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Use of the Glutograph Instrument in Durum Wheat Quality Evaluation

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Abstract: Wheat proteins especially the gluten proteins are the primary determinant of rheological properties and quality differences. The major objective of this study was to use the glutograph, a less used rheological instrument for evaluating quality differences of durum wheats. A positive and significant relationship was obtained between the stretching (strength) parameter of the glutograph and the following parameters: Dough Development Time (DDT) and Stability (ST) of the farinograph, Peak Time (PT) of the mixograph, the height of the curve of the alveograph and the resistance to extension of the extensograph. The relaxation parameter of the glutograph was highly correlated with Mixing Tolerance Index (MTI) of the farinograph for durum wheat samples. The glutograph appears to show good promise for quality evaluation of semolina samples for assessing dough strength among cultivars. The better pasta processing operating parameters during extrusion and quality evaluation characteristics were obtained with spaghetti made from strong gluten cultivars than those of spaghetti made from weak gluten cultivar of durum wheats.

Key words: Glutograph, durum wheat, mixing properties, dough stability, spaghetti processing, cooking properties, quality evaluation

INTRODUCTION

Wheat is the leading cereal grain produced, consumed and traded in the world. Wheat is segregated into various classes according to its agronomic and end use attributes (Oleson, 1994). Durum wheat class is widely considered most suitable for pasta products (Dick and Matsuo, 1988).

Proteins are among the primary factors responsible for the variation in wheat quality (Wall, 1979; Wrigley and Bietz, 1988). Protein content of wheat grain of a specific cultivar depends on agronomic and environmental factors (Mariani *et al*., 1995; Bekes and Gras, 1999; Budak *et al*., 2003). Protein quality on the other hand is primarily a genotypic trait and can also be affected by certain environmental stress conditions (Bushuk, 1984). Wheat proteins comprise an extremely heterogeneous mixture of molecular species with different properties and functions in the wheat grain (Bushuk, 1984; Wrigley *et al*., 2005). However, protein content and gluten quality are the most important variables in determining pasta-cooking quality (Dick and Matsuo, 1988; D'Egidio *et al*., 1990; Novaro *et al*., 1993).

Rheological properties are significant in determining the behavior of wheat flour dough during mechanical handling in addition to their influence on the quality of the finished product. However, the rheological properties of a dough system are analogous to the properties of gluten. These properties depend on the structure of the aggregates and their tendency to interact with each other. Specific non-protein components of flour interact with specific proteins of gluten (Chung, 1985; Lasztity *et al*., 1987). Intermolecular interactions among gluten proteins and between protein and non-protein components lead to the formation of various aggregates; the most important interactions between these aggregates appear to result from hydrogen bonds (Bushuk, 1985). The rheological properties of gluten are known to be affected by the quality and quantity of the protein fraction in the gluten complex (amino acid composition, molecular weight and shape) and the interaction between different protein components of the gluten complex (disulfide bonds, hydrogen bonds and hydrophobic interactions) (Lasztity, 1980). Several instruments are used to obtain empirical information on mixing.

Two commonly used instruments, the farinograph and the mixograph record the resistance of dough to the mixing blades during prolonged mixing (Spies, 1990). During the mixing process, many physicochemical changes occur and the different flours have different responses (Hoseney and Rogers, 1986).

Traditionally, wheat dough rheological properties have been determined using dough mixing instruments such as the farinograph or mixograph or large strain

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(non-linear) descriptive rheological methods such as the extensograph or alveograph (Bloksma and Bushuk, 1988; MacRitchie, 1992). These testing methods have led to the use of a number of physical indicators of dough strength, in addition to the basic definition of ultimate strength as stress at rupture. These methods are still useful especially for determination of the relative strength and extensibility of cultivars. Protein quality measurements using lower-cost accessible equipment and less material (such as with the glutograph equipment) would enable wheat-breeding programs, researchers and end-users to perform the same tests allowing direct comparison of protein quality measurements with improved understanding of quality requirements.

The glutograph measures the Stretching (STR) and elastic properties of wet gluten. The measuring system consists of two parallel, round, corrugated plates mounted at a defined distance opposite each other. One of these plates deflects against the other one stretching the sample. There is only one type of glutograph and a wet gluten sample is needed for analysis. Wheat flour (10 g) is used to obtain gluten with a Glutomatic machine (Perten Instruments AB., Huddinge, Sweden). The time required for one glutograph test (including washing out the starch and forming a wet gluten ball with the glutomatic machine) is only about 7 min.

Different values can be obtained from the glutograph profile such as the Shear Time (STR) (determines the extension/stretching of sample) and Relaxation time (RX) (determines the elasticity of sample). Sietz (1987) described the glutograph as a new method to test gluten quality such as the extensibility and elasticity of washed wet or dry gluten. Research comparing farinograph and extensograph parameters with the glutograph parameters was carried out by Sietz (1987). He concluded that in spite of the glutograph being a good instrument for testing of gluten quality, it cannot replace more sensitive tests like the extensograph but it is a good complement as a rapid test. The glutograph, therefore could be very helpful for wheat semolina quality evaluation in breeding programs and in industry where there is a need to analyze many samples in a short time. Therefore, the objectives of this study were to use the glutograph as a potential tool to evaluate gluten quality and to determine the correlations between the parameters of glutograph and other standard protein quality testing instruments using a set of selected durum wheats.

MATERIALS AND METHODS

Three North Dakota (ND) durum wheat cultivars Ben, Rugby and Belzer were taken and chosen on the basis of their wide quality differences. Also for comparison purposes, a strong gluten desert durum cultivar, Kofa, grown in California (CA) was used. In addition, one commercial durum wheat semolina was obtained from the ND mill in Grand Forks and used as a control.

Sample cleaning: A Carter-Day dockage tester (Carter-Day Co., Minneapolis, MN) was used to clean the durum wheat samples. Further, samples were scoured using a Forster scourer (Forster Manufacturing Co., Wichita, KS).

Wheat grain quality evaluation: AACC International (American Association of Cereal Chemists, 2000) approved methods were used to determine the following: moisture (method 44-11), Motomco moisture meter was used; protein (method 46-30), Leco protein analyzer was used; test weight (method 55-10). An electronic seed counter (Seedburo Equipment Co., Chicago, IL) was used to determine 1000 kernel weight on a 10 g sample of wheat. The vitreous kernels from 50 g of cleaned wheat were picked manually by visual observation. The percentage of vitreous kernels was reported by weighing the vitreous kernels as a ratio of the starting 50 g.

Milling: The durum wheat cultivars were tempered to 17.5% moisture content for 24 h then milled on a durum Buhler experimental mill (Buhler Co., Minneapolis, MN) fitted with two laboratory-scale purifiers. Milling was performed according to a standard procedure of American Association of Cereal Chemists (2000) approved method 26-20.

Physical and chemical analyses of durum wheat semolina: American Association of Cereal Chemists (2000) approved methods were used to determine moisture (method 44-15A); protein (method 46-30) using Leco protein analyzer (conversion factor N x 5.7); ash (method 08-01); wet gluten and gluten index (method 38-12A); falling number (method 56-81B).

Farinograph: The farinograph (Brabender GmbH and Co. Duisburg, Germany) 50 g sample bowl was used for all samples except reconstituted semolina fractions to determine the level of water required to reach a predetermined consistency for semolina dough. Farinograph evaluation was performed according to the AACCI (2000) approved method 54-28A. Absorption (%), peak or dough development time (min), stability (min) and mixing tolerance index (BU) were calculated according to the AACCI method.

Mixograph: The 10 g bowl mixograph (National Manufacturing, TMCO Division, Lincoln, NE) (AACCI, 2000 approved method 54-40A) was used for measuring dough mixing strength of semolina and reconstituted semolina fractions based on protein content to give the following data: peak height (mixograph unit, MU): the point of maximum plasticity at the center of the curve; peak time (min): the time elapsed from the start of the test to when the peak height is reached; height of curve at 8 min (MU): the height of curve at 8 min after start of mixing.

Extensograph: (Brabender GmbH and Co. Duisburg, Germany). AACCI (2000) standard method 54-10 with a 100 g sample of semolina was used for measuring the following data: resistance to extension (BU) (the maximum height of the curve); extensibility (cm) (the length of the curve) and area under the curve (cm^2) (the area under the curve).

Alveograph: (Chopin Co., Villeneuve-La-Garenne Cedex, France). AACCI (2000) standard method 54-30A with a 250 g sample of semolina was used for measuring the extent to which the dough might be stretched to give the following data: the height of the curve (mm): measures the pressure applied during inflation and indicates the tenacity or viscosity of the dough; the length of the curve (mm): measures the extensibility of the dough from the first application of pressure to the point at which the surface of the bubble ruptures and the deformation energy (10^{-4} J) which indicates the strength of the dough.

Glutograph: The procedure was carried out according to the manual of the manufacturer (Brabender GmbH and Co. Duisburg, Germany) of the glutograph-E: wet gluten from 10 g of semolina and from reconstituted semolina fractions was used for measuring the stretching and elastic properties of the dough to obtain the following data: Shear Time or stretching (STR) (sec): time to reach the deflection or shear angle (determines the extension of the dough) and Relaxation (RX) (BU): the recovery of the sample after 10 sec (determines the elasticity of the dough).

Pasta processing: The respective durum wheat semolina (1000 g) were separately mixed with distilled water that was added slowly within 45-60 sec at slow speed in a Hobart mixer (Hobart Manufacturing Co., Troy, OH) equipped with a special mixing paddle. After all water was added (to achieve the desired level of hydration at 32% moisture), the sample was mixed at the high speed setting for 4 min to reach uniform mix. The wetted dough was placed in the mixing chamber of the extruder and extruded into spaghetti using the Demaco semi-commercial laboratory extruder (Melbourne, FL, USA). The other processing conditions were as follows: water temperature 40°C, extruder shaft speed 25 rpm, vacuum 18 in of Hg and the dough was pressed through an 84 strand, Teflon-coated, spaghetti die with 0.157 cm openings. The extruded spaghetti samples were case hardened by allowing them to stand/hang on a wooden rack for approximately 15 min at room temperature and 65% Relative Humidity (RH) before being placed in a drying cabinet. Spaghetti was dried for 12 h using a low temperature of 40-45°C and RH of 83%. Dough temperature, AMP-meter, die pressure, extrusion time and weight of spaghetti extruded were recorded during extrusion of each sample. Each semolina sample was extruded in triplicate.

Energy requirements: Specific Mechanical Energy (SME, KJ Kg^{-1}) was calculated as the mechanical energy (KJ sec^{-1}) to extrude pasta divided by the amount of spaghetti extruded (Kg sec^{-1}). The mechanical energy required to operate the empty pasta press was subtracted from the mechanical energy required to operate the press under load.

Pasta quality evaluation

Color: The color of dried spaghetti was determined by light reflectance using a colorimeter (model CR310, Minolta Corp., Ramsey, NJ). Color readings were expressed by Hunter values for L, a and b where L values measure black to white (0-100), a values measure redness when positive and b values measure yellowness when positive.

Cooked weight: Dry spaghetti (10 g) was broken into lengths of approximately 5 cm then placed in 300 mL boiling distilled water and cooked for 12 min. The cooked and drained spaghetti samples were weighed and the results were reported in grams.

Cooking loss: Percentage of total solids weight was measured by evaporating the cooking water to dryness overnight in a forced-air oven at 110°C. The residue remaining after drying was weighed and reported as cooking loss.

Firmness: The cooked firmness was measured according to the AACCI approved method 66-50 (American Association of Cereal Chemists, 2000) with a TA-XT2 Texture Analyzer (Texture Technologies Corp., Scarsdale, NY). The energy required to shear five cooked spaghetti strands was reported in g-cm.

Data analysis: Completely Randomized Design (CRD) was used for the statistical analysis for all data of selected durum wheats. Each analysis was based on three replicates. All statistical analyses were conducted using SAS programs. Significant differences between group means were analyzed by Duncan's multiple-range test. A level of significance of 95% was used throughout the statistical analyses. Pearson's correlation coefficients were used to measure the strength of the linear correlation between two variables.

RESULTS AND DISCUSSION

Evaluation of durum wheat grain quality: Four durum wheat cultivars representing both strong and weak gluten quality were selected for this study. Table 1 shows the values obtained for durum wheat moisture content, protein content, Test Weight (TW), 1000 Kernel Weight (TKW) and Vitreous Kernel content, (VK). Wheat moisture content was lower for cultivar Kofa (desert durum) grown in California (CA) than those cultivars grown in North Dakota (ND) (Belzer, Ben and Rugby). Generally, average moisture content of desert durums (such as Kofa) is <8%. In this study, the range in protein content was relatively narrow (14.2-15.1%) among cultivars. Higher grain protein content is associated with longer dough mixing time, greater stability and firmer pasta (Sissons and Hare, 2002). Protein content of durum wheat varies in quality and quantity depending on cultivar and environmental factors (Feillet, 1988). Therefore, in the present study, differences in protein quantity should not have a major effect on rheological and functional properties because of the narrow range. Therefore, differences in performance among the samples of the present study should be due to differences in protein composition/quality.

Table 1: Grain quality of durum wheat cultivars^{a}

Cultivar	Moisture (%)	Protein^{b} (%)	TW^{c} (lb bu^{-1})	TKW^{d} (g)	VK^{e} (%)
Belzer	9.9^{c}	14.8^{a}	55.7^{d}	39.9^{b}	97.8^{c}
Rugby	10.3^{a}	14.1^{b}	58.3^{b}	39.1^{b}	96.7^{d}
Ben	10.2^{b}	13.9^{c}	57.8^{c}	41.4^{b}	98.4^{b}
Kofa	7.5^{d}	13.5^{d}	63.7^{a}	57.7^{a}	99.8^{a}

^{a}Values followed by the same letter in the same column are not significantly, different from each other, ^{b}12% moisture basis, ^{c}Test weight, ^{d}Thousand kernel weight, ^{e}Vitreous kernel

Besides the chemical composition, the physical characteristics of durum wheat such as TW, TKW and VK have been known to affect the milling performance of durum wheat and also pasta quality (Troccoli *et al*., 2000). The values of these three physical properties in the present study were significantly higher for Kofa than the other cultivars. Posner *et al*. (2006) reported that desert durum wheat kernels are larger and more uniform than the conventional non-desert durum. TW of US durum wheat usually averages about 60 lb bu^{-1} in a normal year (Dick and Youngs, 1988). Kofa had a significantly high TW of 63.7 lb bu^{-1}. The slightly lower TW values (<60 lb bu^{-1}) of Belzer, Ben and Rugby may be attributed to lower moisture content and partial shriveling of kernels.

The range in TKW is normally 30-40 g (Halverson and Zeleny, 1988). Kofa, the desert durum had a significantly high TKW (57.7 g) which is greater than the range given above while ND cultivars showed values similar to each other and close to the higher limit of the range. However, the high TKW value of Kofa is in line with its high value of TW. The four durum cultivars showed a high percentage of VK: significantly different from each other with Kofa having the highest value. Hard VK are desirable for production of semolina (Dick and Matsuo, 1988). However, it does not necessarily mean that semolina derived from vitreous grains always produces pasta of good cooking quality (Cubadda, 1988).

Chemical composition of durum wheat semolina: The results of moisture content, protein content, ash content, wet gluten content, gluten index and falling number of durum wheat semolina including commercial semolina as a control are shown in Table 2. The moisture content desired in semolina is between 13.5-14.5% (Dick and Youngs, 1988).

This range was consistent with the semolina samples obtained from the four durum wheat cultivars in this study. However, the commercial semolina (control) was lower than the above range in moisture content. This could be due to cultivars used, milling and the storage conditions. Mariani *et al.* (1995) reported that protein content is significantly affected by environment while

Table 2: Chemical composition of durum wheat semolina^{a}

Cultivar	Moisture (%)	Protein^{b} (%)	Ash^{b} (%)	Wet gluten^{b} (%)	Gluten index^{b} (%)	Falling number (sec)
Belzer	13.7^{b}	14.2^{a}	0.84^{ab}	36.7^{a}	88.5^{b}	375^{b}
Rugby	14.1^{a}	13.5^{b}	0.85^{a}	34.2^{c}	1.2^{e}	278^{b}
Ben	14.3^{a}	13.4^{b}	0.81^{b}	35.3^{b}	81.8^{c}	406^{b}
Kofa	13.8^{b}	12.9^{c}	0.67^{c}	30.7^{d}	98.4^{a}	922^{a}
Control^{c}	11.6^{c}	12.2^{d}	0.69^{c}	30.9^{d}	64.9^{d}	400^{b}

^{a}Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$), ^{b}14% moisture basis, ^{c}Commercial durum wheat semolina obtained from the ND mill in grand forks protein quality appeared to be influenced more by genotype. Semolina milled from the four durum wheat cultivars had high protein content being above the average of the 2004 growing season (12.4 and 12.7% for CA and ND, respectively). The ash content in the endosperm of durum wheat is characteristically higher than in the endosperm of other hard wheats (Dick and Matsuo, 1988). Experimental results have confirmed a significant role of genotype-environment interactions in determining ash content (Fares *et al*., 1995). In this study, ash content of cultivars Kofa, Rugby and Belzer were slightly higher (0.67, 0.85 and 0.84%, respectively) than the average of the 2004 growing season for CA and ND (0.65 and 0.82%, respectively).

Generally, these higher values still are within the range of first grade semolina according to Cubadda (1988), who classified semolina with ash content <0.9% as first grade semolina. Usually, results of protein and wet gluten contents are parallel thatis as protein content increases, wet gluten content also increases. The percentages of wet gluten in the semolina samples were generally in the same order of semolina protein content with cultivar Belzer having the highest protein content (14.2%) and wet gluten content (36.7%). It was observed that Rugby had extremely sticky and soft wet gluten compared to the other cultivars. In durum wheat, Gluten Index (GI) is an excellent indicator of gluten strength (Cubadda *et al*., 1992) as also shown for a number of HRS wheat cultivars (Alamri, 2007; Alamri *et al*., 2009). Semolina from Kofa had significantly the highest GI (98.4%) and semolina from Rugby had the lowest GI (1.2%). This would mean that Kofa should have very strong gluten while Rugby should have very weak gluten. The Falling Number (FN) test is an indicator of the amount of alpha amylase activity in the semolina. For durum wheats, a FN of 250 sec or higher is acceptable (Donnelly, 1980). Semolina from kofa showed extremely high FN (922 sec) which agrees with Posner *et al*. (2006) who reported that durum wheats grown in dry climatic conditions, usually have a very high FN indicating sound wheat with no pre-harvest sprouting. Semolina from Belzer and Ben were near the average of a normal growing season in the northern great plains of the USA whereas Rugby (278 sec) was slightly lower (North Dakota Wheat Commission, 2004).

Farinograph and mixograph properties of dough from durum wheat semolina: Results from the farinograph and mixograph evaluations of doughs from semolina samples are shown in Table 3. The farinograph parameters of dough from Kofa had the highest Water Absorption (WA) (62.1%), Dough Development Time (DDT) (4.6 min), Stability (ST) (17.5 min) and lowest Mixing Tolerance Index (MTI) (21.7 BU). Conversely, dough from Rugby had the lowest WA, DDT, ST and highest MTI. Dough from Belzer had significantly higher WA and ST than dough from Ben or the Control.

These results are in agreement with those found by Pomeranz (1988), Pyler (1988) and Gupta *et al.* (1992) who reported that the strong gluten cultivars showed significantly higher WA, longer DDT and ST and lower MTI than those of the weak gluten cultivars. Mixograph data showed that dough from Rugby had the lowest values of three mixograph parameters. Dough from the Control and Belzer had the highest peak height followed by Kofa. Kofa also had the highest values of peak time and height of curve at 8 min. These results are similar to those of the farinograph in terms of strong and weak gluten cultivars.

Extensograph properties of dough from durum wheat semolina: Table 4 shows the results obtained of

Table 3: Farinograph and mixograph data of dough from durum wheat semolina[a]

	Farinograph parameters				Mixograph parameters		
Cultivar	Water absorption (%)	Dough develop. time (min)	Stability (min)	Mixing tolerance Index (BU)	Peak height (MU)	Peak time (min)	Height of curve at 8 min (MU)
Belzer	60.8^{b}	2.9^{c}	6.8^{b}	76.7^{b}	5.9^{a}	3.0^{c}	4.7^{a}
Rugby	56.9^{d}	2.1^{d}	2.4^{e}	150.0^{a}	4.0^{d}	2.7^{c}	2.7^{c}
Ben	56.9^{d}	2.9^{c}	6.0^{c}	86.7^{b}	5.0^{c}	3.7^{b}	4.4^{b}
Kofa	62.1^{a}	4.6^{a}	17.5^{a}	21.7^{c}	5.4^{b}	5.5^{a}	5.0^{a}
Control[b]	59.4^{c}	3.4^{b}	3.4^{d}	85.0^{b}	5.8^{a}	3.1^{c}	4.7^{a}

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$), [b]Commercial durum wheat semolina obtained from the ND mill in grand forks

Table 4: Extensograph data of dough from durum wheat semolina[a]

	Resistance to extension (BU)			Extensibility (cm)			Area under curve (cm^2)		
Cultivar	45[b]	90[b]	135[b]	45[b]	90[b]	135[b]	45[b]	90[b]	135[b]
Belzer	434^{b}	412^{b}	420^{b}	23^{a}	23^{a}	24^{a}	144^{b}	137^{b}	138^{b}
Rugby	147^{d}	73^{e}	55^{e}	11^{d}	5^{c}	7^{c}	21^{d}	7^{e}	6^{e}
Ben	318^{c}	318^{c}	327^{c}	20^{ab}	22^{a}	22^{a}	88^{c}	94^{c}	95^{c}
Kofa	807^{a}	867^{a}	927^{a}	17^{c}	15^{b}	15^{b}	186^{a}	175^{a}	174^{a}
Control[c]	222^{d}	223^{d}	200^{d}	20^{b}	21^{a}	22^{a}	63^{c}	66^{d}	63^{d}

[a]Values followed by the same letter in the same column are not significantly, different from each other ($p<0.05$), [b]Minute, [c]Commercial durum wheat semolina obtained from the ND mill in grand forks

dough made from semolina using the extensograph. The Resistance to Extension (RE) indicates the ability of dough to retain gas; the Extensibility (EX) indicates to what degree the dough can be extended or sheeted (Bloksma and Bushuk, 1988). Resistance to Extension (RE) and area under the curve (Ara) are used to indicate dough strength (Preston and Hoseney, 1991). Dough from Kofa and Rugby had the greatest and lowest RE, respectively, after 45, 90 and 180 min rest time. It was obvious that dough of Rugby (very slack) gave the least EX value among the other doughs after 45, 90 and 180 min rest time. The largest Ara after 45, 90 and 180 min rest time was found for dough made from Kofa while the smallest Ara was found for dough made from Rugby. Doughs from Belzer, Ben and the Control showed significantly intermediate RE and Ara values between Kofa and Rugby. However, dough from Belzer showed significantly higher RE and Ara values than dough of Ben. Usually a larger area indicates stronger dough and a smaller area indicates weaker dough. These results agree with the classification system of the extensograph by Preston and Hoseney (1991) who reported that areas under the extensograph curve <80 cm^2 could be classified as weak dough, areas between 80-120 cm^2 as medium dough and areas more than 120 cm^2 as strong dough. This classification would place Kofa and Belzer as strong, Ben as medium and Rugby as weak based on the data in Table 4.

Alveograph and glutograph properties of dough from durum wheat semolina: Alveograph and glutograph data showed significant differences among dough from semolina samples (Table 5). Three parameters of alveograph were used the height of the alveogram curve or maximum overpressure (P), the length of the curve or extensibility (L) and the deformation energy (W). The alveograph W value was identified as among the best parameter for determining durum wheat gluten strength and for predicting pasta cooking quality (D'Egidio *et al*., 1990). In the study, dough from Kofa showed significantly the highest values of P and W while it showed the lowest L value. Conversely, dough from Rugby had the lowest values of P and W. The dough of Rugby was very difficult to handle due to it being very weak and sticky.

Dough from Belzer had statistically higher P and W values than doughs of Ben or the Control. These results are in agreement with the findings of Faridi and Rasper (1987) who stated that the higher values of P and lower values of L result in a consequent increase also of W values. Similarly, information from the glutograph showed that dough from Kofa had the highest stretching, STR, (125 sec, the maximum value that the glutograph registers) and the lowest relaxation, RX, (417 BU). Dough from Rugby had completely opposite results of Kofa, no STR (0 sec) and the highest RX (915 BU). Glutograph STR and RX values of Belzer, Ben and Control dough samples were intermediate between Kofa and Rugby. These results are similar to those obtained with the farinograph, mixograph, extensograph and alveograph instruments that dough from Kofa had the strongest gluten and Rugby had the weakest gluten while dough from the other cultivars were in between.

Relationship between parameters of glutograph and other rheological instruments for prediction of semolina quality: Correlation coefficients were obtained to evaluate various parameters of the farinograph, mixograph, alveograph and extensograph compared to those of the glutograph as a predictor of pasta quality (Table 6). The glutograph STR showed positive correlations with farinograph WA and positive significant correlations with DDT and ST. However, it showed negative and non-significant correlations with farinograph MTI. The farinograph WA, DDT and ST were negatively and not significantly correlated with the RX parameter of the glutograph. In contrast, MTI showed a positive and significant correlation with the RX parameter.

The mixograph PH, PT and H-8 min were positively correlated with glutograph STR while they were negatively correlated with glutograph RX. The only significant relationships of mixograph parameters were PT (positive) and H-8 min (negative) with the glutograph STR and RX, respectively.

The alveograph parameters (Table 6) showed a mixture of positive and negative correlations with glutograph parameters. The alveograph P and W parameters were positive and only p-value had a highly

Table 5: Alveograph and glutograph data of dough from durum wheat semolina^{a}

	Alveograph parameters			Glutograph parameters	
Cultivar	P^{b} (mm)	L^{c} (mm)	W^{d} (10^{-4} J)	Stretching (sec)	Relaxation (BU)
Belzer	80^{b}	102^{a}	221^{b}	24^{b}	684^{b}
Rugby	29^{e}	45^{c}	35^{e}	0^{d}	915^{a}
Ben	69^{c}	91^{b}	181^{c}	11^{c}	600^{c}
Kofa	233^{a}	30^{d}	322^{a}	125^{a}	417^{d}
Control^{e}	40^{d}	102^{a}	90^{d}	3^{d}	631^{bc}

^{a}Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$), ^{b}P-Maximum overpressure, ^{c}L-Abscissa at rupture (length of curve), ^{d}W-Deformation energy of the dough, ^{e}Commercial durum wheat semolina obtained from the ND mill in grand forks significant correlation with STR. P and W were negatively and not significantly associated with RX. The alveograph L value showed negative and positive correlations but not at a significant level with STR and RX, respectively. The extensograph (Table 6) RE after 45, 90 and 180 min of proofing time was positively and high significantly correlated with STR but it was negatively and non-significantly correlated with RX. The EX after 45, 90 and 180 min showed negative and non-significant correlations with both glutograph STR and RX. The Ara after 45, 90 and 180 min was positively and negatively correlated with STR and RX, respectively but none of the correlations were significant. In general, these correlations on durum dough samples from semolina provide additional evidence that these results are similar to the correlations obtained from HRS wheat flour samples (Alamri, 2007; Alamri *et al.*, 2009) that the glutograph STR parameter is more related to the farinograph DDT and ST, the mixograph PT, the alveograph P and the extensograph RE parameters all strength-related parameters than other rheological instrument parameters. In contrast, the glutograph RX parameter is more related to the farinograph MTI parameter. Data from more durum wheat cultivars of varying gluten strength and functional properties are needed to make a better evaluation of the glutograph with the commonly used rheological instruments and whether the glutograph can replace some of the tests of these other rheological instruments.

Table 6: Correlation coefficients of rheological parameters[a] between glutograph instrument and other instruments for testing durtum wheat semolina

Parameters of rheological instruments	Glutograph parameters Stretching (sec)	Relaxation (BU)
Farinograph		
WA	0.764	-0.672
DDT	0.946*[b]	-0.866
ST	0.988**	-0.823
MTI	-0.830	0.968**
Mixograph		
PH	0.235	-0.620
PT	0.946*	-0.866
H-8 min	0.514	-0.889*
Alveograph		
P	0.995**	-0.808
W	0.853	-0.850
L	-0.641	0.091
Extensograph		
RE 45	0.967**	-0.826
RE 90	0.963**	-0.871
RE 135	0.964**	-0.865
EX 45	-0.252	-0.273
EX 90	-0.035	-0.528
EX135	-0.139	-0.428
Ara 45	0.837	-0.813
Ara 90	0.793	-0.860
Ara 135	0.786	-0.853

WA-Water Absorption, DDT-Dough Development Time, ST-Stability, MTI-Mixing Tolerance Index, PH-Peak Height, PT-Peak Time, H-8 min-Height of curve at 8 min, P-Maximum overpressure, W-Deformation energy, L-Length of curve, RE-Resistance to extension, EX-Extensibility and Ara-Area under the curve, [b]*and **indicate significance at p< 0.05 and p<0.01, respectively

Evaluation of pasta processing parameters of semolina: Processing operating parameters during extrusion of pasta are shown in Table 7. At constant semolina hydration (32%), semolina from Belzer, Rugby and Kofa showed statistically similar die pressure values followed by Ben and the control. Significant differences were not found in extruder temperatures among semolina samples. The extrusion rate was significant and the fastest for spaghetti made from Rugby while spaghetti from Kofa had the slowest extrusion rate. These observations were expected since Rugby and Kofa are classified in the present study as weak and strong cultivars, respectively. Levine (2001) reported that dough strength will affect the rate of extrusion and the amount of mechanical energy required to extrude. The Mechanical Energy (ME) required to operate the empty pasta press was subtracted from the mechanical energy required to operate the press under load. ME was significantly higher for spaghetti made from Rugby, Ben and Belzer than for Kofa or the control semolina. It would be expected that spaghetti made from Kofa should have the most energy requirement values based on the results obtained from rheological instruments. The inconsistency in extruder operating parameters with the previous results of Kofa is most likely due to the addition of 50 mL water more than the optimum required for hydration of Kofa's dough during processing. This was done in order to avoid any potential mechanical problems of extruder screw or other parts that could have occurred as a consequence of its extremely strong dough. Specific Mechanical Energy (SME) is the

Table 7: Extruder operating parameters during pasta processing of durum wheat semolina[a]

Cultivar	Die pressure (psi)	Temperature (°C)	Extrusion rate (g sec^{-1})	Me[b] (kJ)	SME[c] (kJ kg^{-1})
Belzer	501^{a}	45.4^{a}	3.25^{c}	0.238^{a}	73.1^{a}
Rugby	493^{a}	45.2^{a}	3.97^{a}	0.241^{a}	60.6^{c}
Ben	418^{b}	45.2^{a}	3.56^{b}	0.239^{a}	67.1^{b}
Kofa	470^{a}	45.3^{a}	3.13^{c}	0.203^{b}	64.9^{b}
Control[d]	403^{b}	44.9^{a}	3.22^{c}	0.212^{b}	65.9^{b}

[a]Values followed by the same letter in the same column are not significantly different from each other (p<0.05), [b]Mechanical energy, [c]Specific mechanical energy, [d]Commercial durum wheat semolina obtained from the ND mill in grand forks

Table 8: Pasta quality characteristics from durum wheat semolina[a]

	Color values (hunter)[b]					
Cultivar	L	A	b	Cooked weight (g)	Cooking loss (%)	Firmness (g-cm)
Belzer	50.1[c]	3.64[a]	22.0[a]	29.3[b]	7.0[ab]	5.4[a]
Rugby	52.5[b]	2.73[c]	23.1[a]	30.6[a]	7.6[a]	4.1[d]
Ben	52.7[b]	3.00[b]	23.0[a]	30.0[ab]	7.0[ab]	5.1[b]
Kofa	53.7[a]	2.43[d]	23.7[a]	30.4[ab]	6.2[b]	5.0[bc]
Control[c]	53.6[a]	2.55[cd]	22.6[a]	30.4[ab]	6.8[ab]	4.7[c]

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$), [b]L-values measure black to white (0-100), a-values measure redness when positive and b-values measure yellowness when positive, [c]Commercial durum wheat semolina obtained from the ND mill in grand forks

total energy applied to the dough during mixing. SME was calculated as the ME (KJ sec^{-1}) to extrude pasta divided by the amount of the spaghetti extruded (Kg sec^{-1}). It was obvious that spaghetti made from Rugby semolina had significantly the lowest Specific Mechanical Energy (SME). The spaghetti strands of Rugby stuck slightly to the drying rods and some of the strands matted together during the drying stage. On the other hand, spaghetti made from Belzer and Rugby showed significant differences in SME whereas spaghetti made from Ben, the control and kofa did not show significant differences.

Evaluation of pasta quality: Pasta color, cooked weight, cooking loss and firmness values are shown in Table 8. Dry pasta color is an important marketing factor with light amber color being preferred by the consumer. The best spaghetti brightness (L), redness (a) and yellowness (b) values were obtained with Kofa whereas spaghetti made from Belzer had the lowest of L and b and the highest a color values though not significantly different in b value from spaghetti from the other cultivars. The higher color values of spaghetti from Kofa are likely to be a reflection of its semolina obtained from sound and vitreous kernels while the lower color values of spaghetti from Belzer, Ben or Rugby are most likely associated with high ash content (Table 2) in their original semolina. Another aspect of interest in pasta-making is cooking quality.

Cooking quality can be assessed by viscoelastic behavior and the surface condition of the cooked pasta (D'Egidio *et al.*, 1990). Cooked weight was reported as the total weight after 12 min of cooking of a sample having an initial precooked, dry weight of 10 g.

Spaghetti from Rugby, the weak gluten cultivar had a significantly higher cooked weight than Belzer. Spaghetti from the other strong gluten cultivars was lower than Rugby but similar to each other in cooked weight. Protein content and gluten quality are the most important variables in determining pasta cooking quality (D'Egidio *et al.*, 1990).

Cooking loss is the percent solids lost to the cooking water. Spaghetti made from Rugby had the greatest cooking loss (7.6%). Spaghetti made from Kofa had the lowest cooking loss (6.2%). Dick and Youngs (1988) reported that cooking loss of 8% or below is considered acceptable for good quality pasta. Firmness values ranged from 4.1 g-cm (Rugby) to 5.4 g-cm (Belzer). Spaghetti samples processed from the strong gluten cultivars were more firm than that processed from the weak gluten cultivar. Matsuo and Irvine (1970) stated that the type of gluten was an important factor in determining tenderness or firmness in cooked spaghetti. They showed a correlation between a softer cooked product and weak gluten semolina and conversely, strong gluten semolina was associated with firm cooked product.

CONCLUSION

Rheological properties of four durum wheat cultivars were evaluated. These wheat genotypes exhibited different mixing characteristics although some had similar protein content. Kofa and Rugby durum wheat cultivars had good and poor grain quality, chemical composition, rheological properties and pasta-making quality, respectively while Belzer and Ben cultivars had intermediate results between Kofa and Rugby cultivars in this evaluation.

It was hypothesized that the glutograph instrument might help in the evaluation of gluten quality and functional properties to replace certain tests of other rheological instruments. A direct relationship between stretching (strength parameter) of the glutograph and dough strength parameters of the farinograph, mixograph, extensograph and alveograph was found for dough from semolina samples. The Relaxation parameter (RX) of glutograph was highly correlated with MTI of the farinograph for durum wheat samples. This is probably the first study to investigate the relationship between the glutograph and other rheological standard testing instruments. The glutograph parameters may have potential usefulness in rapid quality tests since the method is technically simple, reduces time and cost of milling and is a small-scale test method which may be used to predict the gluten strength and end-use quality of wheat cultivars in breeding programs and at country elevators.

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