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Analysis of Kernel Colour, Flour and Whole Wheat End-product Quality of Commercially Grown Canada Hard White Spring Wheat, Snowbird

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Abstract

Kernel colour variation in hard white wheat can be concern due to a lack of consistency because one of the main advantages is their lighter kernel colour which can produce visually appealing lighter coloured end-products. This study was carried out to determine the effect of the environment on commercially grown hard white wheat grain quality including colour and its association with whole wheat end-product quality. Commercial samples of the hard white spring cultivar Snowbird were collected over the 2003-2007 crop years from agro-climatic zones in western Canada. Samples were analyzed for kernel colour and for physicochemical, rheological and end-product properties. Kernel, bran, whole wheat and straight grade flour and whole wheat end-product colours were recorded using the CIE L^* a^* b^* scale. The agro-climatic zone in which the grain was grown had a significant effect on the kernel and bran colour. However the agro-climatic zone had only a limited effect on whole wheat pan bread colour but did have a greater effect on whole wheat tortilla and whole wheat yellow alkaline noodle colour. Kernel colour parameters only had a limited effect on the whole wheat end-product colour.

Keywords: colour, whole wheat flour, end-products, environment, grain

1. Introduction

The interest in hard white wheat for end-products ranges from the production of pan breads (Dexter & Worden, 2005; Sterk & Donley, 2006) and flat breads (Seib, Liang, Guan, Liang, & Yang, 2000) to the production of noodles (Sieb et al., 2000; Dexter & Worden, 2005). The introduction of the Canada Western Hard White Spring Wheat (CWHWS) class into the Canadian wheat registration system in 2004 has brought with it the challenge of producing hard white spring wheat irrespective of their growing environment. Grain colour is of a primary concern as the presence of darker kernels may be considered a disadvantage particularly in markets where Australian white wheat is considered the standard (Bason, Zounis, Ronalds, & Wrigley, 1995; Reifschneider, 2003). Several researchers (Bequette & Herrman, 1994; Bason et al., 1995; Wu, Carver, & Goad, 1999; Peterson et al., 2001; Matus-Cádiz, Hucl, Perron, & Tyler, 2003; Matus-Cádiz et al., 2008; Lukow, Adams, Suchy, DePauw, & Humphreys, “in press”) have reported that there is variability in the white-seeded varieties with seed coats ranging from very white and pasty to reddish in colour.

Since a main advantage of hard white wheat compared to hard red wheat is their lighter and brighter kernel colour this variability is a concern. The white kernel colour allows higher extraction flour to be produced that can be used to produce light coloured end-products (Bequette & Herrman, 1994; Qarooni, Bequette, & Posner, 1994; Ambalamaatil et al., 2002; Taylor, Brester, & Boland, 2005; Ambalamaatil, Lukow, & Malcolmson, 2006). Flour and end-product colour are influenced by both the bran and endosperm colour along with end-product processing interactions (Mares & Campbell, 2001). Previous work has investigated the performance of flour (Qarooni et al., 1994; Peterson et al., 2001; Gélinas & McKinnon, 2011), bran (Miller, 1979; Matus-Cádiz et al., 2008; Jiang, Martin, Okot-Kotber, & Seib, 2011), pan bread (Qarooni et al., 1994; Pike & MacRitchie, 2004; Gélinas & McKinnon, 2011), flat bread (Qarooni, Ponte, Jr., & Posner, 1992; Qarooni et al., 1994) and noodle (Seib et al., 2000; Hatcher, Lukow, & Dexter, 2006) made from white wheat.

The cultivar Snowbird was released in the CWHWS class in 2004 and was the primary cultivar from 2004 to

2008 (McCallum & DePauw, 2008). Researchers comparing hard white spring wheat to hard red spring wheat performance included Snowbird in their investigations (Ambalamaatil et al., 2002; Ambalamaatil et al., 2006; Hatcher et al., 2006). Additional research into genotype by environment effects also included Snowbird along with other cultivars (Hatcher et al., 2006; Finlay et al., 2007). These investigations were based on plot grown material and were limited in the numbers of years and/or the number of sites used to produce the grain. In this study we aim to document the variation in quality of commercial samples of the hard white wheat, Snowbird with the emphasis on the effect of the environment and kernel colour on straight grade (SG) and whole wheat (WW) flour and WW end-products properties.

2. Materials and Methods

2.1 Grain and Environmental Conditions

More than 1000 commercial samples of the hard white wheat cultivar, Snowbird, were collected in the 2003 through 2007 crop years. A combination of crop insurance risk/growth zones (Alberta Seed Partnership, 2008; Saskatchewan Seed Growers Assoc., 2008; Manitoba Agricultural Services Corp., 2008) were used to define the growing areas or agro-climatic zones. Grain was delivered to a total of 58 elevators distributed over 18 agro-zones (Figure 1).The crop years had different combinations of agro-climatic zones and elevators within the agro-climatic zones. The grain testing procedures are described in detail in Lukow et al. ("in press").

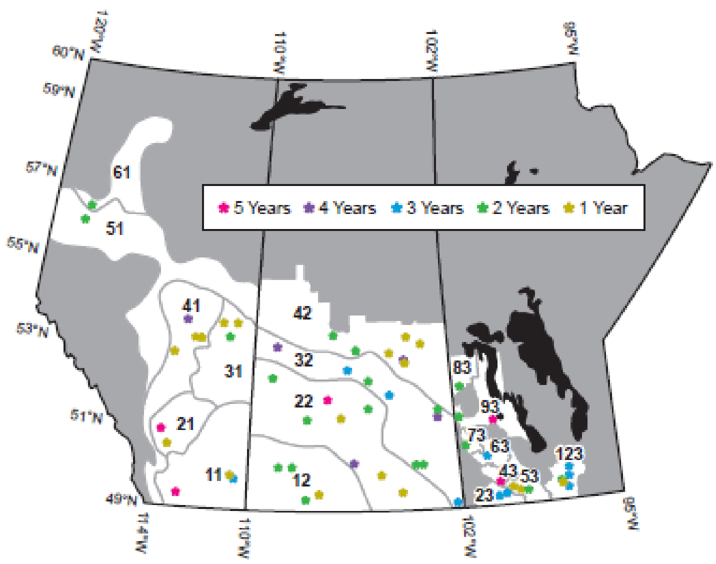

Figure 1. Map showing the agro-climatic zones, elevator locations and number of delivery years (Lukow et al. "in press")

Weather data used were obtained from Environment Canada (Environment Canada, 2010). Monthly temperature (mean, extreme maximum, extreme minimum, mean maximum and mean minimum) and precipitation (mean) parameters were accessed for each location for the months of May, June, July, August and September. The climatic data for these 5 months was combined and defined the growing season across western Canada based upon the production information supplied by the growers.

2.2 Milling and Flour Testing

A restricted number of samples (431) were milled into straight-grade (SG) flour on a Buhler experimental mill (model MLU-202, Buhler Ag, Uzwil, Switzerland) after the grain had been tempered to 16.5% moisture. Whole wheat (WW, 95% extraction) flour was produced on 240 samples according to Ambalamaatil et al. (2002). Straight grade and WW flour and bran colour were measured with a Minolta spectrophotometer CM-525i set at 2° observer and "C" illuminant. Straight grade flour protein content and moisture was determined by NIR (Dickey-john Instalab 600 near infrared reflectance analyzer) while WW flour protein was determined by the

Dumas total combustion method using a Leco FP-528 nitrogen analyser method (Leco Inc, St Joesph, MI, USA) (method 46-30.01) (American Association of Cereal Chemists International, 2010). Whole wheat flour dough strength properties were determined using 50g farinograph (method 54-21.01) (AACCI, 2010).

2.3 End-products

2.3.1 Pan Bread

Whole wheat flours were made into bread using a long fermentation bake method with modifications (Uthayakumaran & Lukow, 2003). Bread production used the equivalent of farinograph absorption (FAB) with loaves being produced using 25 g of flour (14% mb) mixed in a 35 gram mixer (National Mfg, TMCO, Lincoln, NE, USA). Loaf volume was measured by the rapeseed displacement method. Bread crumb colour was determined using a Minolta Baking Meter BC-1 with an 8° observer and "D" illuminant.

2.3.2 Tortilla

Tortillas were made according to the method of Ambalamaatil et al. (2006) with modifications. Flour (50g, 14% mb) was combined with shortening (9%) and salt and baking powder (1.5% each) and mixed for 2 minutes. Water was added at the equivalent of FAB-6%. The tortillas were evaluated for stretchability using the TA.XT2 (Texture Technologies Corp., Scarsdale, NY/Stable Micro Systems, Godalming, Surrey, UK) (Wang & Flores, 1999).

2.3.3 Noodles

Yellow alkaline noodles were made using the formulation and quality testing regime of Hatcher et al. (2006) with modifications Noodles were made at 47% absorption and mixed in a 35 gram mixer (National Mfg, TMCO, Lincoln, NE, USA) to create the crumble. The noodles were sheeted according to Pronyk, Cenkowski, Muir and Lukow (2008).

2.4 Statistical Analysis

The data collected were analyzed using PROC MIXED, PROC CORR and stepwise regression (SAS Institute Inc., 2008). The statistical analysis of the grain was carried out using PROC MIXED with the component year, year*agro-climatic zone and year*elevator (agro-climatic zone) considered as random factors while agro-climatic zone was considered as the fixed factor. With a decreasing number of samples that were milled the PROC MIXED model was altered to only include year and year*elevator (agro-climatic zone) as the random effects for flour and pan bread parameters. For tortilla and yellow alkaline noodles the PROC MIXED model was altered to include year as the only random effect. Changes were made in the random effects statements due to variance components having negative estimates (SAS, 2010). Only Pearson correlations with significance levels of $P \leq 0.0001$ were discussed in this paper. Stepwise regression variables were considered when the significance level was less than or equal to 0.001 and the determinant is expressed as a percentage. The contribution of each variance component was calculated as a percentage by summing the mean squares of the appropriate terms to give an estimate of the total variance and then dividing the specific variance component of the significant terms by the total variance (Lukow & McVetty, 1991).

3. Results and Discussion

3.1 Agro-climatic Zones and Climatic Conditions

Results of climatic conditions for the agro-climatic zones are described in detail in Lukow et al ("in press"). The results are summarized here for reference. Growing season mean temperatures ranged from 12.6°C in agro-climatic zone #51 to 15.9℃in agro-climatic zones #53, 63 and 123. Seven out of eight agro-climatic zones in Manitoba had mean temperatures over 15℃ while there was only one agro-climatic zone in either of Saskatchewan (#12) or Alberta (#11) that reached these temperatures. The agro-climatic zones #11 and #12, however, had the same or higher mean maximum and extreme maximum as the agro-climatic zones in southern Manitoba (#23, 43, 53, 63, 73 and 123). The agro-climatic zones in southern Manitoba tended to have slightly higher extreme minimum and mean minimum temperatures while the agro-climatic zones in the more northerly latitudes (#31, 41, 51, 32, 42 and 83) tended to have the lowest temperatures except for agro-climatic zone #61 in northern Alberta. The southern Manitoba agro-climatic zones #23, 53 and 123 were the wettest areas in 2003 - 2007, averaging over 70 mm of rain during the growing season while agro-climatic zones #73 in Manitoba, #12 in Saskatchewan and #11, 51, and 61 in Alberta were the driest averaging below 50 mm. The combination of low precipitation and high mean maximum and extreme maximum temperatures would make agro-climatic zones #11 and #12 on average the driest in western Canada over the five years.

3.2 Agro-climatic Zones and Climatic Effects on Milling, Bran and Flour Characteristics

3.2.1 Milling

Flour yields for 2003-2007 differed significantly across agro-climatic zones with agro-climatic zone #61 having the lowest yield at 68.1% and the Manitoba agro-climatic zones #23, 73, 83, 93 and 123 having the highest yields ranging from 73.0 to 73.2% (Table 1). The differences however accounted for more by the year*elevator (agro-climatic zone) interaction than by the agro-climatic zone (Table 2). Stepwise regression analysis also indicated that the growing season extreme minimum and mean maximum temperatures had an effect on flour yield and accounted for 12% of the variability. In addition latitude and longitude also accounted for 5% of the variability in the flour yield.

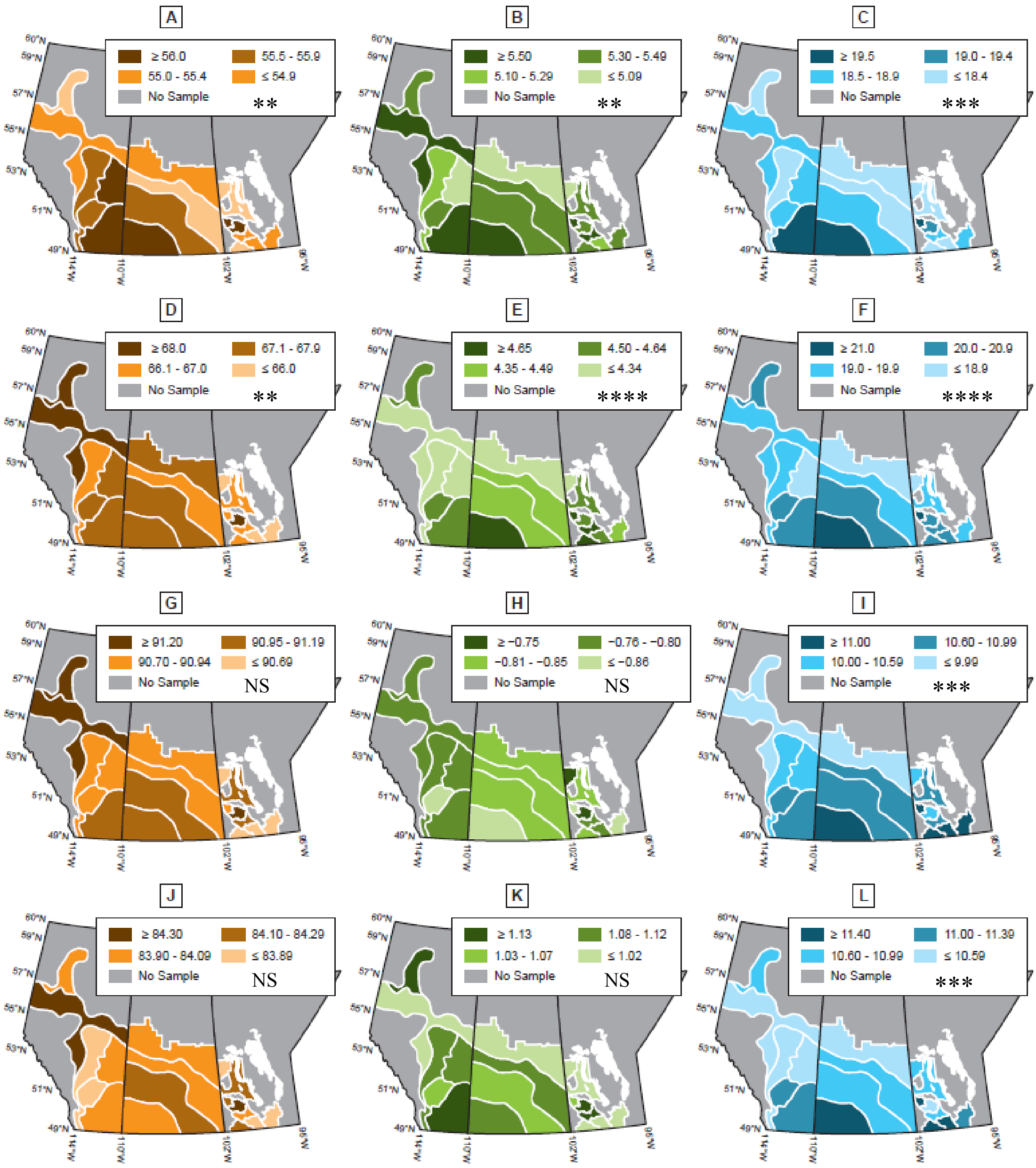

Figure 2. Maps showing average colour parameters L^*, a^*, and b^* for grain (A-C), bran (D-F), straight grade flour (G-I) and whole wheat flour (J-L), respectively for the agro-climatic zones

Fixed effects: **, ***, ****, significant at $P \leq 0.01$, 0.001, 0.0001, respectively; NS =non-significant.

3.2.2 Bran

Although wheat bran tends to be considered as a by-product of the milling process it is becoming more important to the breakfast cereal and bread industries as consumers look for products with more fibre and higher nutrients (Bequette & Herrman, 1994; Pike & MacRitchie, 2004). Bran from white wheat is preferred because of its lighter colour and possibly milder taste (Miller, 1979). Bran colour in this study was found to be significantly different between the agro-climatic zones with the brightest bran occurring in agro-climatic zone #63, 51 and 61 (Figure 2D) while agro-climatic zones #12 and 83 tended to have the reddest and the most yellow bran (Figure 2E and F, respectively). Agro-climatic zones also accounted for 4.9 to 11.1% of the variation in the bran colour (Table 2).

Bran colour $L*$ values increased with latitude, longitude and altitude (Figure 2D) and stepwise regression indicated that latitude and altitude accounted for 5% of the variability. Stepwise analyses also suggested that mean maximum and minimum growing season temperatures had an effect and accounted for 17% of the variability in bran colour L*. Bran colour $a*$ and $b*$ values decreased with latitude (Figure 2E and F respectively). Although stepwise regression indicated that 68% of the variability in bran colour a* could be accounted for, the only climatic parameter that had any affect was extreme maximum temperature (4%). Extreme maximum temperature however has a major effect on bran yellowness (b*) accounting for 48% of the variability while mean maximum temperature and altitude accounted for another 2%. The relationships of bran colour $L*$ values with latitude, longitude and altitude and of bran colour $b*$ values with altitude suggests that bran from parts of Alberta may be lighter than bran from Saskatchewan and Manitoba.

Table 1. Agro-climatic zone means and standard error of milling and straight-grade and whole wheat flour[z] parameters

	Straight grade		Whole wheat			
Agro-climatic zone	Flour yield (%)	FPC (%)	FPC (%)	FAB (%)	DDT (min)	MTI (BU)
Fixed effect[y]	*	*	NS	NS	NS	NS
11	72.1 ± 0.2	13.0 ± 0.2	12.8 ± 0.3	71.0 ± 0.3	7.8 ± 0.6	22 ± 2
12	72.5 ± 0.3	12.4 ± 0.2	13.0 ± 0.1	69.8 ± 0.4	6.6 ± 0.2	15 ± 1
21	72.6 ± 0.4	12.9 ± 0.4	12.8 ± 0.6	71.5 ± 0.6	7.8 ± 0.6	19 ± 3
22	72.5 ± 0.3	12.8 ± 0.2	12.9 ± 0.2	71.3 ± 0.2	7.7 ± 0.3	20 ± 1
23	73.1 ± 0.2	13.5 ± 0.2	12.9 ± 0.2	70.0 ± 0.5	6.3 ± 0.4	22 ± 3
31	72.2 ± 0.2	12.3 ± 0.3	12.5 ± 0.3	70.2 ± 0.4	10.2 ± 1.5	22 ± 2
32	72.3 ± 0.3	12.6 ± 0.2	12.7 ± 0.2	71.2 ± 0.3	7.5 ± 0.3	25 ± 2
41	72.7 ± 0.3	13.2 ± 0.4	13.0 ± 0.4	72.7 ± 0.4	7.7 ± 0.3	23 ± 3
42	71.0 ± 0.9	11.7 ± 0.2	11.7 ± 0.3	72.2 ± 0.7	8.4 ± 0.8	20 ± 4
43	72.6 ± 0.2	13.6 ± 0.2	13.6 ± 0.2	71.2 ± 0.3	7.8 ± 0.5	20 ± 2
51	71.1 ± 1.3	11.1 ± 0.5	11.1 ± 0.5	72.3 ± 0.4	7.0 ± 0.6	27 ± 5
53	72.5 ± 0.1	14.4 ± 0.4	13.5 ± 0.1	69.7 ± 0.2	5.2 ± 0.1	26 ± 5
61	68.1 ± 1.5	13.0 ± 0.6	13.0 ± 0.6	71.3 ± 0.3	5.9 ± 0.4	31 ± 6
63	70.6 ± 0.3	13.1 ± 0.3	13.4 ± 0.3	71.7 ± 0.3	7.0 ± 0.8	30 ± 5
73	73.1 ± 0.2	12.6 ± 0.2	12.8 ± 0.3	69.8 ± 0.2	6.6 ± 0.3	20 ± 2
83	73.0 ± 0.7	12.8 ± 0.4	12.9 ± 0.5	72.8 ± 0.8	7.7 ± 1.8	34 ± 3
93	73.2 ± 0.4	13.0 ± 0.2	12.6 ±0.3	70.8 ± 0.2	7.5 ± 0.6	22 ± 2
123	73.1 ± 0.2	12.4 ± 0.2	12.6 ± 0.2	69.8 ± 0.5	7.2 ± 0.8	26 ± 3

[z] FPC=flour protein content; FAB=farinograph absorption; DDT=dough development time; MTI=mixing tolerance index

[y] *, **, ***, ****, significant at $P \leq 0.05$, 0.01, 0.001, 0.0001, respectively; NS =non-significant.

3.2.3 Straight Grade Flour

Straight grade (SG) flour milled from wheat grown in different agro-climatic zones differed significantly in b^* (yellowness) (Figure 2I) with flours produced from wheat grown in agro-climatic zones #51 and 61 having the least yellow colour. Straight grade flour L^* (brightness) and a^* (redness) did not differ between the agro-climatic zones (Figure 2G and H, respectively) (Table 2). Straight grade flour yellowness increased with higher temperatures (r=0.46 and 0.53, mean and extreme maximum temperature respectively) and decreased with higher latitudes and longitudes (Figure 2I). Stepwise regression showed that growing season precipitation had a minor effect on flour brightness (3%) while altitude affected yellowness (2%). Straight grade flour protein differed between the agro-climatic zones with agro-climatic zones #42 and 51 having protein contents less than 12.0% while agro-climatic zones #23, 43 and 53 had protein contents greater than 13.5% (Table 1). Variation in protein content was accounted for by agro-climatic zones, year and the interaction of year x elevator (agro-climatic zone) (Table 2). Stepwise regression also indicated that growing season precipitation had a minor effect on SG protein content (data not shown).

3.2.4 Whole Wheat Flour

Whole wheat (WW) flour also differed significantly in yellowness (b^*) (Figure 2L) with flour from grain produced in agro-climatic zones #12 and 23 being the yellowiest. Whole wheat flour L^* and a^* like the SG flour did not differ between the agro-climatic zones (Figure 2J and K, respectively). Whole wheat (WW) flour yellowness increased with higher temperatures while yellowness also decreased with higher latitudes (r=-0.51). Climate parameters did not account for any variation in WW flour colour a^* and b^*.

Whole wheat flour protein content did not differ between the agro-climatic zones and there was no difference between the agro-climatic zones for any of the farinograph parameters (Table 1). Table 2 shows that there was no year effect on the farinograph DDT or MTI. Stepwise regression indicated that WW flour FAB was affected by growing season extreme maximum temperature (17%) with Pearson correlation indicating that higher temperature decreases FAB (data not shown). Extreme maximum temperature also accounted for 5% of the variability in WW flour MTI.

Table 2. Variance components for flour[z] properties expressed as a percentage

	Straight grade							Whole Wheat							
	df	Bran colour L^*	Bran colour a^*	Bran colour b^*	df	Flour Yield	FPC	df	Flour colour L^*	Flour colour a^*	Flour colour b^*	FPC	FAB	DDT	MTI
Agro-climatic zone (A)	17	4.9	9.7	11.1	17	22.0	24.6	17	8.0	15.4	13.3*	17.9	6.8	18.3	25.1
year (Y)	4	91.1	86.5	85.2	4	59.8	53.7	4	74.0	67.7	77.9	59.9	77.5	33.9	35.6
Y*elevator(A)	69	2.6	2.4	2.9	69	14.6	12.5	59	12.1	10.4	5.7	13.4	10.3	25.5	23.6
error	341	1.5	1.5	0.9	346	3.5	9.2	161	5.9	6.5	3.1	8.8	5.4	22.3	15.7

[z] FPC=flour protein content; FAB=farinograph absorption; DDT=dough development time; MTI=mixing tolerance index

3.3 Relationships between Grain, Milling, Bran and Flour

3.3.1 Milling

Flour yield was influenced negatively by the presence of green and frost damaged kernels (r=-0.31 and -0.20, respectively). However, stepwise regression indicated that of these two parameters only the presence of green kernels (12% of the variation) was associated with flour yield. Green kernels are harder in nature and affect the mill balance resulting in lower flour yields and high flour starch damage (Preston, Kilborn, Morgan, Babb, 1991; Canadian International Grains Institute, 2005). Starch damage was not measured in this study however the positive correlations between green kernels with SG flour farinograph absorption (r=0.38) and the negative correlations with flour yield suggested higher starch damage occurs with an increasing number of green kernels. Other grain variables that accounted for an additional 11% variability in flour yield were production yield, midge damage, hardness (SKCS) and protein content.

3.3.2 Bran

Bran colour L^*, a^* and b^* values correlated to kernel colour L^*, a^* and b^* values at r=0.52, 0.75 and 0.37 respectively. Besides the temperature parameters described in section 3.2.2 an additional 39% of the variation in bran brightness (L^*) could be accounted for by the combination of kernel brightness (27%), kernel redness (3%) and kernel yellowness (4%), protein content (4%) and mildew (1%). Bran colour a^* variation was primarily explained by kernel colour a^* (56%) with an additional 8% of the variation accounted for by protein content. Bran colour b^* was highly affected by temperature parameters as mentioned in section 3.2.2 and by kernel brightness and redness which accounted for 20% of the variability. In addition mildew (3%), hardness (1%) and protein content (1%) were also indicated as parameters having minor effects on the bran yellowness. It is interesting that kernel yellowness had no effect on bran yellowness according to the stepwise regression.

3.3.3 Straight Grade Flour

Stepwise regression analysis of SG flour colour parameters indicated that the variability in flour brightness was accounted for by 8 variables to 71%, redness was accounted for by 8 variable to 64% and yellowness was accounted for by 9 variables to 77%. A minimum of 52% to a maximum of 65% of the variability in flour colour is accounted for by the first three variables. The variability in SG flour colour L^* could be accounted for by bran colour L^* (45%) and a^* (4%), percent green kernels (10%), protein content (4%), hardness index (4%), kernel L* (1%), mildew (1%) and growing season precipitation (3%). The primary factors influencing SG flour colour a^* were flour protein content (23%), bran colour b^* (15%), bran colour L^* (14%) and kernel colour b^* (5%) with four more variables (7%). Flour colour b^* was accounted for by protein content (23%), bran L^* (14%), a^* (2%) and b^* (15%), kernel b^* (5%). green kernel (1%) and altitude (2%).

Straight grade flour colour L^* values had low positive correlations with all of the kernel colour parameters (data not shown). Peterson et al. 2001 reported negative correlations between SG flour redness and kernel redness. Our results follow the same trends r=-0.20 for SG flour redness with kernel redness. Flour redness was also positively correlated to grain and flour protein content (r=0.50 and 0.48 respectively). SG flour yellowness correlated positively with mean maximum (r=0.45), mean (r=0.46) and extreme maximum temperatures (r=0.53). Our results also follow those reported by Peterson et al 2001 for SG flour yellowness. Flour yellowness was positively correlated to kernel yellowness (r=0.19).

3.3.4 Whole Wheat Flour

Whole wheat flour colour L^*, a^* and b^* values correlated positively with SG flour colour L^* (r=0.61), a^* (r=0.50) and b^* (r=0.75) values, respectively. Stepwise regression analysis had SG flour colour L^* as the primary factor (37%) responsible for WW flour colour L^* with a total of 62% of the variability accounted for by five parameters including SG flour yield, bran colour L^* and b^* and WW protein content. Whole wheat flour redness is accounted for SG flour redness (25%), SG flour yield (15%) and bran redness (8%). Straight grade flour and bran colour parameters L^* and b^* account for the variability (71%) in the WW flour b*. Whole wheat flour protein content accounted for 10% and 7% of the variability in WW flour DDT and MTI, respectively. Straight grade flour yield accounted for 7% of the variability in WW flour DDT, while mildew accounted for 5% towards the variability in WW flour MTI.

3.4 Agro-climatic Zones and Climatic Effects on Whole Wheat End-product Characteristics

3.4.1 Pan Bread

Tables 3 and 4 show that there were no differences in bread crumb colour or in loaf volume between bread made from flour from the different agro-climatic zones and that year and the interaction of year x elevator(agro-climatic zone) had the greatest effect depending on the parameter. Bread crumb L^* and a^* values and loaf volume had no significant correlations with growing season parameters. Bread crumb colour b^* values (yellowness) were correlated with precipitation (r=0.32). Precipitation also accounted for some of the variation in crumb L*, a* and b* at 4%, 3% and 15% respectively. Crumb yellowness was also slightly affected by the growing season mean temperature (3%) and longitude was indicated as accounting for a minor variation in loaf volume (2%).

Table 3. Agro-climatic zone means and standard error of pan bread parameters

Agro-climactic zone	Crumb colour *L**	Crumb colour *a**	Crumb colour *b**	Loaf volume (cc)
Fixed effect[z]	NS	NS	NS	NS
11	65.26 ± 0.31	4.55 ± 0.12	23.72 ± 0.44	218 ± 4
12	64.67 ± 0.52	4.80 ± 0.19	22.74 ± 0.49	224 ± 5
21	63.75 ± 0.56	4.46 ± 0.16	22.52 ± 1.16	217 ± 7
22	65.25 ± 0.21	4.28 ± 0.09	24.88 ± 0.37	230 ± 3
23	64.51 ± 0.83	4.16 ± 0.19	20.56 ± 0.36	227 ± 3
31	65.44 ± 0.36	4.64 ± 0.13	20.61 ± 0.25	210 ± 4
32	64.81 ± 0.35	4.35 ± 0.10	22.56 ± 0.52	228 ± 3
41	64.21 ± 0.39	4.42 ± 0.10	22.98 ± 0.63	227 ± 5
42	63.97 ± 0.40	4.54 ± 0.11	24.59 ± 0.66	216 ± 8
43	65.10 ± 0.2	4.30 ± 0.07	23.92 ± 0.67	236 ± 4
51	63.37 ± 1.18	4.57 ± 0.14	27.12 ± 0.47	209 ± 10
53	64.90 ± 0.34	4.22 ± 0.17	20.20± 0.31	233 ± 3
61	63.16 ± 1.18	4.48 ± 0.29	27.10 ± 0.48	219 ± 16
63	64.41 ± 0.50	4.42 ± 0.12	26.29 ± 0.28	231 ± 6
73	64.08 ± 0.76	4.45 ± 0.23	20.48 ± 0.47	220 ± 3
83	64.85 ± 0.78	3.98 ± 0.36	23.08 ± 0.74	247 ± 14
93	64.71 ± 0.50	4.12 ± 0.14	23.61 ± 1.07	230 ± 5
123	64.01 ± 0.59	4.33 ± 0.23	21.56 ± 0.93	232 ± 5

[z] *, **, ***, ****, significant at $P \leq 0.05$, 0.01, 0.001, 0.0001, respectively; NS =non-significant.

Table 4. Variance components for pan bread properties expressed as a percentage

	df	Crumb colour *L**	Crumb colour *a**	Crumb colour *b**	Loaf volume
Agro-climatic zone (A)	17	16.0	21.5	1.4	26.7
year (Y)	4	54.4	54.0	97.4	46.2
Y*elevator(A)	59	18.2	17.2	0.8	15.5
error	158	11.8	7.4	0.4	11.6

3.4.2 Tortilla

There were no interactions included in the tortilla variance analysis due to components having negative estimates (SAS 2010). Tortilla crust color brightness, redness and yellowness were all affected by the agro-climatic zones (Tables 5 and 6) with flour from agro-climatic zone #61 producing the darkest, reddest and most yellow tortillas. Tortillas from agro-climatic zone #12 were on average the brightest while those from agro-climatic zone #73 were the least red and yellow. Stepwise regression showed that there was no climatic effect on the tortilla crust brightness. There was an effect of precipitation on tortilla crust redness variability of 10% and crust yellowness variability was also affected by precipitation (9%) and altitude (4%).

Table 5. Agro-climatic zone means and standard error of tortilla parameters

Agro-climatic zone	Crust colour $L*$	Crust colour $a*$	Crust colour $b*$	Diameter (cm)	Thickness (mm)	Stretchability	
						Rupture distance (mm)	Force (g)
Fixed effect[z]	****	**	****	**	NS	*	**
11	64.37 ± 0.20	6.43 ± 0.12	26.73 ± 0.20	16.78 ± 0.12	1.38 ± 0.20	17.73 ± 0.92	631.91 ± 18.57
12	65.00 ± 0.22	5.32 ± 0.33	25.71 ± 0.39	16.79 ± 0.10	1.36 ± 0.03	14.85 ± 0.50	674.26 ± 28.49
21	64.18 ± 0.39	5.87 ± 0.30	25.62 ± 0.31	16.66 ± 0.14	1.36 ± 0.03	14.38 ± 0.69	645.70 ± 32.31
22	63.76 ± 0.19	6.62 ± 0.13	25.52 ± 0.18	16.65 ± 0.05	1.36 ± 0.01	15.27 ± 0.49	624.35 ± 13.90
23	64.75 ± 0.28	5.04 ± 0.32	25.11 ± 0.50	16.91 ± 0.10	1.35 ± 0.04	15.35 ± 0.52	712.74 ± 23.73
31	62.43 ± 0.18	6.16 ± 0.08	25.82 ± 0.16	15.32 ± 0.42	1.49 ± 0.01	25.17 ± 0.49	750.55 ± 22.65
32	63.32 ± 0.26	6.24 ± 0.16	25.96 ± 0.20	16.43 ± 0.09	1.40 ± 0.02	18.81 ± 1.07	658.91 ± 15.51
41	62.79 ± 0.29	6.50 ± 0.08	26.04 ± 0.21	16.37 ± 0.12	1.43 ± 0.02	21.14 ± 1.45	649.83 ± 22.67
42	63.18 ± 0.42	6.33 ± 0.13	25.51 ± 0.28	16.43 ± 0.13	1.40 ± 0.03	14.71 ± 1.08	577.27 ± 18.18
43	63.24 ± 0.24	6.54 ± 0.19	26.16 ± 0.20	16.54 ± 0.11	1.39 ± 0.02	16.81 ± 0.94	680.30 ± 22.27
51	63.52 ± 0.21	6.90 ± 0.08	26.66 ± 0.37	16.94 ± 0.13	1.28 ± 0.03	13.03 ± 0.76	508.82 ± 36.16
53	64.11 ± 1.10	4.82 ± 0.27	24.38 ± 0.23	17.29 ± 0.11	1.27 ± 0.03	13.82 ± 0.65	640.09 ± 31.77
61	62.31 ± 0.96	7.00 ± 0.17	26.84 ± 0.27	16.75 ± 0.36	1.35 ± 0.05	13.90 ± 0.57	578.28 ± 12.79
63	63.85 ±0.30	6.70 ± 0.12	25.76 ± 0.29	16.75 ± 0.13	1.36 ± 0.03	13.35 ± 0.49	540.17 ± 13.24
73	64.73 ± 0.16	4.63 ± 0.05	24.31 ± 0.16	16.96 ± 0.20	1.41 ± 0.05	14.31 ± 0.34	620.63 ± 7.97
83	62.66 ± 0.48	6.26 ± 0.19	25.27 ± 0.77	16.63 ± 0.48	1.34 ± 0.07	16.50 ± 0.69	592.76 ± 80.43
93	64.21 ± 0.42	6.15 ± 0.24	25.77 ± 0.37	16.71 ± 0.15	1.44 ± 0.02	14.21 ± 0.50	624.02 ± 18.03
123	63.50 ± 0.40	5.35 ± 0.27	24.78 ± 0.57	16.84 ± .21	1.35 ± 0.04	14.01 ± 0.60	647.66 ± 24.02

*, **, ***, ****, NS=significant at 0.05, 0.01, 0.001, 0.0001 respectively.

Table 6. Variance components for tortilla properties expressed as a percentage

	df	Crust colour $L*$	Crust colour $a*$	Crust colour $b*$	Diameter	Thickness	Stretchability	
							Rupture distance	Force
Agro-climatic								
zone (A)	17	36.5	1.4	10.6	12.9	8.0	0.7	4.6
year (Y)	4	50.7	98.0	87.3	80.9	85.8	99.0	93.3
error	220	12.7	0.6	2.1	6.2	6.2	0.4	2.0

The diameters of the tortillas differed between agro-climatic zones with the smallest tortillas coming from agro-climatic zone #31 and the largest from agro-climatic zone #53 (Tables 5 and 6). Although there were no significant differences in the tortilla thickness, these agro-climatic zones had the thickest (#31) and the thinnest (#53) measured product. Stepwise regression indicated that the tortilla diameter was also affected by latitude (5%).

Both of the parameters that express the stretchability of the tortillas differed across agro-climatic zones with agro-climatic zone #31 having the highest rupture distance and force while agro-climatic zone #51 had the lowest (Tables 5 and 6). Up to 7% of the variability in the force necessary to puncture the tortilla and the rupture distance was accounted for by the growing season precipitation.

3.4.3 Noodles

Both raw and cooked noodle colour is important in the evaluation of yellow alkaline noodles (Hatcher et al 2006). Raw noodle colour was measured at 2 and 24 hours after sheeting to duplicate the fresh and stored end-product. In Indonesia flours with extraction levels as high as 85% have been known to be used for noodle production (Van Hung & Hatcher, 2011) therefore there is the possibility that yellow alkaline noodles made from whole white wheat flour also might be consumed in niche markets. The addition of bran to make whole wheat flour had an effect on the noodle colour (Tables 7 and 8). Noodle $L*$ showed a difference for the 24hr raw noodles agro-climatic zone variance component (Table 8) but not in the ANOVA (Table 7). There were no significant correlations between any of the noodle $L*$ (cooked, 2hr or 24hr) and any of the environmental parameters (data not shown).

Table 7. Agro-climatic zone means and standard error of yellow alkaline noodle parameters

Agro-climatic zone	Cooked colour $L*$	Cooked colour $a*$	Cooked colour $b*$	Raw 2 hour colour $L*$	Raw 2 hour colour $a*$	Raw 2 hour colour $b*$	Raw 24 hour colour $L*$	Raw 24 hour colour $a*$	Raw 24 hour colour $b*$	Compression stress (g/mm)	Cut stress (g/mm)
Fixed effect[z]	NS	NS	****	NS	****	****	NS	****	**	*	**
11	56.75±0.22	10.67±0.11	26.16±0.38	58.51±0.22	8.39±0.10	28.23±0.18	54.82±0.21	10.15±0.11	27.38±0.22	4.10±0.13	12.17±0.47
12	57.29±0.99	10.43±0.22	26.20±0.84	60.24±1.11	7.94±0.31	27.60±0.47	57.01±1.46	9.90±0.34	27.46±0.73	4.49±0.55	12.97±1.42
21	55.77±0.62	10.10±0.37	25.34±0.81	58.11±0.60	7.83±0.19	27.81±0.42	54.39±0.56	9.52±0.28	26.68±0.45	4.26±0.42	14.54±1.45
22	56.21±0.19	10.19±0.09	25.04±0.17	58.50±0.20	7.84±0.08	27.65±0.17	54.91±0.23	9.68±0.07	26.34±0.21	4.38±0.06	13.95±0.31
23	57.01±0.42	10.01±0.31	25.31±0.32	58.70±0.37	8.50±0.20	28.70±0.23	54.56±0.18	9.86±0.17	27.99±0.28	4.84±0.15	14.35±0.50
31	56.45±0.34	10.18±0.18	26.30±0.36	58.37±0.32	7.55±0.08	26.56±0.17	54.01±0.40	9.57±0.09	26.52±0.24	4.24±0.11	11.69±0.40
32	56.63±0.29	9.89±0.15	25.25±0.26	58.60±0.39	7.75±0.10	27.35±0.15	54.26±0.43	9.62±0.10	26.55±0.20	4.16±0.11	12.96±0.53
41	55.95±0.33	9.61±0.10	24.68±0.34	57.71±0.32	7.38±0.11	26.50±0.20	53.32±0.36	9.25±0.11	25.91±0.26	4.21±0.15	13.00±0.56
42	56.49±0.33	13.39±3.80	25.69±0.51	58.32±0.38	7.44±0.14	26.94±0.35	54.23±0.35	9.22±0.20	26.15±0.42	3.90±0.15	12.33±0.72
43	55.85±0.19	10.06±0.14	24.57±0.27	57.81±0.18	7.80±0.12	27.55±0.24	53.93±0.22	9.52±0.11	26.51±0.19	4.36±0.14	13.19±0.50
51	55.81±0.46	9.50±0.36	25.90±0.22	57.64±0.21	7.76±0.25	27.55±0.56	53.59±0.83	9.57±0.21	26.16±0.54	3.37±0.19	9.98±0.39
53	55.98±0.65	10.32±0.47	25.12±0.26	58.93±0.26	8.08±0.22	27.67±0.32	54.38±0.67	9.68±0.18	27.17±0.26	4.21±0.28	15.54±0.81
61	54.80±0.44	10.10±0.29	24.66±0.64	56.79±0.27	7.76±0.27	28.06±0.21	52.67±0.65	9.91±0.16	26.59±0.36	3.81±0.34	10.75±1.94
63	55.91±0.39	10.47±0.17	24.84±0.47	57.35±0.42	8.22±0.11	28.04±0.24	52.78±0.45	10.04±0.11	26.56±0.27	4.03±0.13	12.10±0.33
73	57.60	9.55	26.35	62.80	6.45	24.70	56.45	10.15	27.70	3.71	9.37
83	55.77±0.55	9.20±0.03	23.68±1.32	57.53±0.75	7.15±0.31	25.98±1.24	51.98±1.87	8.67±0.06	24.30±1.68	4.52±0.27	15.04±0.71
93	56.52±0.37	9.99±0.17	25.60±0.41	58.59±0.48	7.79±0.20	28.20±0.38	54.50±0.43	9.63±0.14	26.82±0.42	4.19±0.19	13.86±0.78
123	56.25±0.27	9.63±0.38	24.89±0.81	59.02±0.70	7.22±0.14	26.80±0.27	54.79±1.24	9.10±0.16	26.13±0.52	4.03±0.44	13.42±0.95

*, **, ***, ****, NS=significant at 0.05, 0.01, 0.001, 0.0001 respectively.

Table 8. Variance components for yellow alkaline noodle properties expressed as a percentage

	df	Cooked L^*	Cooked a^*	Cooked b^*	Raw 2 hour L^*	Raw 2 hour a^*	Raw 2 hour b^*	Raw 24 hour L^*	Raw 24 hour a^*	Raw 24 hour b^*	Compression stress	Cut stress
Agro-climatic zone (A)	17	8.4	26.2	2.6	6.4	37.1	34.5	10.3	31.9	13.2	23.2	128.1
year (Y)	4	83.8	50.9	96.6	86.2	53.7	55.1	83.7	61.2	80.9	65.2	57.9
error	192	7.8	22.9	0.8	7.4	9.2	10.4	6.0	6.8	5.9	11.6	14.0

Cooked noodles did not differ in redness depending on the agro-climatic zone while 2hr and 24hr raw noodle redness did (Table 7 and 8). Two hour noodle redness varied from 6.45 in agro-climatic zone #73 to 8.50 in agro-climatic zone #23 while 24 hr noodle redness ranged from 8.67 in agro-climatic zone #83 to above 10 in agro-climatic zones #11, 63 and 73. There were similar positive Pearson correlations between 2hr and 24hr noodle redness and the growing season temperature parameters extreme minimum (r=0.40), mean maximum (r=0.43) and mean temperature (r=0.41). No parameters could account for the variability in cooked noodle a*.

Two hour, 24hr and cooked noodles differed in noodle yellowness depending on the agro-climatic zone. Agro-climatic zones #73 and 83 had noodles that were the least yellow at 2hr while agro-climatic zone #83 also had the least yellow noodles at 24hr and cooked noodles. Flours from agro-climatic zone #73 produced the yellowest cooked noodles while flours from agro-climatic zone #23 produced the yellowest noodles at 2hr and 24hr respectively (Table 7). Cooked noodle b^* was affected by growing season extreme maximum temperature (11%) and precipitation (4%). The 24hr noodle b^* was the only other noodle parameter that was affected by environmental conditions with growing season mean maximum temperature accounting for 12% of the variability in the parameter.

Both compression and cut stress parameters for noodles showed significant differences between agro-climatic zones with agro-climatic zone #51 having the lowest compression stress value and agro-climatic zone #23 having the highest. Agro-climatic zone #73 had noodles with the lowest cut stress although only one sample was analyzed, while agro-climatic zone #53 had the highest cut stress. Neither compression nor cut stress was significantly correleated with any of the environmental parameters.

3.5 Relationships between Grain, Flour and WW End-products

3.5.1 Pan Bread

Bread correlations of note are crumb colour L^* values with kernel colour L^* values (r=0.26), crumb colour L^* values and WW flour colour L^* values (r=0.41) and crumb colour a^* values with WW flour colour a^* values (r=0.41). Stepwise regression indicated that WW flour colour L^* accounted for 16% of the variation in crumb colour L^* while SG flour yield, WW flour a* and kernel colour b* accounted for 9%, 4%, and 3% respectively. Variation in WW crumb a^* colour was affected by SG flour yield (27%), WW flour colour L^* (11%), WW DDT (10%) and kernel colour b^* (6%). Crumb yellowness also primarily accounted for SG flour yield (25%) but also bran yellowness (5%) and WW flour yellowness (7%). Most of the variability in the WW loaf volume was explained by WW DDT (26%) and WW flour protein content (13%) and to a lesser extent WW flour redness (6%), bran redness (2%) and WW FAB (2%). Similar to Qarooni et al. (1994) the increase in extraction rate to whole wheat resulted in a correlation between FAB and loaf volume (r=0.40).

3.5.2 Tortilla

Although there were differences in tortilla crust L^* between the agro-climates stepwise regression for crust L^* indicated that WW flour L^*, a^* and b^* were the only parameters that had an effect with the variability accounted for at 27%, 7% and 21% respectively. Pearson correlations indicated that WW flour L^* (r=0.51) and b^* (r=0.34) were positively correlated with crust L^* while WW flour a^* (r=-0.37) was negatively correlated. The negative correlation between crust L^* and WW FAB (r=-0.31) indicated that as water absorption increased the tortillas become darker. Stepwise regression indicated that in addition to precipitation tortilla crust redness was affected by WW FAB with 20% of the variability accounted for by this parameter. Other parameters that affected the tortilla redness were WW flour colour L^*, a^* and b^* and WW flour protein, together accounting for a total of 58% of the variability. Tortilla crust yellowness variability was also partially accounted for by WW FAB (8%), WW flour L^* (9%) and a^* (9%). The positive correlations between WW FAB and crust a^* (r=0.45) and b^* (r=0.29) also indicated that the crust increased in redness and yellowness with increasing water. Tortilla diameter and thickness variability were both affected by WW DDT at 24% and 6% respectively. Up to 49% of the variability in the force necessary to puncture the tortilla was accounted for by the four parameters; tortilla diameter, WW flour protein content, WW flour yellowness and bran brightness. The rupture distance variability is accounted for primarily by tortilla thickness (25%), WW flour protein content (6%), bran redness (10%), tortilla diameter (6%) and WW MTI (3%). The negative correlation between bran colour yellowness and rupture distance (r=-0.31) and the occurrence of the bran colour parameters in the stepwise regression models may be linked to the weakening of the gluten network due to the increase in the fibre content through the addition of the bran (Barros, Alviola, & Rooney, 2010).

3.5.3 Noodle

Pearson correlations indicated that there were few relationships between cooked noodle colour L^* and other parameters and no significant correlations with cooked noodle a^* (data not shown). Stepwise regression also did not indicate the effect of any parameter on cooked noodle L^* or a^*. Stepwise regression analysis indicated that cooked noodle b^* was affected by WW flour a^* (4%) and b^* (15%) and bran L^* (6%) in addition to the climatic conditions. Correlations also indicated relationships between cooked noodle b^* with kernel colour L^* (r=0.31) and b^* (r=0.52), WW flour protein (r=-0.61) and WW FAB (r=-0.45). Stepwise regression indicated that 2hr raw noodle colour could be accounted for by the individual parameters WW flour a^* and b^* and bran b^* or combinations of them with the highest estimate only being 29% for 2hr raw noodle a^*. Only 19% of the variability in 2hr raw noodle L* could be accounted for with WW flour a^* accounting for 9% and WW flour b^* for 10%. Whole wheat flour redness also accounted for 9% of the variability in 2hr raw noodle a^* while bran yellowness accounted for 19%. Bran yellowness also had the highest correlations with 2hr noodle a^* (r=0.49) and b^* (r=0.58). Whole wheat flour colour a^* correlated with 2hr raw noodle a^* (r=0.44) and WW flour colour b^* correlated with 2hr raw noodle a^* (r=0.43) and b^* (r=0.38). Up to 28% of the variability in the 24hr raw noodle colour L^* was accounted for by bran and WW flour L^*, WW flour b^* and kernel b*while correlations ranged from not significant to r=0.48. Bran b^* correlated with 24hr raw noodle a^* (r=0.52) and stepwise regression also indicated that 20% of the variability in the 24hr raw noodle a^* was accounted for by bran b^*. In addition to the climatic parameters WW flour L^* and b^* accounted for the rest of the variability in the 24hr noodle b* with a total of 22% being estimated. Whole wheat flour L^* and b^* also correlated with 24hr noodle b* at r=0.34 and 0.46 respectively. Whole wheat flour protein correlated positively with compression (r=0.51) and cut stress (r=0.49) and accounted for 26% and 25% of the variability, respectively. Variability in the compression stress was accounted for by the addition of bran with bran L^* being the only parameter (34%), while 45% of the total variability in the cut stress was accounted for with the addition of bran L^* and WW flour L^*. The relationships between bran colour and the noodle stress parameters may be similar to the tortilla results and are probably an indirect effect of the presence of the bran disrupting the protein matrix.

4. Conclusions

This five year study concentrated on finding the effect of the environment on whole wheat end-product quality and on the colour of kernels and their relationship to whole wheat end-product colour from the Canadian hard white spring wheat cultivar Snowbird grown under commercial conditions. The Prairie Provinces were divided into climatically distinct areas, agro-climatic zones, based on provincial seed industry associations and farmers for crop insurance purposes. Grain produced in agro-climatic zones located in lower latitudes and higher longitudes tended to be darker and more yellow and red in appearance. Bran from the grain produced in the lower latitudes as expected was also redder and more yellow however there was little effect on the brightness of the bran. Bran brightness was partially explained by a combination of kernel brightness, redness and yellowness while bran redness was primarily explained by kernel redness. Bran yellowness was also partially explained by kernel brightness and redness but there was no effect from kernel yellowness.

Although straight grade flour brightness and yellowness moderately increased on average with increasing kernel brightness and yellowness, darker kernels did not always directly translate into darker flour under laboratory milling conditions. The greatest relationship between agro-climatic zones and SG and WW flour colour was an effect on flour yellowness. There was also an effect on SG and WW flour redness which increased with increasing protein content. Kernel redness was negatively correlated to SG flour redness.

Agro-climatic zones had no direct effect on farinograph parameters however FAB decreased with increasing temperature resulting in agro-climatic zones in southern Manitoba having the lowest absorptions.

Agro-climatic zones had little effect on the pan bread properties with yearly fluctuations in temperature and precipitation having a greater effect. There were minor relationships between kernel colour and whole wheat bread crumb colour.

Agro-climatic zones had an effect on tortilla properties. In particular the crust colours of tortilla were influenced by the agro-climatic zone in which the grain was produced. Tortillas produced from grain grown at higher altitudes tended to be darker however stepwise regression showed no effect of kernel colour on tortilla colour.

The yellowness of the yellow alkaline noodles (raw 2hr and 24hr, cooked) was related to the agro-climatic zones in which the grain was grown whereas noodle brightness was not related to the growing area at all. In addition the redness of the raw noodles was also affected by the agro-climatic zones. Stepwise regression indicated that kernel colour had minor relationships with noodle colour along with bran colour.

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