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Evaluation of the performance of flours from cross- and self-pollinating Canadian common buckwheat (*Fagopyrum esculentum* Moench) cultivars in soba noodles

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Abstract

Two Canadian cross-pollinating common buckwheat (*Fagopyrum esculentum* Moench) varieties, Koban and Koto, and two self-pollinating lines, BR01 and BR06, were dehulled and roller milled on a pilot mill to produce three distinct milled products, white flour, dark flour and whole groat flour. The white flours contained mostly starch (79.2–87.2%), whereas the dark flours were rich in proteins (37.1–38.7%), dietary fibre (15.2–22.0%), ash (5.49–5.99%), and fagopyritols (1420–2220 mg/100 g). The buckwheat flours were blended with wheat flour (Canada Western Red Spring straight grade flour) at 60:40 ratios and evaluated for soba noodle properties. Significant differences in milling properties, and in raw noodle colour and texture were detected among cultivars, although the impact of flour type on noodle properties was far greater. The self-pollinating lines exhibited comparable milling and soba noodle properties to Koban. Koto exhibited slightly higher white flour yield and generally firmer noodle texture compared to the other lines. White flours produced the brightest noodles, followed by whole groat and dark flours. Dark flours yielded the thickest cooked noodles with the largest maximum cutting stress and greatest resistance to compression. Noodles prepared with white flour offered the best chewiness, springiness and recovery parameters. Soba noodles prepared with dark flours contained considerably higher amounts of minerals, proteins, dietary fibre, and fagopyritols than noodles prepared with white flour.

Keywords: Buckwheat; Soba noodles; Fagopyritols; Flour

1. Introduction

Common buckwheat (*Fagopyrum esculentum* Moench) is a broad-leafed herbaceous annual that belongs to the family Polygonacea. Because its seed resembles cereal grains structurally and chemically, buckwheat is usually handled and classed with cereals (Pomeranz, 1979; Li & Zhang, 2001).

Buckwheat has gained an excellent reputation for its nutritious qualities in the human diet (Mazza & Oomah, 2005; Wijngaard & Arendt, 2006). Buckwheat proteins have a well-balanced amino acid composition, exhibiting one of the highest amino acid scores of plant foodstuffs (Ikeda, 2002). Buckwheat is gluten-free and can be used by those with celiac disease (Wijngaard & Arendt, 2006). Buckwheat protein also acts similarly to dietary fibre by exhibiting cholesterol-lowering and antihypertension effects, and reducing constipation and obesity (Ikeda, 2002; Li & Zhang, 2001). Fagopyritols, mono-, di-, and trigalactosyl derivatives of D-*chiro*-inositol, have been associated with reduction of symptoms of non-insulin-dependent diabetes mellitus and suggested as natural constituents to treat diabetes (Kawa, Taylor, & Przybylski, 2003; Steadman et al., 2000). Incorporation of buckwheat

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into bread has been shown to significantly lower postprandial blood glucose and insulin responses compared to white wheat bread, and has potential use in the production of foods with lower glycemic index (Skrabanja, Elmstahl, Kreft, & Bjorck, 2001). Rutin and quercetin are the main polyphenols with antioxidant activity present in buckwheat (Oomah & Mazza, 1996; Holasova et al., 2002). In addition to their antioxidant activity, both rutin and quercetin can help with treatment of chronic venous insufficiency/peripheral vascular disease (Erlund et al., 2000).

Buckwheat usually is roller milled or ground on stone mills either to produce whole grain flour, or to produce fractions/flours by combining streams (Ikeda, 2002; Skrabanja et al., 2004). The textural characteristics of heated buckwheat dough differ among buckwheat flour fractions (Ikeda, Kishida, Kreft, & Yasumoto, 1997). Bonafaccia, Marocchini, and Kreft (2003) found that for stone ground buckwheat, lipids, protein and some B vitamins were more concentrated in bran than flour. Fagopyritols and soluble carbohydrates also concentrate in bran because they are found in embryo and aleurone tissues (Steadman et al., 2000). Phytate, minerals and polyphenolics, including tannins, are also concentrated in the bran, whereas rutin is concentrated in the hull (Steadman, Burgoon, Lewis, Edwardson, & Obendorf, 2001b). Fancy white flour is largely starchy endosperm, so compared to bran it contains much lower levels of protein, lipid, other soluble carbohydrates and total dietary fiber, and more starch (Steadman, Burgoon, Lewis, Edwardson, & Obendorf, 2001a).

Traditional foods made from buckwheat flour are consumed in China, Japan, Korea and Bhutan, with Japanese buckwheat consumption primarily in the form of noodles (Ikeda, 2002). Buckwheat, or soba noodles, are normally made from a blend of common wheat flour and buckwheat flour, *sobako.* The Japanese Food Agency stipulates that a minimum of 35% buckwheat must be present for noodles to be called soba. Most of the soba noodles contain at least 60% of buckwheat. Some hand made soba noodles, available only in selected restaurants, are made with 100% buckwheat flour. In Europe and North America, buckwheat has been blended with other grains to produce multigrain pasta (Catelli, 2007), energy bars, waffles, pancake mixes, cereal flakes (www.glutino.com), crepes, bagels and bread (Dempster's, 2007; http://www.dempsters.ca/products/Wholegrains_12Grain.html).

Buckwheat is a well-established special crop in Canada with production occurring mainly in the province of Manitoba (Canadian Special Crops Association, 2007). A major breeding emphasis in Manitoba is the development of self pollinating buckwheat, aimed at decreasing weather-related variability in yields, and enhanced quality characteristics. Value-added processing of buckwheat into a variety of Asian-type noodles (e.g., soft, firm, fresh, instant) has a tremendous potential to expand on both international and domestic markets, given the verifiably high demand for a new generation of food products that are convenient, palatable, and deliver health benefits. This study was initiated to compare the soba-making potential of two promising self-pollinating lines to two cross-pollinating lines, Koban a popular large seeded variety, and Koto, a new black-hulled variety. Another objective of this study was to determine the effects of various buckwheat flour refinements on the composition, appearance and texture of buckwheat soba noodles.

2. Materials and methods

2.1. Materials

Two buckwheat varieties, Koto and Koban, and two experimental self-pollinating lines, BR01 and BR06, were grown in southern Manitoba in 2003 and obtained from Kade Research Ltd (Morden, MB). The source of wheat flour was commercially grown No 1 Canada Western Red Spring (CWRS) wheat.

2.2. Methods

2.2.1. Milling

The CWRS wheat was conditioned to 16.5% moisture, and milled into a straight-grade flour of about 75% extraction on the Grain Research Laboratory (GRL) tandem Buhler pilot mill (Buhler, Uzvil, Switzerland) as per Martin and Dexter (1991).

The buckwheat samples were dehulled using an 8" stone dehuller (R-Tech Industries, Homewood, MB). Groats were conditioned to 14% moisture overnight and milled on the GRL tandem mill. Because buckwheat groats are much softer than CWRS, the wheat mill flow of Martin and Dexter (1991) was shortened to include only three breaks (instead of four) without a bran finisher passage, one sizing passage (quality passage eliminated) and four reduction passages (instead of six) (Table 1). Buckwheat was fed to the mill at 175 g per minute. Roll gaps were set at 0.0087 mm for first break, 0.0014 mm for third break, 0.00098 mm for sizing, 0.0014 mm for first reduction, 0.00059 mm for third reduction and 0.00098 mm for fourth reduction. Three buckwheat milled products were prepared: white flour (three break flours, sizing flour and first and second reduction flours combined), dark flour (remaining reduction flours and shorts from last reduction) and whole-groat flour (all fractions combined including bran).

2.2.2. Analytical

Buckwheat moisture content was determined by AACC (2000) Approved Method 44–15 A. Analytical data are expressed on a dry matter basis.

Tristimulus colour coordinate measurements were performed with a Minolta Chroma Meter CR 300 Minolta Canada Inc., Mississauga, Ontario. Colour readings were expressed by Judd-Hunter values for L^* (brightness), a^* (red-green chromaticity) and b^* (yellow-blue chromaticity) (Francis, 1983).

Table 1
Summary of roller milling yields and ash and protein contents (%N × 5.7) of individual milling streams (dry matter basis) of Canadian cross-pollinating buckwheat cultivars, Koto and Koban, and two self-pollinating lines, BR01 and BR06[a]

Milling streams	Koto			Koban			BR01			BR06		
	Milling yield %	Ash %	Protein (%)	Milling yield (%)	Ash (%)	Protein (%)	Milling yield (%)	Ash (%)	Protein (%)	Milling yield (%)	Ash (%)	Protein (%)
Break 1 (B1)	10.3	0.32	4.7	10.2	0.32	4.7	10.8	0.32	4.8	10.8	0.23	4.2
Break 2 (B2)	18.0	0.27	4.5	18.2	0.30	4.6	17.4	0.31	4.6	18.1	0.18	4.1
Break 3 (B3)	1.9	0.42	5.5	1.9	0.45	6.0	1.6	0.49	6.4	2.0	0.41	5.6
Sizing (S)	24.4	0.44	5.7	22.8	0.45	5.6	18.5	0.46	5.8	23.5	0.42	5.6
Reduction 1 (R1)	18.0	1.05	9.7	12.9	0.97	9.1	16.4	0.96	9.1	15.5	1.22	10.5
Reduction 2 (R2)	8.4	2.76	19.9	8.4	2.55	19.2	8.2	2.27	17.7	7.1	3.46	25.7
Reduction 3 (R3)	4.5	5.70	38.0	5.0	5.10	36.1	5.0	5.08	36.0	4.5	6.08	43.6
Reduction 4 (R4)	2.7	5.84	39.0	5.2	5.60	39.6	3.8	5.69	39.9	3.4	5.80	41.9
Bran	4.7	4.29	33.3	4.0	6.65	45.3	5.1	6.34	46.9	4.6	5.74	35.0
Fine Bran	2.0	6.67	33.3	1.7	4.54	33.1	2.4	4.42	35.0	2.1	4.29	44.0
Shorts	4.0	5.83	41.4	8.3	5.99	48.7	10.3	5.96	44.0	7.0	5.68	45.9
White flour (B1-R2)	81.0	0.76	6.5	74.4	0.71	6.4	72.9	0.72	6.8	77.0	0.78	7.2
Dark flour (R3-shorts)	17.4	5.49	37.1	24.2	5.99	37.1	26.6	5.69	38.0	21.6	5.66	38.7
Whole flour (B1-shorts)	98.9	1.86	13.4	98.6	2.05	14.2	99.5	2.05	15.1	98.6	1.86	14.2

[a] Yields expressed as percentage of dehulled buckwheat recovered in each stream. Total recoveries are less than 100% due to some moisture lose, and some loss of fine material. White flour comprises all break flours, sizing flour and the first two reduction flours. Dark flour comprises remaining reduction flours, bran (from break 2), fine bran (from sizing) and shorts (from fourth reduction). Whole flour comprises all milling streams.

Protein content (%N × 5.7) was determined by combustion nitrogen analysis (CNA) with a LECO Model FP-428 Dumas CNA analyzer (Williams, Sobering, & Antoniszyn, 1998). Ash content was determined by AACC (2000) Approved Method 08–01. Starch and amylose contents were determined using commercial assay kits (Megazyme International, Bray, Ireland) according to AACC (2000) Approved Method (76–13) and to the method of Gibson, Solah, and McCleary (1997), respectively. The soluble and total dietary fibre contents were determined by the enzymatic-gravimetric procedure by AACC (2000) Approved Method 32–31. Fagopyritols and D-*chiro*-inositol were extracted from buckwheat flours with ethanol/water (1:1) and analyzed by gas chromatography according to the method of Kawa et al. (2003). RVA pasting curves were obtained using a Rapid-Visco Analyzer RVA-4 (RVA, Newport Scientific, Warriewood, Australia). Flours (3.5 g, 14% m.c) were mixed with water (25 mL) and analyzed according to the 13-min general pasting method. All analytical tests were conducted in duplicate and coefficient of variation (CV) was ⩽5% in each case.

2.2.3. Microscopy

Samples were prepared for SEM by mounting them onto aluminum stubs covered with double-sided carbon adhesive discs and allowed to set for 24 h. The mounted samples were placed in a Hummer VII (Anatech, Ltd., Alexandria, USA) sputter coater and coated with 50 nm of gold and examined with a JEOL JSM-6400 scanning electron microscope (Tokyo, Japan) at 10 KV.

2.2.4. Noodle preparation

Each buckwheat flour was individually blended with the CWRS flour at a 60:40 ratio. When the dark flour was blended an absorption level of 32% was required, while both the white flour and whole-groat blends required an absorption level of 40%.

The flour-buckwheat blends (50 g) and water were mixed for 30 s at 3000 RPM using a Speed mixer (Model DAC 150 FV, FlackTec Inc., Landrum, SC) in a Pin Max 80 bowl according to the method of Hatcher and Preston (2004). The resulting dough was hand-molded into a rectangular shape, placed on a rolling board and hand-sheeted to a thickness of 2 mm using a depth guide and wooden rolling pin (Dahliwal, Hatcher, Sekhon, & Kruger, 1996).

The dough sheet underwent four further reductions on an Ohtake noodle machine (Otake, Tokyo, Japan) at successive roll gap settings of 2.0, 1.6, 1.3 and 1.1 mm, incorporating a 30 s rest between passes. The rolls were maintained at 33 °C. The resulting dough sheet was cut into noodles with a B12 cutter.

2.2.5. Raw noodle colour

A Labscan II spectrocolourimeter (HunterLab, Reston, VA) equipped with a D65 illuminant using the L^*, a^*, and b^* colour scale was used to measure raw noodle colour.

Two hours after processing, a portion of the raw noodle sheet was folded three times. The sheet was enclosed within a blackened container to exclude ambient light. Measurements were made in triplicate at two locations on the noodle sheet surface. The remaining raw noodle sheet was stored in a sealed plastic bag at 24 °C and colour was measured again 24 h after processing.

2.2.6. Cooked texture analyses

Fresh noodles were allowed to rest for 1 h prior to texture evaluation. The noodles were cooked in boiling water until no visible core was detected (80 s), rinsed under running distilled water maintained at 20 °C, drained, and stored in small sealed plastic tubs until textural analyses as per Kruger, Anderson, and Dexter (1994).

Texture measurements of cooked noodle "bite", as defined by maximum cutting stress (MCS) and chewiness via recovery (REC) and resistance to compression (RTC), were conducted using a TA-XT2i (Texture Technologies, Scarsdale, NY) with fixtures and procedures similar to those described by Oh, Seib, Deyoe, and Ward (1983) and Kruger et al. (1994).

Stress relaxation was determined using the method of Sopniwnyk (1999), a modified version of the methods presented by Heaps, Webb, Russell-Eggitt, and Coppock (1968), Frazier, Leigh-Dugmore, Daniels, Russell Eggitt, and Coppock (1973) and Rasper and deMann (1980). Cooked noodles (3 strands) were compressed to a 250 g load and the stress was allowed to relax under constant sample deformation using the TA-XT2i. As it required greater than 10 minutes per test to achieve 36.7% of the initial stress (Rasper & deMann, 1980), reduction to 85% of initial stress, as used by Sopniwnyk (1999) was chosen. The noodles received an initial load of 1.25 g/mm^2 and measurements were recorded until the force decreased by 15%.

Texture profile analysis (TPA) was performed on the cooked noodles as per Bourne (2002). Texture testing commenced 10 min after the rinse step. Noodle temperature at the start of testing was 16 °C. The testing order remained constant, beginning with MCS, compression analyses (RTC and REC), stress relaxation and finally TPA. The respective texture measurements were performed at specific timed intervals of 10, 15, 20 and 25 min. Cooked noodle thickness was determined at the point where 2 g of force was recorded on the TX-XT2i unit.

2.2.7. Experimental design

All noodles were processed in triplicate following a randomized design. Texture measurements of cooked noodles were carried out five times on sets of three noodle strands for each noodle replicate. All statistical analyses were carried out using SAS (SAS Institute, Cary, NC) version 8.2. Analysis of variance (ANOVA) was determined using Proc GLM or Mixed, nesting flour type within buckwheat line. The use of significance throughout the manuscript is based upon $P < 0.05$ unless stated otherwise.

3. Results and discussion

3.1. Buckwheat milling properties and flour composition

The buckwheat cultivars and lines exhibited different milling properties (Table 1). Relatively small variations in the yield of the break flours were observed among the different lines, but major differences were noticed in the yield of sizing flour (S) and first reduction flour (R1). Among the four buckwheat lines, Koto gave the highest amount of S and R1 flours, BR01 the smallest amount of S flour, whereas Koban the smallest amount of R1 flour. Another notable difference was in the yield of shorts from the final reduction passage, with Koto yielding the smallest amount. The ash and protein contents in individual milling streams showed an increasing pattern, with break flours exhibiting the lowest amount, reduction flours an intermediate amount, and the bran and short fractions the highest amount of ash and protein (Table 1). The milling streams were combined based on the ash and protein contents of individual streams to obtain three ground buckwheat products differing in appearance and composition and yielding a reasonable amount of milled products. Therefore, the white flour was prepared by combining the three break flours, sizing flour and first and second reduction flours. The dark flour comprised remaining reduction flours, bran (from break 3), fine bran (from sizing) and shorts. The whole-groat flour was obtained by combining all flour streams including bran and shorts. Koto gave the highest yield of white flour, Koban and BR01 the lowest yields, and BR06 an intermediate yield. Variations among cultivars were also apparent for all dark flour streams; Koto gave the lowest yield of dark flour, and Koban and BR01 the highest. It is possible that differences in milling performance observed among cultivars could be minimized by optimizing roll settings, however, the objective of this study was to compare the milling performance of buckwheat lines under the same milling regime.

The compositions of white and dark flour in relation to whole flour for the cultivars in this study are in general agreement with previous reports on the composition of roller milling fractions from common buckwheat, although the milling streams in this study were combined somewhat differently compared to previous studies (Bonafaccia et al., 2003; Skrabanja et al., 2004; Steadman et al., 2000, 2001a, 2001b). The white flour obtained in this study, appeared to contain clusters of starch granules surrounded by thin cell walls (Fig. 1b), and originated mostly from the central endosperm (Fig. 1a). The white flour was much brighter (higher L^* value), less yellow (lower b^* value), lower in ash, lower in protein content and higher in starch content than dark flour (Table 2). The dark flour, containing fragments of the seed coat, embryo, maternal tissues, and starch granules associated mostly with the peripheral tissues or cotyledons (Fig. 1c and d), was very rich in protein, averaging over 37% among cultivars. The dark flour also was rich in ash and other bioactive components such die-

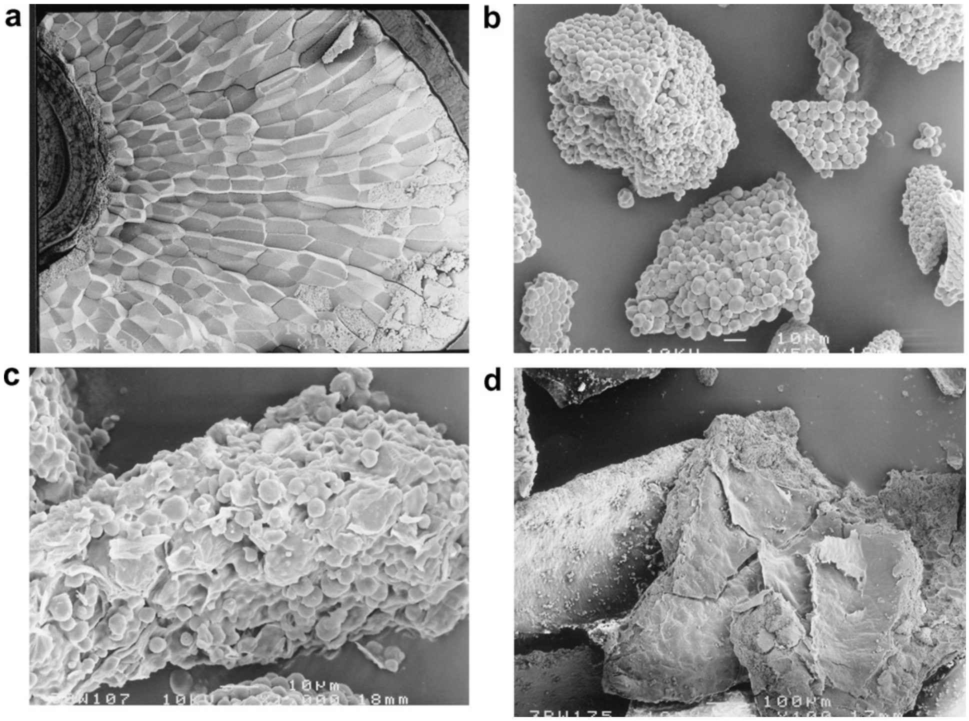

Fig. 1. SEM micrographs of a cross section of the buckwheat groat, cv. Koto (a); white flour particles (b); and dark flour particles (c and d).

Table 2
Composition (dry matter basis) and colour values of roller milling products from Canadian cross-pollinating buckwheat cultivars and self-pollinating lines

Milling products	Color values			Starch, %	Fiber, %		Total Fagopyritols, mg/100 g	Free D-*chiro*-Inositol, mg/100 g
	L^*	a^*	b^*		Total	Soluble		
Koto								
White flour	91.7	−0.4	6.3	79.2	4.64	1.62	101	3.4
Dark flour	80.5	−0.2	11.6	29.8	22.0	2.18	2220	43.4
Whole flour	85.8	−0.4	9.0	69.3	7.70	1.70	485	10.6
Koban								
White flour	91.8	−0.6	6.5	83.6	5.44	1.74	171	4.5
Dark flour	79.8	−0.7	12.4	28.0	17.6	2.10	1470	30.6
Whole flour	85.7	−0.5	8.9	69.0	8.30	1.80	491	10.9
BR01								
White flour	91.8	−0.4	6.2	85.8	5.30	1.69	191	5.5
Dark flour	79.9	−0.2	12.0	27.2	15.2	1.80	1420	32.8
Whole flour	85.8	−0.4	8.8	69.8	7.90	1.70	521	12.8
BR06								
White flour	92.0	−0.6	6.4	87.2	4.20	1.27	185	5.4
Dark flour	79.6	−0.3	12.8	29.2	15.9	1.93	1630	37.9
Whole flour	86.3	−0.3	8.3	73.5	6.70	1.40	503	12.5

tary fibre, and fagopyritols (Table 2). Our results confirmed that the dark flour, containing bran fractions and the 3rd and 4th reduction flour streams, was a very good source of fagopyritols and free D-chiro-inositol. The dietary fibre (DF) constituents were also concentrated in the dark flour, but the majority of DF in the dark flour was insoluble. Interestingly, the DF associated with the white flour exhibited much greater solubility than DF present in the dark flour. The lower starch content of dark flour compared to white and whole meal flour is a likely explanation for the lower water absorption (32% versus 40% for the others) needed to sheet it into noodles. Buckwheat starch granules are small (Fig. 1b), and therefore exhibit high water absorption due to large surface area (Dexter & Matsuo, 1979).

The pasting parameters for all buckwheat samples are shown in Table 3. All whole flours and white flour fractions exhibited relatively high peak viscosity, final viscosity and

Table 3
RVA pasting parameters for whole, white, and dark buckwheat flours

Sample	Peak viscosity (RVU)	Trough (RVU)	Breakdown (RVU)	Final viscosity (RVU)	Setback (RVU)	Peak time (min)
Whole flour						
Koto	259 ± 1.9	229 ± 3.4	30.1 ± 1.4	507 ± 7.0	278.0 ± 3.5	6.1 ± 0.1
Koban	222 ± 2.5	208 ± 1.2	14.3 ± 3.7	462 ± 2.7	264.1 ± 3.8	6.3 ± 0.1
BR01	217 ± 2.5	197 ± 0.3	20.7 ± 2.2	451 ± 12	264.92 ± 12	6.2 ± 0.0
BR06	229 ± 0.5	209 ± 2.6	19.5 ± 3.1	460 ± 0.9	250.9 ± 1.7	6.4 ± 0.0
White flour						
Koto	365 ± 1.2	311 ± 11	54.4 ± 10	654 ± 2.7	343.3 ± 14	5.9 ± 0.1
Koban	372 ± 0.7	325 ± 0.2	47.6 ± 0.9	691 ± 2.9	366.6 ± 3.1	5.8 ± 0.0
BR01	379 ± 1.5	327 ± 1.3	51.4 ± 0.2	678 ± 2.7	350.4 ± 1.4	5.8 ± 0.0
BR06	374 ± 1.8	331 ± 0.3	43.0 ± 1.5	685 ± 5.1	353.8 ± 4.8	6.0 ± 0.0
Dark flour						
Koto	26.8 ± 0.9	23.4 ± 0.6	3.4 ± 0.4	53.2 ± 0.3	29.8 ± 0.3	7.0 ± 0.0
Koban	26.1 ± 0.1	23.3 ± 0.2	2.8 ± 0.4	45.9 ± 0.5	22.6 ± 0.7	6.9 ± 0.1
BR01	27.3 ± 0.1	23.8 ± 0.1	3.4 ± 0.0	48.4 ± 0.1	24.6 ± 0.2	7.0 ± 0.0
BR06	25.7 ± 0.3	23.0 ± 0.2	2.7 ± 0.5	45.1 ± 0.9	22.0 ± 0.8	6.9 ± 0.2

setback values compared to those obtained for the wheat flour. These results confirm the differences in the physicochemical properties between buckwheat and cereal starches and indicate a greater swelling and gelling tendency for buckwheat starch than for wheat starch in agreement with previous reports (Li, Lin, & Corke, 1997; Yoshimoto et al., 2004). High setback and final viscosity values of flours are often associated with firm texture of pasta and noodle products (Bhattacharya & Corke, 1996). The differences in the pasting properties between buckwheat whole flour and white flour fractions can be ascribed to the differences in their starch contents (Table 2). The dark flour fractions exhibited very low pasting parameters compared to whole and white flours because of substantially lower starch content in the former.

Table 4
Colour values for raw buckwheat noodles containing 60% buckwheat flour at 2 h and 24 h after preparation

Noodle	L^*		a^*		b^*	
	2 h	24 h	2 h	24 h	2 h	24 h
White flour						
Koto	81.0	75.5	−0.14	0.84	13.2	13.8
Koban	80.9	75.6	−0.28	0.93	13.3	12.5
BR01	80.9	78.8	−0.01	0.89	13.3	15.0
BR06	81.3	78.9	−0.31	0.50	13.4	15.1
Dark flour						
Koto	56.4	50.6	5.38	5.67	20.6	19.5
Koban	56.4	50.1	4.25	4.49	21.6	19.8
BR01	55.8	50.3	5.33	5.52	21.5	20.4
BR06	56.9	50.9	5.02	5.20	21.9	20.3
Whole flour						
Koto	72.8	66.8	2.09	3.04	17.0	16.9
Koban	70.9	65.3	1.76	2.88	18.4	16.5
BR01	69.4	67.5	2.74	3.51	19.1	20.3
BR06	72.2	70.0	1.80	2.65	18.4	19.4
LSD[a]	1.53	1.81	0.51	0.56	1.19	1.42

[a] LSD = least significant difference within a column.

3.2. Properties of noodles prepared with 60% buckwheat flour

3.2.1. Raw noodle colour

Examination of raw noodle colour for noodles prepared with 60% buckwheat flour at 2 h and 24 h after preparation indicated that for all colour components, brightness (L^*), redness (a^*) and yellowness (b^*), there were highly significant ($P < 0.0001$) effects due to both flour type and cultivar (Table 4). Although differences in raw noodle colour attributable to cultivar were observed, differences were minor compared to the effects of flour type, and therefore would be unlikely to have much impact on consumer acceptance.

As anticipated, preparation from the high starch content white flour yielded significantly brighter noodles than corresponding whole meal noodles, which in turn, were significantly brighter than noodles prepared using the dark flour. These results were consistent with the significant differences observed in the corresponding brightness (L^*) of the respective dry flours (Table 2). Noodles prepared with either white or whole meal flours from BR01 and BR06 exhibited a significantly smaller decline in noodle brightness over 24 h compared to either Koto or Koban. No appreciable differences due to cultivar were observed in decline of noodle brightness over 24 h for noodles prepared using the dark flours.

Raw buckwheat noodles redness (a^*) at both 2 h and 24 h after preparation was greatest when dark flours were used, significantly lower for whole flour, and still lower for white flours. Aging noodles for 24 h resulted in generally consistent increases in noodle redness across all varieties and flours. Similarly, dark flours imparted the greatest yellowness (b^*) to raw buckwheat noodles, white flour the least yellowness while whole meal gave intermediate values. Yellowness values declined significantly for all Koban raw noodles over 24 h, whereas yellowness values for the other cultivars exhibited less consistent and generally minor changes in yellowness.

3.2.2. Cooked noodle properties

The texture of wheat noodles is directly related to flour protein content, and in particular gluten proteins because of the unique visco-elastic properties (Crosbie, Ross, Moro, & Chiu, 1999). The high protein content of the CWRS base flour (16.4% on a dry mater basis) makes it ideal to blend with the buckwheat flours, because buckwheat proteins are primarily globulins (Ikeda, Sakaguchi, Kusano, & Yasumoto, 1991; Radovic, Maksimovic, Brkljacic, & Varkonji-Gasic, 1996; Wijngaard & Arendt, 2006), and hence would not be expected to integrate into the wheat gluten network. Noodle texture is also influenced by starch amylose content (Guo, Jackson, Graybosch, & Parkhurst, 2003). However, the narrow range of starch amylose content among buckwheat lines in the current study (21.6–22.2%) would not be expected to significantly impact noodle texture. The strong gelling properties of buckwheat starches, on the other hand, are likely to substantially contribute to the texture of soba noodle. For example, the texture of hand-made soba noodles prepared from 100% buckwheat flour is almost solely attributed to the properties of buckwheat starch.

Water uptake during cooking was not significantly ($P > 0.05$) affected by buckwheat cultivar, but flour type was found to be highly significant ($P < 0.0001$), with the largest water uptake during cooking occurring for noodles prepared using whole groat flour, followed by the white flour and finally the dark flour within a cultivar (Fig. 2a). The lower starch content of dark flour is likely a major reason for the lower water uptake of dark flour noodles. The differences in water uptake of white flour noodles compared to whole groat noodles may reflect differences in their composition as well as differences in hydration properties of starch and non-starch polymers during processing (Franks, 1991).

Cooked noodle thickness, while also being significantly ($P < 0.05$) influenced only by flour type, displayed a different pattern than would be anticipated from the amount of water uptake only (Fig. 2b). In all cases cooked dark flour noodles were thicker than either cooked white flour or whole groat noodles. These results again point to a different mechanism of water imbibition by starch versus insoluble fibre particles. With the exception of the cultivar BR06, no differences in noodle thickness were observed between white or whole groat noodles.

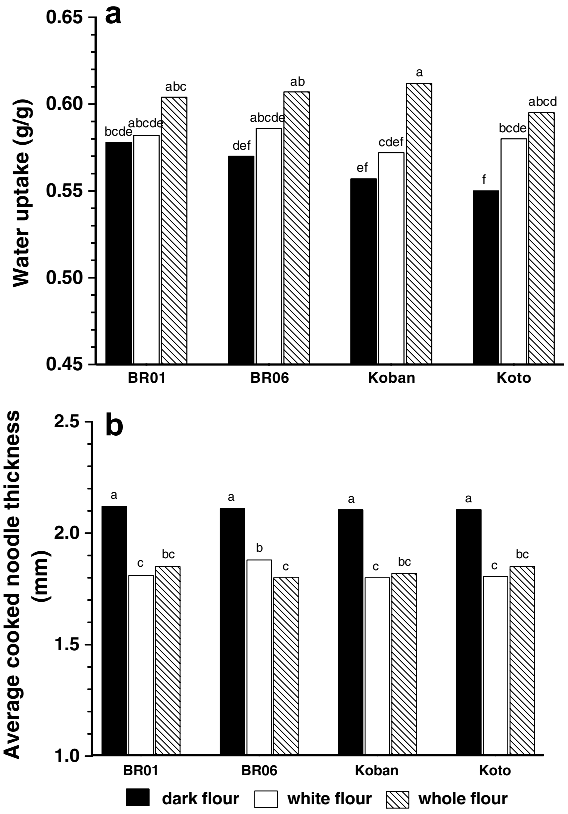

Fig. 2. Water uptake during cooking (80 s) for the various buckwheat (60:40) noodles for different buckwheat cultivars and flour types (a). The resulting thickness of the various buckwheat noodles (60:40) for different buckwheat cultivars and flour types (b).

The consumer's first impression of noodle texture is governed by the "bite" (MCS) of the noodle when the front teeth close. Buckwheat cultivar, flour type and cultivar to flour type interactions all exerted significant effects on MCS. Within each cultivar significantly greater MCS values were found for noodles prepared using dark flour, followed by white and whole groat flours (Fig. 3a). Several factors likely contribute to the greater MCS of dark noodles including their greater thickness, lower water uptake, and presence of considerable amounts of fibre particles. During cooking of noodles, these fibre particles are expected to entrap water, swell, and even exude some soluble fibre components, but even after cooking they remain in the noodles as distinct particles reinforcing the noodle matrix. On the other hand, the presence of fibre particles disrupts the continuity of protein-starch network resulting in lower noodle firmness. The overall effect of fibre particles in noodles depends on the relative amount of starch, protein, and fibre content in a given system. A small amount of fibre particles most likely disrupts the protein -starch network rather than contribute to the firmness of noodles. This could explain why the soba noodles containing whole groat flour exhibited lower MCS values than their counterparts made from white buckwheat flour. In the case of dark flour noodles, containing two to three times more DF than whole buckwheat noodles, the contribution of DF to noodles firmness was substantial, resulting in a greater firmness of dark than whole flour noodles. Noodles prepared using Koto dark flour exhibited the highest MCS values among all buckwheat lines, consistent with having the highest DF content (Table 2). Significant differences in MCS values were also observed among other buckwheat lines. Noodles prepared from whole groat flour, with the exception of Koto, displayed significantly lower MCS characteristics than those noodles prepared using white flour.

The first indication of noodle chewiness is provided by resistance to compression (RTC) as cooked noodles are compressed between back molars. Evaluation of the RTC

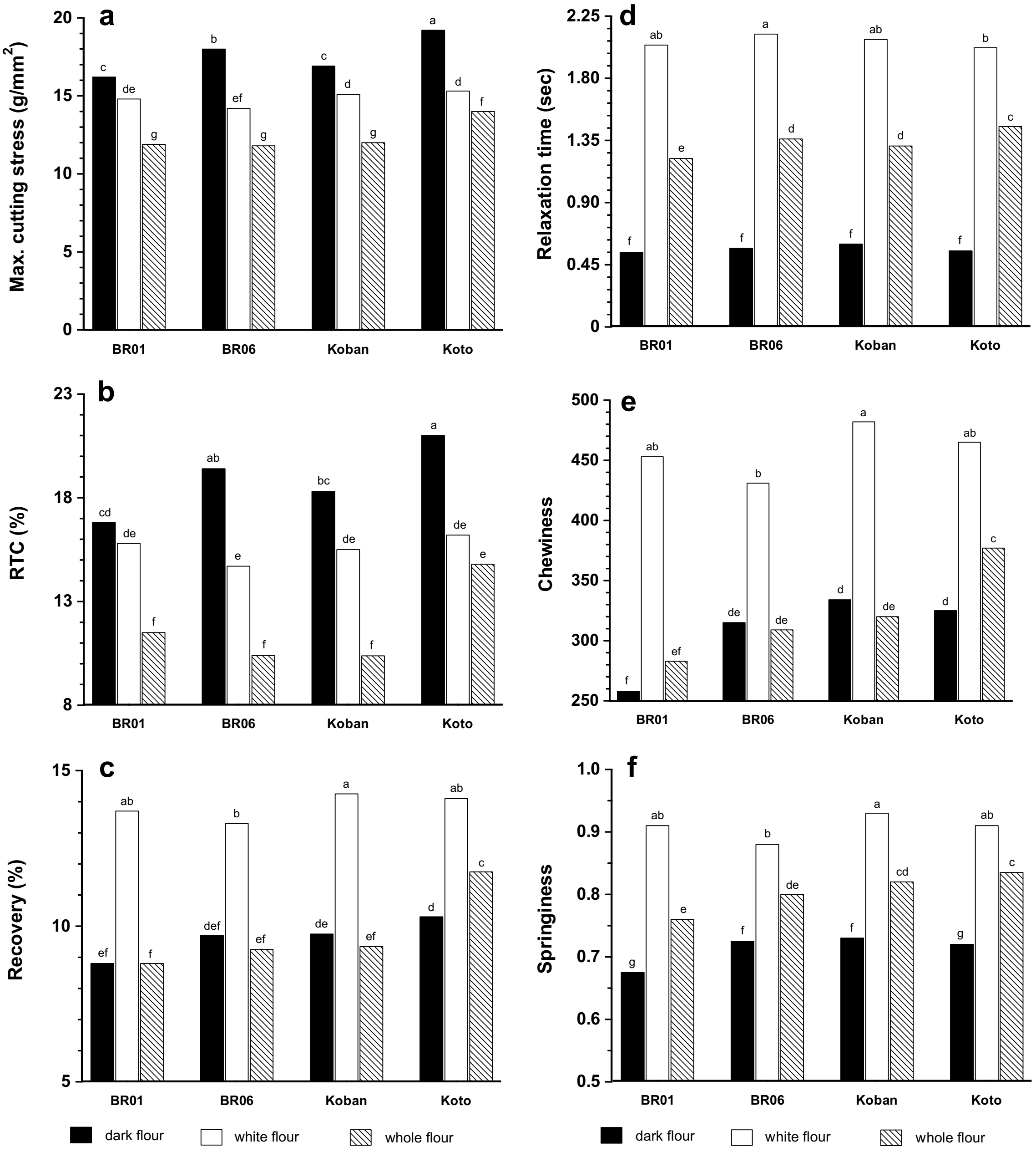

Fig. 3. Texture parameters of soba noodles prepared with 60% buckwheat flours and 40% wheat flour. (a) Maximum cutting stress; (b) Resistance to compression; (c) Recovery; (d) Relaxation time; (e) Chewiness resistance to compression; (f) Springiness.

of buckwheat noodles indicated that cultivar, flour and cultivar to flour interaction were all significant, but the influence of flour type far outweighed the importance of the others (Fig. 3b). As was the case for MCS, the largest RTC values were found in those noodles prepared from dark flours and the lowest RTC values were found in whole groat noodles. The cultivar rankings were the same as for MCS, with Koto displaying the greatest RTC, but unlike for MCS, Koto RTC values were not significantly different from those of BR06. All noodles prepared using white flour, with the exception of BR01, exhibited significantly lower RTC than those prepared from dark flour. White buckwheat flour noodle RTC values were not significantly influenced by cultivar. Noodles prepared from BR01, BR06 and Koban whole groat flour showed low RTC values, with Koto exhibiting significantly better results.

Recovery values were significantly influenced by cultivar, flour and cultivar to flour interaction. Once again Koto differentiated from the other cultivars and lines by exhibiting significantly better recovery values for dark flour and whole groat noodles than the other cultivars. In direct contrast to MCS and RTC, the largest recovery values were observed using white buckwheat flour, and the lowest for dark flour (Fig. 3c). These recovery rankings are directly related to starch content (Table 2), and reflect the unique gelation properties of buckwheat starch. It has been shown that buckwheat amylopectin exhibit very high molecular weights as well as containing a considerable portion of unusually long linear chains compared to other cereal starches (Yoshimoto et al., 2004; Izydorczyk, You, & Campbell, 2004). The length and amount of long linear chains in the structure of amylopectin can explain certain properties of buckwheat starches such as the high iodine affinity, strong gelation properties, as well as swelling and pasting properties (Noda et al., 1998). The formation of strong starch gels upon cooling and further reinforcement of the networks upon retrogradation would be expected to exert a positive influence on cooked noodle recovery values.

Relaxation time provides an insight into the structural matrix of noodles, as it indicates the time to achieve a fixed deformation under a constant, applied strain. A longer relaxation time indicates better structural integrity and the ability of the structure to resist collapse. There were significant cultivar and flour effects observed on relaxation time, with maximum relaxation times being observed for noodles prepared using 60% white flour (Fig. 3d). Relaxation times for dark flour noodles were the lowest among the flour types, with whole flour noodles giving intermediate values. The differences in relaxation values again reflect substantial differences in composition of white, dark and whole buckwheat flours noodles. While the dark flour has very high protein and insoluble dietary fibre contents, both these constituents are unable to form strong viscoelastic networks and, therefore, the gelling properties of the buckwheat starch would supersede the influence of high buckwheat protein and DF contents on relaxation time.

Texture profile analyses (TPA) offer a complementary means by which to assess noodle texture (Bourne, 2002). Unlike the previously described methods, TPA attempts to mimic the mastication process by measuring the force response measurements of two repetitive compressions on the same noodle site. In this study, the chewiness and springiness of the noodle by this dual step process were evaluated and compared against the previous single stage measurements. Chewiness results (Fig. 3e) were consistent with trends observed for both recovery and relaxation time. Buckwheat noodles prepared with white flour yielded significantly chewier noodles (greater force) than those prepared with either of the two other flours for the reasons explained above. BR06 yielded a significantly lower chewiness value for white flour noodles than for the other buckwheat cultivars. The BR06 white flour noodle chewiness value was still significantly higher than for noodles made from dark and whole meal flours, regardless of cultivar. It was of interest to note that Koto was somewhat anomalous, being the only cultivar to exhibit a significantly larger chewiness value for whole groat noodles than for dark flour noodles.

Noodle springiness displayed a similar pattern to chewiness, noodles prepared with the white flour yielding significantly higher springiness values than the corresponding dark or whole groat flours (Fig. 3f). However, unlike chewiness, all noodles prepared with whole meal flour showed significantly greater springiness than those prepared from dark flour. Koto whole groat flour yielded significantly higher springiness values than BR01 and BR06.

4. Conclusion

Statistically significant differences were observed in buckwheat noodles derived from the four different buckwheat lines, but the influence of flour type was by far the dominant factor. The strong influence of flour type on noodle properties was to be expected, considering their variable composition due to the heterogeneous distribution of constituents within the buckwheat groat. Significant differences in raw buckwheat noodle colour were very evident depending upon the flour used. The high starch content within the white buckwheat flour yielded the brightest raw noodles while the dark flour yielded the darkest noodles. There were significant effects due to cultivar and flour type on all buckwheat noodle texture parameters. Dark buckwheat flour consistently yielded the thickest cooked noodles with the largest maximum cutting stress (MCS) and greatest resistance to compression (RTC). Noodles prepared with white buckwheat flour offered the best chewiness, springiness and recovery parameters. Stress relaxation analyses indicated a significantly firmer noodle when prepared with white flour. Soba noodles prepared with 60% dark buckwheat flour contained considerably higher amounts of minerals, proteins, dietary fibre, and fagopyritols than noodles prepared with white flour. Since, the bioactivity and usefulness of these constituents in prevention or treatment of certain diseases are becoming evident, the potential health benefits of dark buckwheat noodles may be substantially greater than those prepared with white buckwheat flour.

The two self-pollinating lines, BR01 and BR06, exhibited comparable milling and noodle making properties to that of the well-established cross-pollinating cultivar Koban, indicating that the self-pollinating lines would satisfy the quality requirements for soba noodles. The newer black-hulled cross-pollinating cultivar Koto gave higher white flour milling yield than the other cultivars. Koto noodles also exhibited higher MCS, REC and RTC compared to the other cultivars regardless of flour used.

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