Evaluation of pasting and dough rheological properties of composite flours made from flour varied in gluten strength

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Abstract Flours from various wheat varieties varied in gluten strength were blended in varying proportions and evaluated for pasting and dough rheological properties. The different blends of strong: very weak/weak/medium flour (100:0, 75:25, 50:50, 25:75 and 0:100) (w/w) were prepared. Two strong and three weak wheat varieties were selected for this study on the basis of Farinograph dough stability (DS). Strong wheat (HUW468 and HP1761), medium weak (HUW234), weak (HD2894) and very weak (WH1021) wheat variety had DS of 11.4–13.5 min, 9.9 min, 6.2 min, and 2.8 min, respectively. Protein content of the flour decreased with increase in proportion of weak wheat flours in the blends. The lowest values of protein content, paste viscosities and mixographic parameters were observed for blend of strong and very weak wheat flour (25:75). The blending of strong wheat flour with weaker wheat flour decreased the protein content and mixographic properties. The regression equations for blending of weak wheat with strong wheat flour had the highest regression coefficient for paste viscosities (Peak, final, breakdown and setback) and pasting temperature indicated that the greatest change in these properties with increase in blending level of weak wheat. The blending of weak wheat with strong wheat flour had the highest regression coefficient indicating the greatest change in MPT as the blending level was increased. The blending of

very weak, weak and medium wheat flour with strong wheat flour showed significant effect on G' and G'' . The flours with variable dough rheological properties suitable for different products can be produced by blending strong and weak wheat flour.

Keywords Wheat flour blends · Pasting · Mixograph · Rheology

Abbreviations

BDV	Breakdown viscosity
FV	Final viscosity
G'	Elastic modulus
G''	Viscous modulus
LPV	Left peak value
LPW	Left peak width
MPT	Mixograph peak time
MPV	Mixograph peak value
MPW	Mixograph peak width
PT	Pasting temperature
PV	Peak viscosity
RPV	Right peak value
RPW	Right peak width
SBV	Setback viscosity
WS	Weakening slope

Introduction

Wheat is classified into different types on the basis of planting season, grain color and hardness. Wheat is generally divided into hard and soft wheat varieties depending on the way of breakage of endosperm. The endosperm of hard wheat adhere tightly while the endosperm of soft wheat break down very easily during milling and helps in

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determining the suitability of flour for different products. Hard wheat with protein content of 10–14% used for bread making whereas soft wheat with protein content of 8–10% is preferred for muffins, cookies and cake making (Delcour et al. 2012). Haddad et al. (1999) reported that increase in virtuousness of endosperm resulted into higher yield of hard wheat flour. The functionality of flours is affected by various factors such as kind of wheat varieties, variation in grain hardness variability due to the variation in season and growing conditions (Gaines et al. 1996). The dough rheological properties were largely affected by absorption of water, salt, elasticity of gluten and damaged starch (Ren et al. 2008). Blending of wheat flour varied either in their gluten strength, protein content and dough stability required to meet the miller's requirements to deliver flour to customers in terms of both functional attributes and composition. Blending of wheat flour is done to complete the consumer preferences which are a crucial part of production process that enables millers to provide consistent flour to their customer in terms of both composition and functional quality. Posner and Hibbs (2005) reported that the different wheat flours were blend before or after milling to yield dough with good handling properties during processing and help in achieving good product quality. The industrial approach of blending flours had been done to improve the protein content and other properties of flour. Gwirtz et al. (2006) reported that the products such as crackers and doughnuts were usually prepared with the blends of hard and soft wheat flours in North America. Morris (1992) demonstrated the effect of blending of hard and soft white winter wheat grown in the northwest region of US. Gwirtz et al. (2006) reported that cake doughnuts required 50:50 blend ratio of flour produced from hard and soft wheat while yeasted doughnuts required 30:70 blend ratio of flour produced from hard and soft wheat. Hard and soft wheat quality had diverse array of products require various flour quality targets as well as a lack of understanding of the genetic basis and control of those quality parameters (Bock and Seetharaman 2012). The objective of current study was to see the effect of blending strong wheat flour with highly weak, weak and medium wheat flour on composition, pasting and dough empirical rheological properties that might help in improving functional properties, product quality and processing performance of flours.

Materials and methods

Materials

Wheat varieties (HUW468 and HP1761) with dough stability (DS) ranged from 11.4 to 13.5 min considered as

strong wheat were blended with wheat varieties with very weak (WH1021, DS = 2.8 min), weak (HD2894, DS = 6.2 min) and medium (HUW234, DS = 9.9 min) wheat varieties (Singh et al. 2016). These classes of wheat flour were classified in terms of gluten strength. Blends were prepared by mixing strong wheat flour with very weak, weak and medium wheat flours on a dry weight basis to ensure uniform dry matter contributions. Five different levels of blending were obtained with the ratios of strong flour: very weak/weak/medium flour (100:0, 75:25, 50:50, 25:75 and 0:100) (w/w).

Methods

Protein content

The protein content of various composite flours was done determined using AOAC methods (1990).

Pasting properties

The pasting properties of various composite flours were evaluated as described earlier by Singh et al. (2016).

Mixographic characteristics

The dough mixing properties of various composite flours were analyzed as described earlier by Singh et al. (2016).

Dynamic rheology of dough

Dynamic rheology of dough was performed using a RheoStress 6000 controlled stress rheometer (Haake, Karlsruhe, Germany) equipped with a Phoenix II P1-C25P refrigeration circulation bath as described earlier (Kaur et al. 2013).

Statistical analysis

The data obtained were subjected to two-way ANOVA to find out significant difference in different properties amongst various varieties. The relationship between different properties was established by Pearson correlation (*r*) analysis. The statistical analysis was carried out by using Minitab Release 14 Statistical Software (Soft College, PA, USA).

Results and discussions

Protein content

The protein content of flour milled from various wheat varieties ranged from 11.46 to 12.3% (Table 1). Figure 1 illustrates the protein content of composite flours prepared

using flours of wheat varieties varied in flour gluten strength. Regression equation for protein content as a function of blending levels of flours from strong and weak wheat gluten is shown in supplementary Table 1a. The quadratic and exponential equations for the relationship of protein content with blending levels of flours from wheat with gluten strength showed R^2 values of more than 0.99

Table 1 Effect of blending of flours from very-weak, weak and medium wheat varieties with flours from strong common wheat varieties on protein content and pasting properties

Varieties	Blend proportion		Protein content (%)	PV (cP)	FV (cP)	BDV (cP)	SBV (cP)	PT (°C)
HUW468:WH1021 (Strong wheat: very weak wheat)	100	0	11.46 ± 0.04	2840 ± 116	2773 ± 119	1459 ± 49	1392 ± 52	61.57 ± 0.2
	75	25	11.33 ± 0.03	2868 ± 120	2777 ± 120	1478 ± 50	1387 ± 50	60.17 ± 0.1
	50	50	11.20 ± 0.02	2559 ± 90	2672 ± 104	1221 ± 24	1334 ± 38	62.63 ± 0.03
	25	75	11.06 ± 0.04	2288 ± 80	2580 ± 79	1013 ± 39	1305 ± 38	60.10 ± 0.1
	0	100	10.93 ± 0.03	2155 ± 85	2526 ± 81	911 ± 42	1282 ± 38	60.23 ± 0.1
HUW468:HD2894 (Strong wheat: weak wheat)	100	0	11.46 ± 0.03	2878 ± 116	2779 ± 119	1497 ± 49	1398 ± 52	61.16 ± 0.2
	75	25	11.37 ± 0.01	2877 ± 124	2759 ± 116	1502 ± 61	1384 ± 53	64.53 ± 0.3
	50	50	11.27 ± 0.03	2886 ± 118	2723 ± 109	1516 ± 50	1353 ± 41	64.48 ± 0.02
	25	75	11.18 ± 0.02	2922 ± 133	2648 ± 100	1588 ± 66	1314 ± 33	61.59 ± 0.01
	0	100	11.08 ± 0.02	2847 ± 126	2531 ± 76	1535 ± 72	1219 ± 22	62.07 ± 0.05
HUW468:HUW234 (Strong wheat: medium wheat)	100	0	11.46 ± 0.04	2878 ± 116	2779 ± 119	1497 ± 49	1398 ± 52	61.16 ± 0.31
	75	25	11.35 ± 0.05	2858 ± 138	2771 ± 117	1478 ± 68	1391 ± 47	61.07 ± 0.03
	50	50	11.23 ± 0.02	2763 ± 115	2775 ± 120	1413 ± 51	1425 ± 56	61.09 ± 0.01
	25	75	11.12 ± 0.02	2598 ± 91	2698 ± 112	1289 ± 22	1389 ± 43	61.07 ± 0.02
	0	100	11.00 ± 0.02	2540 ± 101	2675 ± 107	1237 ± 44	1372 ± 50	60.55 ± 0.05
HP1761:WH1021 (Strong wheat: very weak wheat)	100	0	12.30 ± 0.3	2652 ± 109	2709 ± 113	1316 ± 43	1373 ± 47	61.63 ± 0.03
	75	25	11.96 ± 0.02	2636 ± 101	2694 ± 106	1294 ± 40	1352 ± 45	61.12 ± 0.1
	50	50	11.62 ± 0.02	2456 ± 95	2665 ± 99	1140 ± 40	1349 ± 44	61.57 ± 0.04
	25	75	11.27 ± 0.03	2290 ± 88	2604 ± 89	1004 ± 38	1318 ± 39	61.08 ± 0.02
	0	100	10.93 ± 0.03	2155 ± 85	2526 ± 81	911 ± 42	1282 ± 38	60.23 ± 0.1
HP1761:HD2894 (Strong wheat: weak wheat)	100	0	12.30 ± 0.03	2652 ± 109	2709 ± 113	1316 ± 43	1373 ± 47	61.63 ± 0.03
	75	25	12.00 ± 0.02	2684 ± 105	2696 ± 97	1352 ± 45	1364 ± 37	60.11 ± 0.05
	50	50	11.69 ± 0.02	2791 ± 112	2652 ± 101	1463 ± 57	1324 ± 46	64.47 ± 0.2
	25	75	11.39 ± 0.01	2808 ± 120	2581 ± 83	1504 ± 69	1277 ± 32	61.05 ± 0.05
	0	100	11.08 ± 0.02	2847 ± 126	2531 ± 76	1535 ± 72	1219 ± 22	62.07 ± 0.05
HP1761:HUW234 (Strong wheat: weak wheat)	100	0	12.30 ± 0.3	2652 ± 109	2709 ± 113	1316 ± 43	1373 ± 47	61.63 ± 0.03
	75	25	11.98 ± 0.02	2653 ± 109	2726 ± 110	1294 ± 51	1367 ± 52	60.11 ± 0.1
	50	50	11.65 ± 0.05	2470 ± 98	2694 ± 106	1118 ± 38	1342 ± 46	62.06 ± 0.04
	25	75	11.33 ± 0.03	2313 ± 89	2733 ± 115	963 ± 28	1383 ± 54	62.06 ± 0.05
	0	100	11.00 ± 0.02	2540 ± 101	2675 ± 107	1237 ± 44	1372 ± 50	60.55 ± 0.05

Data represented as mean value ± SD. Strong wheat (HUW468 and HP1761), very weak (WH1021), weak (HD2894) and medium (HUW234) BDV breakdown viscosity, FV final viscosity, PT pasting temperature, PV peak viscosity, SBV setback viscosity

Fig. 1 Regression analysis of blending of flours from very-weak, weak and medium wheat varieties with flours from strong (HUW468) common wheat varieties

(supplementary Table 1a). Figure 1 illustrated the effect of blending level of different flours on protein content of composite flours. The blending of very weak, weak and medium-weak wheat flour with strong wheat flour showed significant effect on protein content. The regression equations for blending of weak wheat with strong wheat flour had the highest regression coefficient of protein content. This indicated that the protein content changed to the greatest extent as blending level of weak flour in strong wheat flour was increased. The difference in protein content among the varieties may be due to genetic difference between strong and weak wheat flour. Strong wheat

(HP1761) flour showed the highest protein content while very weak flour showed the lowest. Kaur et al. (2014) and Singh et al. (2011) reported similar values of protein content for various Indian wheat varieties. The protein content of highly weak, weak and medium wheat flours blended with strong wheat (HUW468) flour ranged from 11.06 to 11.37%. Issarny et al. (2017) reported similar range of protein content when Canadian hard red wheat flour was blended with soft red wheat flour (7.2–12.1%). They reported the lowest values of protein content for hard and soft wheat flour blend (25:75). The presence of soft wheat flour in the blend was negatively correlated with

protein content (Issarny et al. 2017). Greenblatt et al. (1995) indicated that the bound polar lipids found mainly on the surface of starch particles in soft wheat classes has close relationship with friabilin, but they were absent on the surface of starch of hard wheat cultivars. The statistical analysis showed a significant effect of varieties and blending level on protein content; however varieties showed more pronounced effect as compared to blending level. The statistical analysis revealed a significant effect of weak gluten varieties and blending level on protein content (Table 3). The composite flours from strong wheat (HUW468) and very weak wheat flour in the ratio of 25:75 and 0:100 showed lower protein content. The results reflected that the protein content of the composite flour progressively decreased with decrease in proportion of strong wheat flour. Morris (1992) studied the effect of blending on baking and milling quality and linear relationship was observed for protein content and water absorption in blends of hard winter and soft spring wheat grown in the northwest region of US.

Pasting properties

Pasting properties of composite flours made by blending strong wheat varieties flours with very weak, weak and medium-weak wheat flours in different ratio (100:0, 75:25, 50:50, 25:75 and 0:100, w/w) are shown in Table 1. ANOVA showed a significant effect of varieties and blending level on pasting properties. The statistical analysis showed a significant effect of weak gluten varieties and blending level on pasting parameters (Table 3). Figure 1 illustrates the effect of blending of strong gluten wheat varieties with very weak, weak and medium wheat varieties on pasting properties. Supplementary Table 1a showed the regression coefficients and coefficients of determination for all pasting parameters on blending of very weak, weak and medium wheat flour with strong wheat flour. The results indicated that with increase in proportion of very weak wheat flour in both strong wheat flours (HUW468 and HP1761) progressively decreased pasting parameters. The blending of weak wheat with strong wheat flour had the highest regression coefficient (slope) indicating the greatest change in PV, FV, BDV, SBV and PT was observed with increase in blending level of weak wheat. The results indicated that with increase in proportion of weak wheat flour in both strong wheat flours PV and BDV progressively increased. The results indicated that with increase in proportion of weak wheat flour in both the strong wheat flours, FV and SBV progressively decreased. Flour from strong wheat (HUW468) showed the highest whereas flour from very weak wheat variety showed the lowest PV, FV and BDV. The difference in pasting properties with the blending of very weak, weak and medium flours may be

because of difference in protein content and composition in these flours. Strong wheat flour (HUW468) had the lowest proportion of UnEx-MP and the highest proportion of UnEx-PP, therefore the protein content decreased on blending of strong wheat flour with very weak, weak and medium wheat flour (Katyal et al. 2016). PV, FV and BV were observed to be related to the protein content. Flours with higher protein content showed higher PV, FV and BV and vice versa. Therefore on blending of strong wheat flour with weaker wheat flour decreased the protein content and consequently PV and BV. FV and SBV positively correlated with protein content. PV, FV, BDV, SBV and PT of different wheat varieties ranged from 2155 to 2878 cP, 2526 to 2779 cP, 911 to 1497 cP, 1219 to 1398 cP and 60.23 to 62.07 °C. PV, FV, BDV, SBV and PT of very weak, weak and medium wheat flours blended with strong wheat (HUW468) flours ranged from 2288 to 2922 cP, 2580 to 2777 cP, 1013 to 1588 cP, 1305 to 1425 cP and 60.1 to 64.53 °C. The results indicated that addition of medium wheat flour in strong wheat flour up to 75:25 ratios did not change FV and further increase of medium wheat flour in strong wheat (HUW468) flour led to decrease FV. The results indicated that an increase in proportion of weak wheat flour in strong wheat flours caused a progressive decrease in PV and BDV. Lu and Seetharaman (2014) reported that FV decreased while BDV increased on blending of Ontario hard and soft red winter wheat at ratio of 0:100. Very weak wheat (75%) flour had the lowest values for all pasting parameters which showed that the addition of 75% very weak wheat flour in strong wheat (HUW468) flour decreased all the pasting properties. The lowest values of paste viscosities were observed for strong wheat (HUW468) and very weak wheat flour blend in the ratio of 25:75. The highest PV was observed for strong wheat (HUW468) and medium wheat flour blend in the ratio of 25:75. PV, FV, BDV, SBV and PT of very weak flour blend with strong wheat (HUW468) flour ranged from 2288 to 2868 cP, 2580 to 2777 cP, 1013 to 1478 cP, 1305 to 1387 cP and 60.10 to 60.17 °C, while PV, FV, BDV, SBV and PT of very weak flour blended with strong wheat (HP1761) flour ranged from 2290 to 2288 cP, 2604 to 2733 cP, 1004 to 1504 cP, 1318 to 1383 cP and 60.11 to 62.06 °C. The lowest values for paste viscosities were observed for strong wheat (HP1761) and very weak wheat flours blended in the ratio of 25:75. The highest value of PV was observed for strong wheat (HP1761) and weak wheat flour blended in the ratio of 25:75. The pasting properties of blended flour decreased with increase in the addition of very weak and medium wheat varieties but PV and BDV increase with increase in the addition of weak wheat in strong wheat flour. Hatcher et al. (2009) reported the change in pasting properties on blending of durum and hard white wheat flour. There was a decrease in PV and FV

with an increase in ratio of durum wheat flour in the blend. Lu and Seetharaman (2014) also reported that HWF demonstrated more favorable pasting properties except for lower PV or noodle making than standard noodle flour. Choy et al. (2013) reported the effect of incorporation of buckwheat flour (0–40%) with Australian Soft (AS) and Baker's flours on noodle making quality. Pasting profile of blending of very-weak, weak and medium-strong with strong common wheat varieties is shown in Fig. 2.

Mixographic characteristics

The relationship between mixographic properties and blending levels for various wheat varieties were plotted on graph (Fig. 1). The R^2 values for different varieties for relationship between MPT and blending levels of various flours varying in strength ranged between 0.922 and 0.997 (supplementary Table 1b). Figure 1 illustrated the effect of blending level of different flours on protein content of composite flours. The blending of very weak, weak and medium wheat flour with strong wheat flour showed significant effect on MPT. The blending of weak wheat with strong wheat flour had the highest regression coefficient (slope) indicating the greatest change in MPT as the blending level was increased (supplementary Table 1b).

Fig. 2 Pasting profile of blending of flours from very-weak, weak and medium wheat varieties with flours from strong common wheat varieties

The difference in mixographic properties with the blending of very weak, weak and medium wheat flours might be due to variation in protein content and composition in these flours. MPT, MPV and LPV were observed to be related to the protein content. Flours with higher protein content showed higher MPT, MPV and LPV and vice versa. Therefore on blending of strong wheat flour with weaker wheat flour decreased the protein content that consequently changed mixographic properties. MPT and MPW of dough made from meal obtained from various durum wheat accessions ranged from 1.14 to 6.59 min and 15.34 to 60.58%, respectively (Katyal et al. 2018). The increase in proportion of very weak wheat flour in both strong wheat flours led to progressive decrease in MPT and LPV. The results reflected that addition of very weak wheat flour in strong wheat flours up to 75:25 ratio decreased MPW, RPV and RPW and further addition led to increase in these. The increase in proportion of very weak wheat flour in strong wheat flour (HUW468) decreased LPW. Mixographic properties of strong wheat (HUW468 and HP1761) and very weak, weak and medium wheat flours blended in ratio of 100:0, 75:25, 50:50, 25:75 and 0:100 (w/w) resulted was significantly varied between varieties and blending levels (Table 2). MPT, MPV, LPV, RPV, MPW, LPW and RPW of different varieties varied from 2.49 to 4.65 min, 58.52 to 64.51%, 19.84 to 41.42%, 27.91 to 60.55%, 24.39 to 41.42%, 57.46 to 60.54%, and 15.46 to 39.04%. Very weak variety flour had the lowest whereas strong wheat (HUW468) flour had the highest MPT. LPV was the highest for medium wheat flour and the lowest for very weak flour. LPW was the highest for strong wheat flour (HP1761) and the lowest for very weak flour. The lowest values of mixographic parameters were observed for strong wheat flour blended with highly weak wheat flour in the ratio of 25:75. The highest value of mixograph peak time was observed for strong wheat flour blended with medium wheat flour in the ratio of 75:25. MPT and MPV for different hard, medium hard and extraordinarily soft wheat varieties ranged from 2.6 to 6.40 min, 32.75 to 48.03%, respectively (Katyal et al. 2017). Oak et al. (2006) reported that the dough with more MPT and wider MPW resulted into stable and strong dough. The addition of weak wheat flour in both strong wheat flours up to 75:25 ratio decreased MPV, LPV and RPV and further addition caused some improvement in these values. MPT and LPV had positive correlation with PV. MPT and MPW had positive correlation with FV ($r = 0.729$ and 0.342 respectively, $p \leq 0.005$). This clearly indicated that varieties or blends with higher FV and PV took longer time to develop the dough with optimum consistency. MPT and MPW showed positive correlation with SBV. The blending of very weak, weak and medium wheat flour with strong wheat flour showed significant effect on MPV. The blending of very

Table 2 Effect of blending of flours from very-weak, weak and medium wheat varieties with strong common wheat varieties on mixographic and rheological properties

Varities	Blend proportion		MPT (min)	MPV (%)	MPW (%)	LPV (%)	LPW (%)	RPV (%)	RPW (%)	G' (Pa)	G'' (Pa)	Tanδ
HUW468:WH1021 (Strong wheat: very weak wheat)	100	0	4.65 ± 0.05	58.52 ± 3.2	27.99 ± 2.60	56.65 ± 3.60	30.30 ± 2.6	57.46 ± 3.9	22.37 ± 2.19	97,620 ± 1005	26,391 ± 499	0.270 ± 0.27
	75	25	3.49 ± 0.01	48.35 ± 2.9	20.04 ± 2.05	46.84 ± 2.46	29.15 ± 2.3	46.55 ± 3.1	13.82 ± 1.6	23,970 ± 590	9311 ± 166	0.388 ± 0.39
	50	50	2.96 ± 0.02	47.77 ± 3.00	19.46 ± 1.99	45.72 ± 2.43	38.79 ± 2.9	44.81 ± 2.88	12.03 ± 1.19	23,130 ± 560	9411 ± 159	0.407 ± 0.41
	25	75	2.6 ± 0.03	38.84 ± 2.6	15.85 ± 1.40	36.09 ± 2.29	18.10 ± 1.5	35.84 ± 2.49	9.16 ± 0.87	15,330 ± 290	6597 ± 110	0.430 ± 0.43
	0	100	2.49 ± 0.06	64.51 ± 4.5	24.39 ± 2.45	27.91 ± 2.42	24.39 ± 2.05	60.54 ± 3.94	15.72 ± 1.19	3489 ± 101	1388 ± 79	0.398 ± 0.39
HUW468:HD2894 (Strong wheat: weak wheat)	100	0	4.65 ± 0.05	58.52 ± 3.2	27.99 ± 2.60	56.65 ± 3.60	30.30 ± 2.6	57.46 ± 3.9	22.37 ± 2.19	97,620 ± 1005	26,391 ± 499	0.270 ± 0.27
	75	25	4.35 ± 0.05	43.58 ± 3.12	24.69 ± 2.36	42.55 ± 2.26	31.06 ± 2.66	42.04 ± 2.86	19.16 ± 1.29	32,260 ± 650	11,836 ± 319	0.367 ± 0.36
	50	50	4.35 ± 0.01	42.85 ± 3.19	22.73 ± 2.34	41.57 ± 2.19	26.25 ± 2.09	40.99 ± 2.69	20.55 ± 1.31	32,640 ± 590	11,769 ± 226	0.361 ± 0.36
	25	75	3.65 ± 0.02	44.43 ± 3.22	24.45 ± 2.52	43.63 ± 2.39	33.83 ± 2.75	42.91 ± 2.81	14.22 ± 0.99	30,330 ± 560	11,299 ± 204	0.373 ± 0.37
	0	100	3.41 ± 0.01	63.51 ± 4.11	19.84 ± 1.86	59.7 ± 3.76	27.00 ± 1.99	60.37 ± 3.74	17.27 ± 1.14	32,104 ± 575	10,162 ± 186	0.317 ± 0.32
HUW468:HUU234 (Strong wheat: medium wheat)	100	0	4.65 ± 0.03	58.52 ± 3.20	27.99 ± 2.60	56.65 ± 3.60	30.30 ± 2.6	57.46 ± 3.9	22.37 ± 2.19	97,620 ± 1005	26,391 ± 499	0.270 ± 0.27
	75	25	4.00 ± 0.05	45.29 ± 2.72	31.96 ± 2.78	41.13 ± 2.39	25.82 ± 2.05	44.62 ± 2.44	22.49 ± 2.02	38,560 ± 755	12,577 ± 211	0.326 ± 0.33
	50	50	4.17 ± 0.02	44.64 ± 2.66	23.55 ± 2.39	43.27 ± 2.59	29.78 ± 2.19	43.00 ± 2.46	14.83 ± 1.19	24,420 ± 555	8436 ± 142	0.345 ± 0.35
	25	75	3.90 ± 0.1	44.04 ± 2.77	17.40 ± 1.65	41.83 ± 2.19	29.57 ± 2.39	41.57 ± 2.29	13.50 ± 1.24	25,710 ± 575	8883 ± 151	0.346 ± 0.37
	0	100	4.36 ± 0.03	64.97 ± 4.26	25.89 ± 2.32	60.55 ± 3.89	31.87 ± 2.59	59.37 ± 3.69	15.46 ± 1.20	7546 ± 129	2804 ± 51	0.372 ± 0.37
HPI761:WH1021 (Strong wheat: very weak wheat)	100	0	3.70 ± 0.02	69.89 ± 4.55	41.42 ± 2.92	48.99 ± 2.99	41.42 ± 2.89	66.40 ± 4.01	39.04 ± 2.36	63,547 ± 890	16,435 ± 166	0.259 ± 0.26
	75	25	3.47 ± 0.02	45.32 ± 2.26	26.50 ± 2.49	42.47 ± 2.52	31.81 ± 2.15	43.73 ± 2.88	14.66 ± 1.09	23,550 ± 545	8454 ± 143	0.359 ± 0.36
	50	50	3.12 ± 0.02	43.41 ± 3.2	19.51 ± 1.45	41.45 ± 2.42	27.51 ± 1.88	41.19 ± 2.45	14.10 ± 1.01	17,840 ± 319	9985 ± 163	0.560 ± 0.56
	25	75	2.86 ± 0.04	41.19 ± 2.4	17.51 ± 1.37	35.89 ± 2.01	23.72 ± 1.59	38.29 ± 2.14	8.91 ± 0.59	28,090 ± 594	13,458 ± 223	0.479 ± 0.48
	0	100	2.49 ± 0.01	64.51 ± 4.01	24.39 ± 2.59	27.91 ± 1.78	24.39 ± 1.52	60.54 ± 3.76	15.72 ± 1.29	3489 ± 106	1388 ± 46	0.398 ± 0.39
HPI761:HD2894 (Strong wheat: weak wheat)	100	0	3.70 ± 0.2	69.89 ± 4.55	41.42 ± 2.92	48.99 ± 2.99	41.42 ± 2.89	66.40 ± 4.01	39.04 ± 2.36	63,547 ± 890	16,435 ± 166	0.259 ± 0.26
	75	25	4.41 ± 0.01	37.38 ± 1.98	16.02 ± 1.34	35.68 ± 1.69	17.99 ± 1.09	36.70 ± 2.19	14.03 ± 1.17	27,730 ± 587	9731 ± 171	0.351 ± 0.35
	50	50	4.28 ± 0.02	40.85 ± 2.05	22.31 ± 2.29	39.26 ± 2.05	28.01 ± 1.79	40.05 ± 2.46	13.25 ± 1.08	25,870 ± 562	9020 ± 146	0.349 ± 0.35
	25	75	3.59 ± 0.02	43.13 ± 2.14	16.83 ± 1.26	40.13 ± 2.14	32.79 ± 2.58	41.12 ± 2.19	12.75 ± 1.03	26,570 ± 572	9430 ± 159	0.355 ± 0.36
	0	100	3.41 ± 0.01	63.51 ± 3.98	19.84 ± 1.38	59.70 ± 2.79	27.00 ± 2.29	60.37 ± 3.81	17.27 ± 1.29	32,104 ± 584	10,162 ± 214	0.317 ± 0.32
HPI761:HUU234 (Strong wheat: medium wheat)	100	0	3.70 ± 0.1	69.89 ± 4.55	41.42 ± 2.92	48.99 ± 2.99	41.42 ± 2.89	66.40 ± 4.01	39.04 ± 2.36	63,547 ± 890	16,435 ± 166	0.259 ± 0.26
	75	25	4.17 ± 0.03	44.02 ± 2.65	22.80 ± 2.09	41.43 ± 2.09	30.87 ± 2.38	42.39 ± 2.36	17.42 ± 1.33	26,740 ± 579	9093 ± 176	0.340 ± 0.34
	50	50	4.02 ± 0.02	43.33 ± 2.35	26.75 ± 2.16	41.43 ± 2.08	31.12 ± 2.54	42.26 ± 2.41	16.33 ± 1.26	27,680 ± 529	9240 ± 173	0.334 ± 0.33
	25	75	3.99 ± 0.01	43.20 ± 2.19	17.63 ± 1.43	42.07 ± 2.11	25.57 ± 1.74	41.54 ± 2.29	15.36 ± 1.35	24,280 ± 492	7415 ± 134	0.305 ± 0.31
	0	100	4.36 ± 0.02	64.97 ± 4.15	25.89 ± 2.33	60.55 ± 2.86	31.87 ± 2.39	59.37 ± 3.49	15.46 ± 1.30	7546 ± 129	2804 ± 81	0.372 ± 0.37

Data represented as mean value ± SD. Strong wheat (HUW468 and HPI761), very weak (WH1021), weak (HD2894) and medium (HUU234)

LPV left peak value, LPW left peak width, MPT mixograph peak time, MPV mixograph peak value, MPW mixograph peak width, RPV right peak value, RPW right peak width, G' elastic modulus, G'' viscous modulus

weak flour with strong wheat flour had the highest regression coefficient (slope) indicating the greatest change in MPV as the blending level was increased. ANOVA revealed significant effect of varieties and blending level on all mixographic parameters. The statistical analysis revealed a significant effect of weak and strong wheat flours and blending level on mixographic properties (Table 3). The addition of medium wheat flour in strong wheat flour up to 75:25 ratio decreased MPV, LPV and RPV and further addition led to an increase. The mixographic parameters of very weak, weak and medium wheat flours blended with strong wheat flour ranged from 2.6 to 4.35 min, 38.84 to 48.35%, 15.85 to 31.96%, 36.09 to 46.84%, 18.10 to 38.91%, 35.84 to 46.55% and 9.16 to 22.49%. Very weak flour (75%) showed the lowest values for all mixographic parameters which showed that the addition of 75% very weak flour in strong wheat (HUW468) flour decreased all the pasting properties. The lowest values of all mixographic parameters were observed for strong wheat flour (HUW468) and very weak flour when blended in the ratio of 75:25. The highest MPT was observed for HUW468 and HD2894 blended in the ratio of 75:25. The highest MPV, LPV and RPV were observed for strong wheat flour (HUW468) and very weak wheat flour when blended in the ratio of 75:25. The mixographic

parameters of very weak flour blended with strong wheat flour ranged from 2290 to 2288 cP, 2604 to 2733 cP, 1004 to 1504 cP, 1318 to 1383 cP and 60.11 to 62.06 °C. The mixographic parameters of highly weak, weak and medium wheat flours blended with strong wheat flour (HP1761) ranged from 2.86 to 4.41 min, 37.38 to 45.32%, 16.02 to 26.75%, 35.89 to 42.47%, 17.99 to 32.79%, 36.70 to 43.73 and 8.91 to 17.42%. The highest MPT was observed for strong wheat flour (HP1761) and medium wheat flour blended in the ratio of 75:25. The lowest value of MPV, MPW, LPW and RPV was observed for strong wheat flour (HP1761) and medium wheat flour blended in the ratio of 75:25. Mixograms of blending of very-weak, weak and medium-strong with strong common wheat flours is shown in Fig. 3.

Dynamic rheology of dough

The various dynamic rheological parameters (G' , G'' and $\tan\delta$) of dough from various wheat varieties were evaluated. G' and G'' ranged from 3489 to 97620 Pa and 1388 to 26,391 Pa, respectively for dough from different wheat varieties (Table 2). The strong wheat flour (HUW468) showed the highest G' and G'' whereas very weak wheat flour showed the lowest value for both. $\tan\delta$ ranged from

Table 3 *F* values from two-way ANOVA analysis of the (strong gluten wheat varieties versus level of blends and weak gluten wheat varieties versus level of blends) reported in Tables 1 and 2

Parameters	Strong gluten wheat varieties × level of blends			Weak gluten wheat varieties × level of blends		
	Strong gluten wheat varieties	Level of blends	Interaction	Weak gluten wheat varieties	Level of blends	Interaction
Protein content (%)	445.08**	242.77**	55.63**	0.50	24.84**	0.06
PV (cP)	10.20**	5.50**	0.75	43.61**	13.33**	7.97**
FV (cP)	3.07**	8.56**	0.49	4.68*	9.15**	0.82
BDV (cP)	10.28**	3.94**	0.67	74.68**	13.88**	12.90**
SBV (cP)	2.57	8.56**	0.26	15.07**	13.58**	3.44**
PT (°C)	0.67	8.62**	2.45*	29.70**	17.09**	5.62**
MPT	1.97	6.81**	3.00*	130.54**	33.75**	16.22**
MPV	2.28	205.20**	13.96**	1.24	130.21**	1.27
MPW	5.22**	51.82**	15.99**	3.02*	33.23**	1.83*
LPV	3.43*	9.20**	0.64	35.87**	50.00**	40.07**
LPW	1.96	10.92**	6.61**	1.39	11.99**	5.16**
RPV	1.32	195.26**	9.87**	0.53	147.01**	1.86*
RPW	21.28**	143.58**	45.09**	3.16*	44.49**	0.75
G'	29.27**	249.23**	20.18**	9.76**	156.86**	3.14**
G''	23.43**	137.10**	17.93**	6.88**	90.34**	3.33**
$\tan\delta$	0.13	19.54**	0.98	71.79**	76.83	13.98**

BDV breakdown viscosity, FV final viscosity, G' elastic modulus, G'' viscous modulus, LPV left peak value, LPW left peak width, MPT mixograph peak time, MPV mixograph peak value, MPW mixograph peak width, PT pasting temperature, PV peak viscosity, RPV right peak value, RPW right peak width, SBV setback viscosity

* = significant ($p \leq 0.05$); ** = highly significant ($p \leq 0.005$)

Fig. 3 Mixograms of blending of flours from very-weak, weak and medium wheat varieties with flours from strong common wheat varieties

HUW468:HD2894 (50:50)

HUW468:HD2894 (25:75)

HUW468:HD2894 (0:100)

HUW468:HUW234 (75:25)

HUW468:HUW234 (50:50)

HUW468:HUW234 (25:75)

Fig. 3 continued

0.26 to 0.40, the highest value for very weak wheat flour while strong wheat flour (HP1761) showed the lowest $\tan\delta$ value. The R^2 values for different varieties for relationship between G' and blending levels of various flours varying in gluten strength ranged between 0.83 and 0.92 (supplementary Table 1c). The blending of very weak, weak and medium wheat flour with strong wheat flour showed significant effect on G' and G'' . The blending of weak wheat flour with strong wheat had the highest regression coefficient (slope) indicating the greatest change in G' and G'' as the blending level was increased (supplementary Table 1c). G' showed positive correlation with BDV and SBV. G'' showed positive correlation with PV and FV. The difference in rheological behavior of strong wheat flour with the blending of very weak, weak and medium flours may be due to difference in protein content in these flours. The increase in proportion of very weak wheat flour in strong wheat flour progressively decreased G' and G'' of both strong wheat flours (HUW468 and HP1761). The increase in proportion of weak wheat flour in strong wheat flour progressively decreased G' and G'' of strong wheat flour (HUW468). Whereas the increase in proportion of medium wheat flour in both strong wheat flours led to progressive decrease in G' and G'' . Both G' and G'' showed positive correlation with protein content (supplementary Table 1d). Flours with higher protein content showed better rheological properties and vice versa. Therefore on blending of strong wheat flour with weaker wheat flour decreased the protein content as well as composition that consequently changed the rheological properties. G' showed positive correlation with PV and FV. G'' showed positive correlation with BDV and SBV. The results depicted that dough rheological parameters were related to paste properties and protein content. Zaidul et al. (2004) also reported the relationship of protein content with the pasting properties and dough rheological properties of wheat flour. Ktenioudaki et al. (2010) reported that the rheological properties of wheat played a crucial role in estimating the baking quality, dough strength, specific volume and several textural attributes. G' showed positive correlation with LPV and LPW. G' showed positive correlation with RPV and RPW. The rheological properties of dough were related to mixographic parameters. G' and G'' of very weak, weak and medium wheat flours blended with strong wheat flour ranged from 15,330 to 38,560 cP and 6597 to 12,577 cP among the different blend ratios. The highest value for G' and G'' was observed for strong wheat flour (HUW468) and medium wheat flour in the ratio of 75:25 and lowest value was observed for strong wheat flour (HUW468) and very weak flour in the ratio of 25:75. G' and G'' of very weak, weak and medium wheat flours blended with strong wheat flour (HP1761) ranged from 17,840 to 28,090 cP and 6597 to 12,577 cP among the different blend ratios. The highest

value for G' was observed for strong wheat flour (HP1761) and very weak flour blended in the ratio of 25:75 and lowest value was observed for strong wheat flour (HP1761) and very weak flour in the ratio of 50:50. The highest value for G'' was observed for strong wheat flour (HP1761) and very weak flour in the ratio of 25:75 and lowest value was observed for strong wheat flour (HP1761) and medium wheat flour blended in the ratio of 25:75.

Conclusion

The flour milled from common wheat varieties varied in gluten strength were blended in different proportion to see the effect of blending on pasting and dough rheological properties of composite flours. Flours with higher protein content showed better rheological properties. The blending of strong wheat flour with weaker wheat flour decreased the protein content and composition that consequently changed the rheological properties. The protein content of the composite flour progressively decreased with decrease in proportion of strong wheat flour. Strong wheat (HUW468) flour had the lowest proportion of UnEx-MP and the highest proportion of UnEx-PP. The blending of strong wheat flour with weaker wheat flour decreased protein content and changed protein composition that consequently changed mixographic properties. The difference in rheological behavior of strong wheat flour with the blending of very weak, weak and medium flours may be due to variation in protein content and composition in these flours.

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