the sliced loaf as crumb color. Hardness of bread crumb during storage was evaluated using a creep meter (RE2-33005C, Yamaden Co., Ltd., Tokyo, Japan). Loaves cooled for 1 h at room temperature after baking were packed into polyethylene bags and stored at 20°C and 70% humidity. After storage for 24, 48 and 72 h, the loaves were sliced at 2 cm thickness and a 3 cm × 3 cm square was cut from the center of each slice. The maximum stress as hardness was measured by compressing the crumbs from 2 cm thickness to 1 cm thickness with 1 mm/s of compression rate using a square plunger (6 cm × 6 cm contact surface, silicon).

Statistical analysis Statistical analyses were conducted using SPSS for Windows (ver. 17.0). One-way analysis of variance and Tukey's multiple-range test were carried out for comparison of

Table 1. Physicochemical properties of D, B and BR potato flours.

Treatment	Moisture (%)	Damaged starch (% dwb)	Mean particle size (μm)	L^*	a^*	b^*
D	9.71 $\pm$ 0.08 c	9.15 $\pm$ 0.43 e	41.28 $\pm$ 0.97 e	83.37 $\pm$ 0.11 d	0.91 $\pm$ 0.03 a	13.92 $\pm$ 0.32 b
10B	10.36 $\pm$ 0.04 a	48.80 $\pm$ 1.37 b	82.24 $\pm$ 3.73 a	89.71 $\pm$ 0.40 a	-1.65 $\pm$ 0.24 e	13.91 $\pm$ 0.72 b
30B	9.38 $\pm$ 0.05 d	51.45 $\pm$ 0.76 a	69.03 $\pm$ 2.67 c	89.15 $\pm$ 0.17 b	-0.83 $\pm$ 0.14 c	15.39 $\pm$ 0.46 a
10BR	10.42 $\pm$ 0.02 a	35.20 $\pm$ 0.53 d	76.33 $\pm$ 1.53 b	88.99 $\pm$ 0.03 b	-1.20 $\pm$ 0.23 d	14.11 $\pm$ 0.78 b
30BR	9.98 $\pm$ 0.08 b	39.97 $\pm$ 0.55 c	59.55 $\pm$ 0.82 d	88.48 $\pm$ 0.09 c	-0.22 $\pm$ 0.10 b	15.11 $\pm$ 0.17 a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

physicochemical properties of potato flours among 5 treatments, and dough and bread properties among 8 different formulations at a 5% significance level. Correlation analysis was performed to evaluate the relationship between dough and bread properties.

Results and Discussion

Physicochemical properties of potato flours Table 1 indicates moisture content, damaged starch content, mean particle size, L^* , a^* and b^* of potato flours. Moisture and damaged starch contents of potato flours ranged from 9.38 to 10.42% and 9.15 to 51.45% dry weight basis (dwb), respectively. The highest content of damaged starch was observed in 30B among all potato flours ($p < 0.05$). 10BR showed the lowest damaged starch content among B and BR ($p < 0.05$). Yadav *et al.* (2006) reported that heat treatments such as blanching and steaming during potato flour production cause significant increases of damaged starch content. Furthermore, it was reported that steam treatment of cassava flour resulted in the degradation of crystalline regions of starch, and subsequent drying and milling processes may have caused greater mechanical damage to the pre-gelatinized starch (Murayama *et al.*, 2014). Thus, the major causes of the significant increase in damaged starch content of B and BR compared to that of D may also be due to the drying and milling processes of gelatinized starch. 10BR and 30BR had significantly lower contents of damaged starch than the corresponding non-refrigerated potato flours, and it was observed that the refrigeration process led to significant decreases in damaged starch content ($p < 0.05$). Storage of gelatinized potato starch at 4°C has been reported to cause starch retrogradation observed by differential scanning calorimetry (Gunaratne and Hoover, 2002). Therefore, the decrease in damaged starch content of BR may be attributed to the partial recrystallization and retrogradation of gelatinized starch by refrigeration.

Mean particle size of potato flours varied between 41.28 μm and 82.24 μm . 10B, 10BR, 30B and 30BR had significantly higher mean particle size than that of D. Andersson *et al.* (1994) reported that starch granules in potato tuber cells absorb cellular water and swell to form a gel during heating. Hence, boiling may have increased the mean particle size by the swelling and adhering of gelatinized starch granules.

Color properties of L^* , a^* and b^* ranged from 83.37 to 89.71,

–1.65 to 0.91 and 13.91 to 15.39 for potato flours, respectively. D showed significantly lower L^* and higher a^* among all potato flours ($p < 0.05$), and these results may be due to the browning of potato slices during drying, caused by enzymes such as polyphenol oxidases (Martinez and Whitaker, 1995). Therefore, it seems that boiling can improve the color of potato flours. Jangchud *et al.* (2003) also reported that color properties of orange and purple sweet potato flour are improved by blanching slices in water at 90–95°C for 1 min. 30B and 30BR had significantly higher b^* among all potato flours ($p < 0.05$). Higher b^* indicates higher yellow color, and longer boiling increased the yellowness of potato flours.

Dough and bread properties Properties of dough and breads made from 8 different formulations are shown in Table 2 and Fig. 1. The addition of 10B, 30B, 10BR and 30BR caused an increase in the water absorption of dough compared to the control and the dough made from S with D. These results agreed with Purhagen *et al.* (2008), who reported that partial replacement of wheat flour with heat-treated barley flour leads to increases in the water absorption of dough compared to the control and the dough made with a wheat and normal barley flour blend. Moreover, it was reported that damaged starch absorbs more water than unmodified starch at temperatures lower than the gelatinization temperature (Lelievre, 1974). Thus, the addition of B and BR, which had a higher content of damaged starch, may have increased the water absorption of dough. In addition, the higher water absorption of the doughs made from S with 10B and 30B compared to their refrigerated counterparts may also be due to the higher content of damaged starch.

GRD ranged from 95.0 to 130.0 mL among all doughs, and the dough made from S with D had the lowest GRD ($p < 0.05$). The doughs made from S with potato flours showed lower GRD than the control. Gan *et al.* (1995) indicated that the quantity and quality of gluten proteins determine the rheological properties of optimally mixed dough and thus contribute to gas retention properties of fermenting dough. Therefore, a reduction in the relative concentration of gluten proteins by the addition of potato flours may have contributed to the decrease in GRD for the doughs with added potato flours. In addition, Yamauchi *et al.* (2004) and Santiago *et al.* (2014) reported that the gluten network of dough becomes weaker and rougher and GRD decreases when rice or

Table 2. Properties of doughs and breads made from 8 different formulations of test flours.

Formulation	Water absorption of dough (%)	GRD (ml)	GP (ml)		SLV (ml/g)	Moisture content of bread (%)
			1 h	2 h		
Control	67.5	110.0 ± 5.0 b	28.3 ± 0.4 a	62.6 ± 0.4 bc	4.70 ± 0.14 b	44.3 ± 0.3 b
S + D	65.0	95.0 ± 0.0 d	26.3 ± 0.2 c	62.8 ± 0.5 bc	4.00 ± 0.07 cd	43.6 ± 0.1 c
S + 10B	72.0	96.7 ± 2.9 cd	28.0 ± 0.2 ab	67.5 ± 0.4 a	3.74 ± 0.23 d	45.7 ± 0.3 a
S + 30B	72.5	101.7 ± 2.9 cd	26.5 ± 0.1 c	60.0 ± 0.3 d	3.76 ± 0.06 d	45.7 ± 0.2 a
S + 10BR	70.5	103.3 ± 2.9 bc	25.8 ± 0.3 d	62.0 ± 0.2 c	4.11 ± 0.05 cd	44.8 ± 0.0 b
S + 30BR	72.0	96.7 ± 2.9 cd	24.5 ± 0.1 e	58.8 ± 0.6 d	3.95 ± 0.05 cd	45.5 ± 0.3 a
ES	69.0	130.0 ± 0.0 a	27.6 ± 0.2 b	63.5 ± 0.5 b	5.16 ± 0.24 a	44.8 ± 0.2 b
ES + 10BR	72.0	110.0 ± 0.0 b	26.1 ± 0.2 cd	63.7 ± 0.6 b	4.31 ± 0.13 c	45.6 ± 0.2 a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

Abbreviations: GRD, Gas retention of dough; GP, Total gassing power; SLV, Specific loaf volume

Fig. 1. Photographs and scanned images of breads and bread crumbs made from 8 different formulations of test flours.

sweet potato flours are added to wheat flour. Wheat flour replacement of S with ES caused a significant increase of GRD, and this result agreed with the report of Yamauchi *et al.* (2001) on breads made with medium-soft, strong and extra-strong wheat flours. Furthermore, the dough made from ES with 10BR maintained a GRD equivalent to the control.

GP of doughs made with 8 different formulations were 24.5–28.3 mL and 58.8–67.5 mL at 1 h and 2 h fermentation, respectively. The addition of 30B and 30BR to dough resulted in significantly lower GP compared to the corresponding doughs with added 10B and 30B throughout the fermentation period ($p < 0.05$). McCance *et al.* (1936) reported that the boiling of peeled potato tuber caused decreased contents of soluble constituents such as carbohydrates and minerals. Thus, this decrease in GP for 30B and 30BR added doughs may be due to leaching of fermentable substrates such as soluble sugars by prolonged boiling. The doughs made from S with 10BR and 30BR showed lower GP than those of the corresponding non-refrigerated potato flours, 10B and 30B, throughout the fermentation period. Refrigeration significantly lowered the content of damaged starch in potato flours in the present study, and Lelievre (1974) indicated that damaged starch is more susceptible to enzymatic degradation. In addition, it is well

known that wheat flour contains amylolytic enzymes such as α - and β -amylase (Kent, 1966); such amylolytic enzymes are responsible for potato starch degradation and the production of lower molecular weights sugars, and further increase the fermentable substrates available for yeast (Burton, 1989; Greene and Bovell-Benjamin, 2004). Therefore, refrigeration following the boiling process restricted gas production in the doughs.

SLV ranged between 3.74 mL/g and 5.16 mL/g, and significantly higher SLV was observed in the bread made with ES, followed by the control. A comparison of SLV among breads made from S with potato flours, the bread made from S with 10BR showed the highest SLV. B or BR addition led to lower SLV than the breads made with S or ES. Similar observations were reported by Greene and Bovell-Benjamin (2004), Hathorn *et al.* (2008) and Santiago *et al.* (2014) on decreases in SLV caused by sweet potato flour addition to wheat dough. According to He and Hosney (1991), SLV is mainly influenced by two factors: GP and GRD. In the present study, there was no significant correlation between GP and SLV ($r = 0.101 - 0.399$), while a highly significant positive correlation between GRD and SLV was observed ($r = 0.921$, $p < 0.01$), which agreed with the report by He and Hosney (1991). Hence, GRD may be the primary factor affecting SLV in the

Table 3. Color properties of bread crumbs made from tested formulations.

Formulation	L^*	a^*	b^*
Control	78.76 ± 1.68 ab	-2.16 ± 0.13 bc	9.08 ± 0.74 e
S + D	74.40 ± 1.61 d	-1.77 ± 0.04 a	12.05 ± 0.51 b
S + 10B	77.76 ± 1.45 abc	-2.45 ± 0.10 e	10.84 ± 0.53 cd
S + 30B	77.19 ± 2.19 bc	-2.27 ± 0.07 cd	10.45 ± 0.71 cd
S + 10BR	79.68 ± 0.95 a	-2.44 ± 0.06 e	11.27 ± 0.38 bc
S + 30BR	78.76 ± 1.25 ab	-2.13 ± 0.04 b	10.67 ± 0.37 cd
ES	77.16 ± 0.93 bc	-1.84 ± 0.03 a	10.04 ± 0.26 d
ES + 10BR	75.28 ± 2.09 cd	-2.31 ± 0.09 d	13.12 ± 0.70 a

Mean values in the same column with different letters are significantly different ($p < 0.05$).

present study. SLV of breads was significantly increased by wheat flour replacement of S with ES, and this result agreed with the report by Yamauchi *et al.* (2001) on breads made with medium-soft, strong or extra-strong wheat flour. The bread made from ES with 10BR had the highest SLV among breads with added potato flours. This improvement of SLV may be due to the formation of a greater gluten network by the extra-strong wheat flour.

The highest moisture contents were observed in the breads made from S with 10B and 30B among all breads. On the other hand, the bread made from S with D showed significantly lower moisture content ($p < 0.05$), which may have resulted from the lowest water absorption among all doughs.

Table 3 indicates the color properties of crumbs from the breads of 8 different formulations. L^* , a^* and b^* ranged from 74.40 to 79.68, -2.45 to -1.77 and 9.08 to 13.12, respectively. Significantly higher b^* was observed in the bread made from ES with 10BR ($p < 0.05$), and all breads with added potato flours had higher b^* than that of the control. The bread made from S with D showed the lowest L^* among all breads ($p < 0.05$). The primary reason for this decrease in L^* may be the addition of D, which had a significantly lower L^* among all potato flours ($p < 0.05$). Thus, it was recognized that the boiling of potatoes improved not only L^* of potato flours but also that of bread crumbs with added potato flours.

Figure 2 illustrates the changes in crumb hardness for breads made from 8 different formulations during storage. Hardness of all bread crumbs increased in a similar linear manner throughout the storage periods. In a comparison of hardness at all storage periods, there were no significant differences between the control and the breads made from S with 10B, 10BR, 30B and 30BR, while significantly higher hardness was observed in the bread made from S with D ($p < 0.05$). According to Maleki *et al.* (1980), higher moisture content and larger loaf volume produce a softer bread, and thus the highest hardness of the bread made from S with D may result from the lowest moisture content and smaller SLV. Wheat flour replacement of S with ES led to significantly lower hardness, i.e., higher softness of the bread crumbs than the control throughout the storage periods ($p < 0.05$). This increase in softness of the bread made from ES may be attributed to the significantly higher SLV ($p < 0.05$). The bread made from ES with 10BR

Fig. 2. The changes of crumb hardness during storage of breads made from tested formulations.

maintained significantly higher softness than the control, and did not significantly differ from the bread made from ES during 3 days of storage ($p < 0.05$). Higher SLV by ES addition and relatively higher moisture content by addition of 10BR may contribute to the higher softness of the bread made from ES with 10BR.

Conclusion

D, B and BR exhibited different physicochemical properties such as moisture content, damaged starch content, mean particle size and color properties. It was observed that refrigeration during potato flour production caused a significant decrease in damaged starch content ($p < 0.05$). Boiling led to improved color properties such as L^* and a^* for B and BR, which may have resulted from the inhibition of enzymatic browning. In a comparison of the water absorption of doughs, the doughs made from S with B and BR had higher values than the control and the dough made from S with D, possibly due to the higher content of damaged starch. The addition of potato flours to wheat flour resulted in lower GRD than the control. In a comparison of SLV among breads made from S with potato flours, the bread made from S with 10BR showed the highest SLV. The bread made from ES with 10BR showed higher SLV than those of other breads made from S with potato flours. Since B and BR had significantly higher L^* ($p < 0.05$), the breads made from S with B and BR had significantly higher L^* than that of the bread made from S with D. Moreover, the bread made from ES with 10BR maintained a significantly higher bread crumb softness than that of the control during 3-day storage ($p < 0.05$). It was revealed that boiling and refrigeration processes during potato flour production and selection of extra-strong wheat flour improved bread making quality. Therefore, BR produced from the table potato variety, May Queen, appears to have high applicability to bread making.

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