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Utilisation of GlutoPeak tester on whole-wheat flour for gluten quality assessment

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RESEARCH ARTICLE

Abstract

Rapid and accurate determination of gluten quality is crucial in the early generation of wheat breeding programs to develop cultivars with proper bread-making quality. Conventional gluten quality tests, involving wet-chemistry or those based on instruments and methods such as farinograph, mixograph, mixolab, alveograph, extensograph and glutomatic, usually require refined white flour, large sample size, certain chemicals and extended time of analysis. Therefore, reliable and faster methods that perform directly on whole-wheat flour are required to evaluate gluten quality of substantial number of materials in wheat breeding programs. In this study, the data derived from GlutoPeak tester on whole-wheat flours and conventional tests conducted on refined white flours were compared. Conventional tests included farinograph, lactic acid solvent retention capacity, Zeleny-sedimentation and swelling index of glutenin. GlutoPeak data collected from whole-wheat flours highly and significantly correlated with the data obtained from GlutoPeak tester and conventional gluten quality tests conducted on refined white flours. Of the GlutoPeak data, especially MT and torque 15 sec after maximum torque were found to be quite useful in the assessment of gluten quality on whole-wheat flour for wheat breeding programs as a fast, reliable and repeatable approach.

Keywords: GlutoPeak, gluten, quality, whole-wheat flour, breeding

1. Introduction

Development of varieties with superior bread-making quality is among the top priorities of wheat (*Triticum aestivum* L.) breeding programs. Bread-making quality of wheat is mainly affected by grain protein content and gluten properties (gluten quality), in which protein content is strongly influenced by the environmental conditions and agronomical practices, while gluten quality is mostly determined by the genetic factors (Cornish *et al.*, 1991; Gupta *et al.*, 1994; Kasarda, 1989; Mikhaylenko *et al.*, 2000; Payne *et al.*, 1982, 1987; Troccoli *et al.*, 2000). Strong-gluten wheat flours, usually milled from hard wheats, are preferred for bread-making as they form doughs with proper viscoelasticity and cohesiveness (Malegori *et al.*, 2018; Marti *et al.*, 2015), leading to higher loaf volume, homogeneous cell structure, softer crumb and longer shelf life (Bushuk, 1998; Hoseney, 1994). In contrast, relatively weaker wheat flours, often time milled from soft wheats, are utilised in such products as cookies and cakes due to a weaker gluten network requirement in those products (Bushuk, 1998; Guzman *et al.*, 2016a; Hoseney, 1994).

Viscoelastic properties of wheat dough determine its suitability for the final products, such as bread, pasta, cake, biscuit, noodle, pastry and other processed foods (Dizlek and Özer, 2016; Shewry, 2009). Gluten, which is formed by mixing flour with water, is the main component responsible for the viscoelastic properties of dough. Thus, accurate determination of proper gluten viscoelasticity (gluten quality) for a given final product is of utmost importance (Guzman, 2016c).

Numerous chemical and instrumental predictive tests have been developed for the assessment of wheat gluten quality (Bagulho *et al.*, 2015; Bushuk, 1998; Butow *et al.*, 2002; Chandi and Seetharaman, 2012; Kinsella and Hale, 1984; Preston, 1981; Sarkar *et al.*, 2014). Of those analytical approaches, lactic acid solvent retention capacity (L-SRC), gluten index, sedimentation volume, gliadin-glutenin ratio and dough rheological measurements by farinograph, mixograph, mixolab, alveograph or extensograph are among the commonly used conventional tests (Dick and Quick, 1983; Hu and Shang, 2007; Kweon *et al.*, 2009). Gluten quality assessment with the conventional methods is of certain limitations and usually requires refined white flours with extended time of analysis (Chandi and Seetharaman, 2012; Miralbes, 2004). For instance, gluten index method fails to produce a doughball on samples of poor gluten quality and thus produce no results. Poor discrimination of moderately strong gluten types by sodium dodecyl sulphate (SDS) sedimentation, mixograph and farinograph is the limitation of those methods. Water absorption level in mixograph is too much dependent on operator skills, whereas alveograph requires quite a large sample size (Sissons, 2018). Baking performance tests are better techniques as compared to other flour quality testing approaches (Bushuk, 1998; Dizlek and Özer, 2017; Hoseney, 1994); however, they are also labour intensive with the requirement of large sample size, rendering them unsuitable for the breeding programs (Chandi and Seetharaman, 2012; Guzman *et al.,* 2016b). Since numerous breeding lines with rather scarce amounts are available especially in the initial stages of breeding, wheat breeders have long been in search of fast and reliable methods that can be accomplished using lesser amounts of samples (Malegori *et al.*, 2018).

GlutoPeak tester, developed in recent years by Brabender company (Duisburg, Germany), is a rapid high-shear method to study such gluten properties as mixing, aggregation, extensibility and tenacity in a dilute water-flour slurry (Fu *et al.*, 2017; Hadnaev *et al.*, 2016; Lu and Seetharaman, 2014; Marti *et al.*, 2015; Melnky *et al.*, 2011). The main data provided by the instrument are: (1) lift-off time, corresponding to the time at which gluten aggregation starts; (2) peak maximum time (PMT), corresponding to the time of maximum torque; (3) maximum torque (MT), corresponding to the maximum torque occurring due to optimum gluten aggregation; (4) torque 15 sec before MT (AM); and (5) torque 15 sec after MT (PM) (Karaduman *et al.*, 2015; Marti *et al.*, 2015). The advantages of GlutoPeak tester are its high sensitivity, short analysis time and small sample requirement compared to other instruments used for rheological analysis (Chandi and Seetharaman, 2012; Malegori *et al.*, 2018). Because of those advantages, GlutoPeak is quite promising for wheat quality breeding, especially in the early generation selection, where time and sample amount are limiting factors (Guzman *et al.* 2016b). Previous studies showed that GlutoPeak tester can be used to compare all kinds of flours, including whole-wheat flours (Chandi and Seetharaman, 2012) and durum wheat flours (Marti *et al.*, 2013). In a recent study, a highly significant correlation between GlutoPeak MT and farinograph water absorption was established (Fu *et al.*, 2017). GlutoPeak MT and PMT values were determined to satisfactorily discriminate weak and strong glutens (Karaduman *et al.*, 2015). It was also found that GlutoPeak MT gave high correlation with dough-strength parameters of 37 commercial flours from 14 mills at fixed water amount (Huen *et al.*, 2018). A recent study showed that farinograph stability can be predicted by GlutoPeak tester using whole-wheat flour (Malegori *et al.*, 2018).

The aim of this study was to evaluate the efficiency of GlutoPeak tester on whole-wheat flour for gluten quality assessment in a wheat breeding program. GlutoPeak data obtained from whole-wheat flours were compared to the gluten quality data derived from refined white flours through GlutoPeak, farinograph, Zeleny-sedimentation, L-SRC and swelling index of glutenin (SIG) tests.

2. Materials and methods

A total of 30 wheat samples were obtained from the Advanced Yield Trial of International Winter Wheat Improvement Program (Table 1). Wheat samples were first cleaned using Labofix-90 mini cleaner (Brabender, Vienna, Austria). Thousand-kernel weight was determined as described by Özkaya and Özkaya (2005). Test weight was measured using Nilema-Liter device (Chopin, Villeneuve-la-Garenne, France). Wheats were milled to whole-wheat flours on an ultra-centrifugal mill (Model ZM 200, Retsch GmbH, Haan, Germany) equipped with a 0.5 mm sieve and to refined white flours on laboratory mill (Model CD1, Chopin). Prior to milling, hard wheat samples were tempered at 16.0% water content for overnight as described by (Özkaya and Özkaya, 2005).

Moisture and protein contents of wheats and flours were determined using near-infrared spectroscopy (NIR 6500, Foss, Hillerød, Denmark), calibrated by the American Association of Cereal Chemists International (AACCI) methods of 44-15.02 and 46-19.01 (AACCI, 2010). SDS-sedimentation test was conducted on whole-wheat flours as described by Williams *et al.* (1986). Conventional gluten quality tests were conducted on refined white flour as follows. Farinograph studies were carried out by the AACCI standard method 54-21.02 (AACCI, 2010). SIG was determined using lactic acid as described by Wang and Kovacs (2002). L-SRC was carried out by Guzman *et al.* (2015). Zeleny-sedimentation test was conducted by the ICC standard no 116 (IACC, 1981).

Gluten aggregation properties were determined on whole-wheat flours using GlutoPeak tester (C.W. Brabender Inc., South Hackensack, NJ, USA) as reported by Chandi and Seetharaman (2012). For this purpose, flour (8.5 g, 14% mb) was dispersed in 9.5 g of 0.5 M $CaCl_2$ solution at 34 °C by circulating water through the jacketed sample cup. The paddle was set to rotate at 1,900 rpm and the test was carried out for 2.5 min.

Table 1. Kernel and whole-wheat flour properties associated with gluten quality.[1]

Genotype	Flour group	Kernel properties		Whole-wheat flour properties			GlutoPeak properties of whole-wheat flours			
		TKW (g)	TW (kg)	MC (%)	PC (%)	SDS-Sedim. (ml)	PMT (sec)	MT (BE)	AM (BE)	PM (BE)
1	Very strong	37.65	78.51	8.83	14.88	86.61	76.0	44.0	35.0	24.0
2	Very strong	31.00	75.59	9.10	14.44	77.33	60.0	46.0	21.0	25.0
3	Very strong	38.95	84.94	9.19	14.19	68.22	85.0	44.0	25.0	32.0
4	Very strong	32.25	79.54	8.57	13.96	82.44	62.0	45.0	16.0	21.0
5	Very strong	39.05	80.32	8.38	15.40	73.44	60.0	45.0	24.0	23.0
6	Very strong	33.05	79.24	9.48	13.42	87.83	73.0	41.0	32.0	25.0
	Average	35.33	79.69	8.92	14.38	79.81	69.3	44.2	25.5	25.0
7	Strong	38.20	81.77	9.84	11.91	62.33	82.0	39.0	21.0	23.0
8	Strong	45.10	80.75	8.76	13.70	63.11	69.0	38.0	22.0	27.0
9	Strong	34.05	80.17	8.81	14.02	74.56	71.0	40.0	17.0	24.0
10	Strong	44.40	83.89	9.73	12.57	67.11	62.0	37.0	20.0	18.0
11	Strong	35.00	83.33	9.61	13.97	64.56	60.0	37.0	14.0	22.0
12	Strong	32.20	77.08	8.97	14.89	72.72	60.0	38.0	41.0	28.0
	Average	38.16	81.16	9.29	13.51	67.40	67.3	38.2	22.5	23.7
13	Medium	45.10	82.22	9.41	12.63	56.72	65.0	35.0	10.0	21.0
14	Medium	41.75	80.68	9.27	12.76	60.22	60.0	35.0	20.0	24.0
15	Medium	31.65	81.07	9.22	13.47	52.50	68.0	34.0	14.0	22.0
16	Medium	35.15	81.07	9.22	13.22	67.67	60.0	31.0	28.0	27.0
17	Medium	39.40	81.49	9.69	11.68	48.72	71.0	30.0	19.0	19.0
18	Medium	31.50	75.74	9.62	12.46	55.06	77.0	30.0	15.0	19.0
	Average	37.43	80.38	9.41	12.70	56.81	66.8	32.5	17.7	22.0
19	Weak	48.85	81.88	9.60	12.92	42.06	60.0	26.0	15.0	20.0
20	Weak	45.10	83.86	8.78	13.73	68.75	60.0	26.0	40.0	25.0
21	Weak	36.25	81.91	9.49	12.49	39.39	60.0	25.0	27.0	20.0
22	Weak	42.75	81.11	9.91	12.30	55.61	71.0	27.0	26.0	27.0
23	Weak	31.80	80.78	9.19	12.57	46.83	60.0	25.0	33.0	20.0
24	Weak	33.00	85.73	9.79	12.51	38.72	77.0	25.0	11.0	18.0
	Average	39.63	82.54	9.46	12.75	48.56	64.7	25.7	25.3	21.7
25	Very weak	47.20	81.78	8.97	14.83	43.53	64.0	15.0	16.0	13.0
26	Very weak	40.20	79.58	8.44	14.38	52.39	101.0	17.0	17.0	13.0
27	Very weak	41.40	80.08	9.71	13.40	36.17	64.0	13.0	13.0	11.0
28	Very weak	32.65	78.78	8.45	15.02	43.28	113.0	23.0	22.0	23.0
29	Very weak	37.55	76.72	9.37	12.82	45.06	71.0	18.0	18.0	17.0
30	Very weak	39.35	84.46	9.64	12.97	36.67	66.0	24.0	13.0	19.0
	Average	39.73	80.23	9.10	13.90	42.85	79.8	18.3	16.5	16.0
LSD		6.41	2.98	0.52	0.96	5.32	14.50	2.91	9.33	4.42
CV (%)		14.2	3.2	4.7	6.0	13.6	17.5	7.7	36.5	17.2
Sig.Prob.		ns	ns	ns	0.01	0.01	ns	0.01	ns	0.01

[1] AM = Torque 15 sec before MT; MC = moisture content; MT = maximum torque; PC = protein content; PM = Torque 15 sec after MT; PMT = peak maximum time; SDS-Sedim = sodium dodecyl sulfate sedimentation; TKW = thousand-kernel weight; TW = test weight.

The study was conducted by the complete randomised design with 3 replications. Statistical analysis was carried out using JMP software. Treatment effects were analysed using one-factor ANOVA and means were separated by the Student's t test that was sized for individual comparisons (Student, 1908). The relationship among the gluten quality traits was examined using Pearson's correlation coefficients (SAS Institute, 1998). Biplot analysis was performed as described by Gabriel (1971) to produce a graphical representation of the relationships between data units and variates.

3. Results and discussion

Whole-wheat flours used in the study were first divided into five groups, from very strong to very weak, based mainly on their GlutoPeak MT values (Table 1). The aim of our study is to test the availability of the parameters obtained from the GlutoPeak device directly from whole-wheat flour in breeding programs, where there are large number of materials with limited quantity. In the tests used for the determination of gluten quality (sedimentation, swelling index and dough properties), white wheat flour is needed. Milling of wheat to white flour is time consuming, however, obtaining whole wheat flour is quite fast. Because of the weakening effect of bran, we thought that whole-wheat flour MT values can be used for discriminating genotypes in terms of gluten strength. The high correlations among whole-wheat MT values and white flour, dough gluten quality parameters and white flour MT value confirmed the usefulness and importance of the whole-wheat MT parameter. The study indicates that nearly in 5 min. (three min. for milling to whole-wheat flour and two min. for GlutoPeak testing), gluten quality of wheat genotypes can be evaluate successfully from whole-wheat flour.

Along with kernel physical properties, gluten-quality associated tests are commonly used in wheat breeding programs (Bushuk, 1998). SDS sedimentation analysis in early generation in breeding programs is mostly used for testing protein quality of the material (Guzman *et al.*, 2016a; Zhao *et al.*, 2012). It was modified from Zeleny sedimentation test (Axford *et al.*, 1979; Zeleny, 1947). However, due to variations by operator and laboratory conditions, sometimes improper evaluation of breeding material is made (as seen our study same sedimentation results of different groups in Table 1). Other quality testing approaches, such as L-SRC, Zeleny-sedimentation and SIG, also provide information on gluten quality (Guzman *et al.*, 2015); however, they are usually conducted on refined white flour, in which milling of kernel to white flour requires extra time and workforce. In this study, GlutoPeak tester was used on both whole-wheat flours (Table 1) and white flours (Table 2). As shown in Figure 1, GlutoPeak MT values obtained from whole-wheat flours and refined white flours had a very strong positive correlation (r^2=0.99), indicating the efficiency of GlutoPeak tester for gluten quality measurement on whole-wheat flour.

GlutoPeak MT and PM values were found to positively correlate with high-molecular weight glutenin subunits (HMW-GS) of *Glu-B1* locus (7 + 8, 7 + 9, 17 + 18) that is related to dough extensibility (Kutlu *et al.*, 2017). Also, Huen *et al.* (2018) found that GlutoPeak MT was correlated with dough strength parameters at fixed water amount. In this study, GlutoPeak PM values on whole-wheat flours were also able to discriminate the flour groups (Table 1). Similarly, in a recent study, GlutoPeak tester was suggested an efficient and valuable tool for evaluation of gluten aggregation in whole-wheat flours (Wang *et al.*, 2018). In the current study, GlutoPeak, PMT and AM values did not exhibit any meaningful discrimination among the flour groups (Table 1). It was reported that hard wheat flours exhibited longer PMT than flours of soft wheats (Lu and Seetharaman, 2014) and that wafer flours had very much delayed peak formation and much lower AM torque (Marti *et al.*, 2015). In a recent study conducted using 11 bread wheat varieties from three different locations (Şanal *et al.,* 2018), farinograph water absorption level produced a significant negative correlation with GlutoPeak PMT value (r^2=-0.25**). Kutlu *et al.* (2017) reported that 17 + 18 allele of HMW-GS encoded *Glu-B1* loci, responsible for dough extensibility (Brandlard and Dardavet, 1985), provided the most important contribution to GlutoPeak MT, AM and PM values in 74 double haploid lines. In the current study, although very strong and very weak groups of flours were comparable in their protein contents, their MT values were quite different (Table 1).

In this respect, very strong group had an average MT value of 44.17 BE, while very weak group produced an average MT value of 18.33 BE. This result strongly supports the previous findings (Karaduman *et al.*, 2015; Marti *et al.*, 2015) that MT value obtained from whole-wheat flour is a useful parameter to differentiate protein quality of wheat genotypes.

As listed in Table 3, significant correlations were established between GlutoPeak parameters of whole-wheat flours and conventional gluten quality tests of white flours. Among the GlutoPeak parameters, especially MT and PM values of whole-wheat flours had very strong positive correlations with L-SRC, Zeleny-sedimentation, farinograph stability and SIG of white flours. In a recent study, Malegori *et al.* (2018) also showed that GlutoPeak test on whole-wheat flour was able to predict farinograph stability. As shown in Figure 2, GlutoPeak MT values of whole-wheat flours well correlated with the SIG of white flours (r^2=0.68). It is known that SIG test is strongly associated with many gluten quality parameters and dough rheological properties (Li *et al.,* 2015; Wang and Kovacs, 2002).

Table 2. Gluten-quality associated properties of refined white flours.[1]

Genotype	Flour group	Gluten qualities of white flours			GlutoPeak properties of white flours				Farinograph properties of white flours			
		L-SRC (%)	Zeleny-Sedim. (ml)	SIG (ml)	PMT (sec)	MT (BE)	AM (BE)	PM (BE)	Water Abs. (%)	Stability (min)	DT (min)	DS (BU)
1	Very strong	121.97	61.75	4.77	130.2	35.5	31.7	31.2	63.70	17.10	11.40	7.00
2	Very strong	110.98	47.50	4.32	84.3	37.7	31.7	29.3	65.90	17.70	7.50	35.00
3	Very strong	115.68	42.83	4.66	142.5	34.5	32.3	31.5	61.40	17.20	1.50	38.00
4	Very strong	112.71	49.08	4.50	148.0	33.2	30.3	31.7	63.10	12.80	1.90	189.00
5	Very strong	120.69	47.83	4.79	97.2	37.0	34.0	30.0	63.10	7.80	2.00	156.00
6	Very strong	116.77	58.58	4.83	189.3	29.2	22.5	8.7	58.90	17.90	16.20	22.00
	Average	116.46	51.26	4.64	131.9	34.5	30.4	27.1	62.68	15.08	6.75	74.50
7	Strong	110.79	38.58	4.04	134.3	33.8	28.5	25.5	61.90	15.70	1.70	81.00
8	Strong	106.06	38.42	4.27	127.8	33.7	28.5	26.5	62.80	17.20	4.90	35.00
9	Strong	113.99	45.25	4.13	134.7	34.5	31.3	28.2	64.50	17.00	3.00	36.00
10	Strong	117.88	43.75	4.21	84.3	34.5	24.7	24.7	60.40	15.90	3.70	67.00
11	Strong	122.39	41.83	4.56	107.7	30.0	25.7	24.3	62.40	15.80	4.20	68.00
12	Strong	107.42	38.17	4.21	69.3	41.8	32.3	31.8	65.00	14.20	3.50	103.00
	Average	113.09	41.00	4.24	109.7	34.7	28.5	26.8	62.83	15.97	3.50	65.00
13	Medium	96.16	33.67	3.80	94.0	33.3	26.5	24.0	61.90	9.60	2.20	122.00
14	Medium	105.83	35.83	4.03	93.2	31.0	25.0	23.8	60.30	12.60	1.90	113.00
15	Medium	106.99	35.25	3.90	103.8	31.7	25.7	23.7	62.80	17.00	6.40	30.00
16	Medium	108.13	35.25	3.96	69.7	39.7	34.2	29.3	65.90	6.30	1.50	158.00
17	Medium	103.40	33.58	3.80	97.0	32.7	25.2	23.7	62.20	14.00	5.70	65.00
18	Medium	98.30	35.17	3.78	154.5	29.3	25.8	23.8	54.70	17.90	15.40	4.00
	Average	103.14	34.79	3.88	102.0	33.00	27.1	24.7	61.30	12.90	5.52	82.00
19	Weak	95.76	29.08	3.69	91.2	29.2	19.5	21.8	63.60	6.90	2.70	175.00
20	Weak	108.40	38.00	4.06	80.7	37.3	36.7	31.3	69.10	9.30	4.50	156.00
21	Weak	91.87	28.50	3.54	71.8	31.2	9.8	21.5	64.90	0.10	0.20	285.00
22	Weak	99.42	34.58	4.04	87.7	31.3	27.2	25.3	62.10	10.20	3.70	118.00
23	Weak	100.36	31.17	3.70	80.8	32.0	25.7	23.3	62.00	14.40	1.50	58.00
24	Weak	105.76	29.25	3.72	115.2	26.8	22.0	20.3	59.30	17.30	5.20	53.00
	Average	100.26	31.76	3.79	87.9	31.3	23.5	23.9	63.50	9.70	2.97	140.83
25	Very weak	89.88	28.42	3.51	60.0	27.2	34.2	22.0	64.40	4.90	1.90	200.00
26	Very weak	98.03	33.67	3.84	60.0	28.3	39.3	22.7	68.50	6.30	2.70	206.00
27	Very weak	98.54	28.25	3.64	60.0	19.8	24.5	17.2	66.30	3.90	2.00	173.00
28	Very weak	90.29	28.83	3.72	60.0	28.3	38.2	22.2	63.80	6.80	2.70	172.00
29	Very weak	96.53	32.83	3.71	74.8	31.8	22.8	23.2	64.10	0.40	0.10	285.00
30	Very weak	96.53	25.42	3.46	78.8	30.0	8.7	19.8	60.10	12.70	4.70	56.00
	Average	94.97	29.57	3.65	65.6	27.6	28.0	21.2	64.53	5.83	2.35	182.00
LSD		4.26	2.92	0.14	16.48	2.39	4.66	3.13	3.41	5.03	4.50	80.88
CV (%)		6.1	11.7	5.1	25.0	11.2	25.6	19.1	4.56	35.6	89.8	62.5
Sig. Prob.		0.01	0.01	0.01	0.01	0.01	ns	0.01	ns	0.01	Ns	0.05

[1] AM = torque 15 sec before MT; DS = degree of softening; DT = dough development time; L-SRC = lactic acid solvent retention capacity; MT = maximum torque; PM = torque 15 sec after MT; PMT = peak maximum time; SIG = swelling index of glutenin; Zeleny-Sedim = zeleny sedimentation.

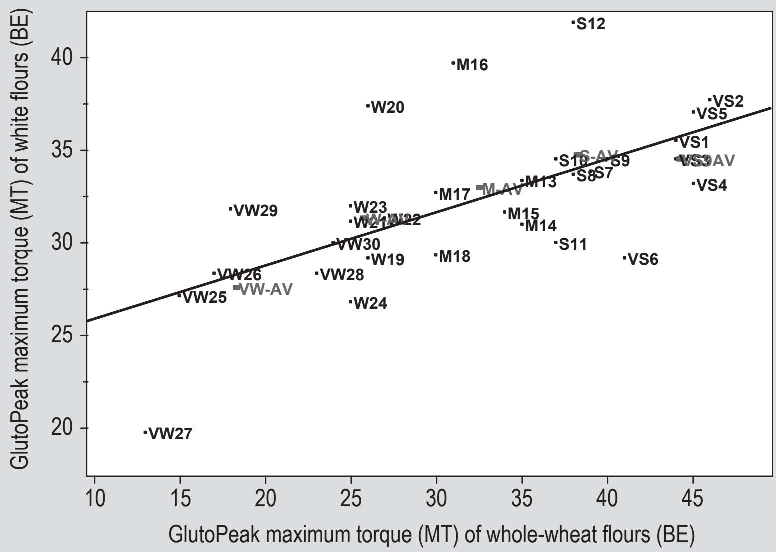

Figure 1. Correlation between GlutoPeak maximum torque (MT) of whole-wheat flours and refined white flours (Y = 23.107911 + 0.2865484X); R^2=0.44*; n=35). M = medium; S = strong; VS = very strong; VW = very weak, W = weak.

Table 3. Important correlations between GlutoPeak parameters of whole-wheat flours and gluten-quality associated tests conducted on refined white flours.[1]

GlutoPeak parameters on whole-wheat flours	Gluten quality parameters on refined white flours	Correlations (r^2)	Number of samples	*P*-value
MT	L-SRC	0.8005	30	<0.0001
MT	Zeleny-sedimentation	0.7969	30	<0.0001
MT	SIG	0.8229	30	<0.0001
MT	SDS-sedimentation	0.8475	30	<0.0001
MT	Farinograph degree of softening	-0.5478	30	0.0017
MT	PMT	0.6476	30	<0.0001
MT	MT	0.6170	30	0.0003
AM	Zeleny-sedimentation	0.3912	30	0.0325
AM	SIG	0.3930	30	0.0317
AM	SDS-sedimentation	0.4721	30	0.0084
AM	MT	0.6144	30	0.0003
PM	L-SRC	0.4864	30	0.0064
PM	Zeleny-sedimentation	0.4610	30	0.0103
PM	SIG	0.5989	30	0.0005
PM	SDS-sedimentation	0.6094	30	0.0004
PM	Farinograph stability	0.4412	30	0.0147
PM	Farinograph degree of softening	-0.3960	30	0.0303
PM	PM	0.5189	30	0.0033
PM	AM	0.5476	30	0.0017

[1] AM = torque 15 sec before MT; L-SRC = lactic acid solvent retention capacity; MT = maximum torque; PM = torque 15 sec after MT; SDS = sodium dodecyl sulphate; SIG = swelling index of glutenin.

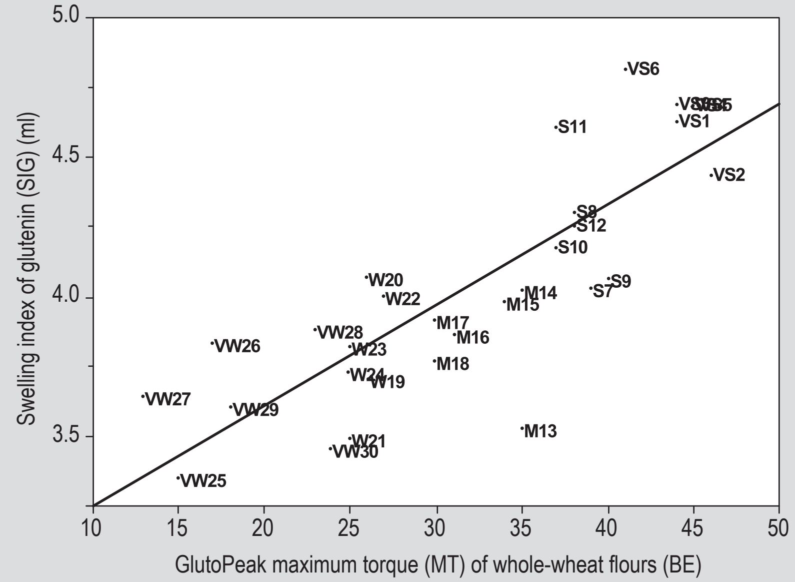

Figure 2. Correlation between GlutoPeak maximum torque (MT) of whole-wheat flours and swelling index of glutenin (SIG) of white flours (Y = 2.8842634 + 0.0361302X; R^2=0.68; n=30). M = medium; S = strong; VS = very strong; VW = very weak, W = weak.**

Figure 3 shows the biplot analysis of GlutoPeak MT of whole wheat flours and gluten-quality associated tests on white flours. It is quite evident that there was a close association between GlutoPeak MT and L-SRC, SIG and SDS-sedimentation values of flour groups, enabling precise separation of flours by their gluten strengths. It was established that L-SRC is strongly associated with glutenin characteristics and gluten strength (Gaines, 2000; Guttieri *et al.*, 2001; Zhang *et al.*, 2007). In contrast to MT, GlutoPeak PM value had weaker discriminating power with other flour gluten quality related tests (Figure 4). It was reported that GlutoPeak PM value indicated the extent of gluten

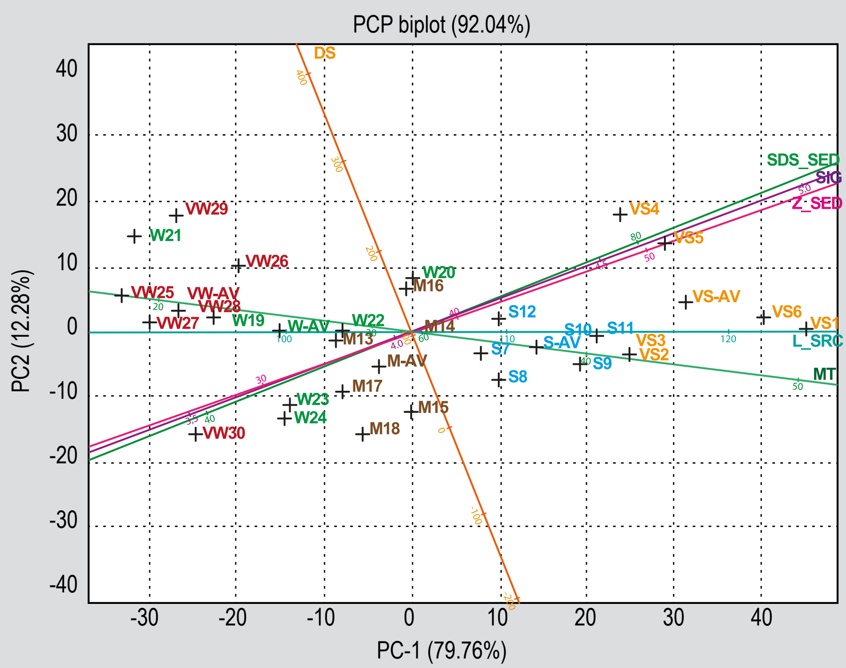

Figure 3. Biplot analysis of flour groups by GlutoPeak maximum torque (MT) of whole-wheat flours and other gluten-quality associated parameters on white flours. M = medium; M-AV = medium average; S = strong; S-AV = strong average; VS = very strong; VW = very weak, VS-AV = very strong average; W = weak; W-AV = weak average; WV-AV = very weak average.

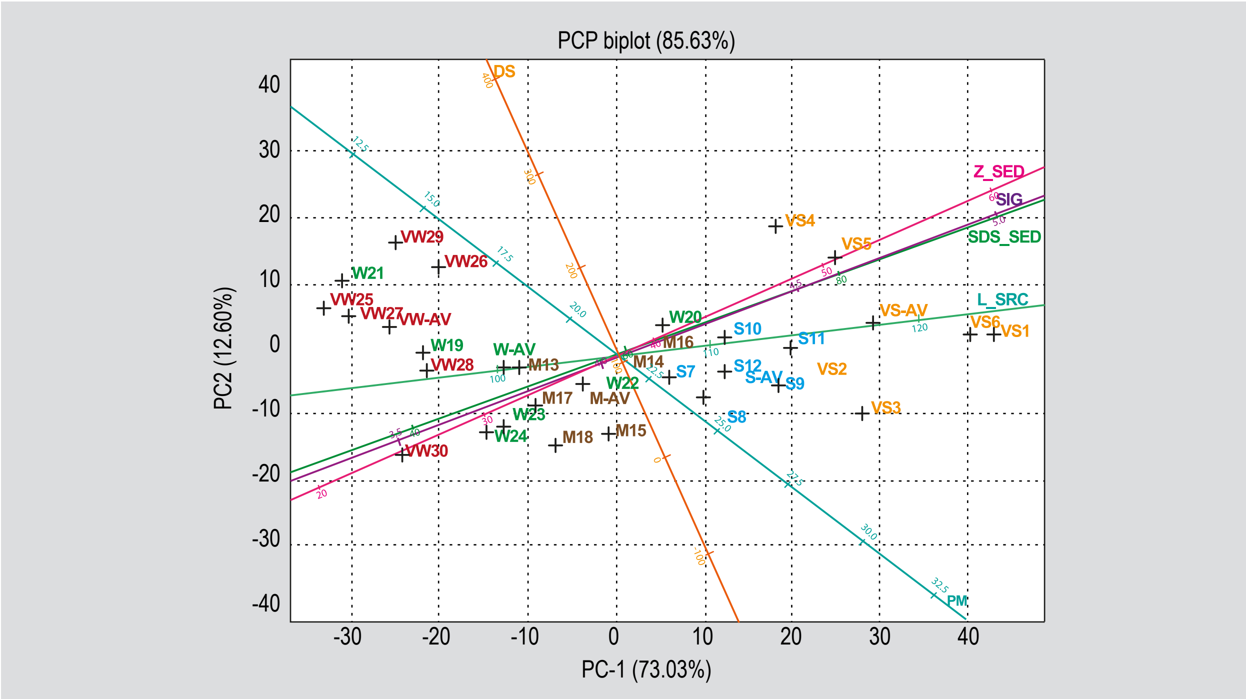

Figure 4. Biplot analysis of flour groups by GlutoPeak torque after 15 sec of maximum torque (PM) of whole-wheat flours and other gluten-quality associated parameters. M = medium; M-AV = medium average; S = strong; S-AV = strong average; VS = very strong; VW = very weak, VS-AV = very strong average; W = weak; W-AV = weak average; WV-AV = very weak average.

network destruction (Marti *et al.*, 2015). In this respect, very strong group of flours had an average PM value of 25.00 BE, while the very weak group produced an average PM value of 16.00 BE (Table 1). Based on MT and PM results; medium, weak and very weak groups of flours were clearly differentiated, which is consistent with the finding of Sissons (2018) that GlutoPeak is useful to screen out flours with low to moderate gluten strength. When whole-wheat flour is used in quality analysis it should be milled as finely as possible to avoid the weakening effect of bran (Wang *et al.*, 2018). In our study we milled the samples to pass 0.5-mm size whole-wheat flours. As strong-gluten genotypes had high GlutoPeak MT and PM this whole-wheat flour size is enough to see the gluten quality difference of the material. Gluten Strength Index (GSI) parameter calculated by multiplying aggregation area and torque was suggested in a recent study by Fu (2018) and gave significant positive correlations with farinograph stability and extensograph area both in 56 lines with wide farinograph water absorption variation (56.0-68.0%) and in 30 lines with narrow range water absorption (63.0-66.0%). GlutoPeak MT and PM values, which are highly correlate with gluten strength of whole-wheat flours, are important parameter to obtain Gluten Strength Index.

4. Conclusions

GlutoPeak test on whole-wheat flours were confirmed to be a rapid and reliable approach in the assessment of wheat gluten quality as it was able to discriminate whole-wheat flours with varying gluten qualities. GlutoPeak MT of whole-wheat flours were determined to correlate strongly with GlutoPeak MT of refined white flours. Furthermore, GlutoPeak data of whole-wheat flours correlated strongly with the L-SRC, Zeleny-sedimentation, SIG and farinograph tests conducted on white flours. In conclusion, GlutoPeak test in combination with SDS-sedimentation volume can be used on whole-wheat flours for gluten quality assessment especially in the initial stages of wheat breeding programs.

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