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# The Effects of Reconstituted Semolina Fractions on Pasta Processing and Quality Parameters and Relationship to Glutograph Parameters

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**Abstract:** Semolina from selected strong and weak durum wheat cultivars was fractionated into their starch, gluten, water soluble and sludge fractions. The effects of the freeze-dried fractions of the individual reconstitution levels and the properties of the Reconstituted Semolina (ReSem) were evaluated in order to understand gluten quality and energy requirements during pasta processing. Also correlations were developed between data from the reconstitution studies and glutograph parameters for prediction of pasta-making quality. Results showed that the gluten fractions were mainly responsible for mixing properties, differences in pasta making quality and pasta extrusion operating parameters with gluten from the desert durum, Kofa, having the largest influence. High correlation coefficients were found with glutograph parameters and pasta processing parameters such as energy requirements during pasta processing and pasta cooking quality characteristics. The Stretching (STR) parameter of the glutograph was positively correlated with good pasta extrusion parameters during processing such as extrusion die pressure and Specific Mechanical Energy (SME). The kelaxation (RX) parameter of the glutograph showed positive and highly significant correlation coefficients with extrusion rate and cooked weight.

**Key words:** Semolina, correlation, relaxatian, parameter, influnce, fraction

## INTRODUCTION

The functional properties of wheat depend on the structure of the various types of proteins that form the gluten complex their interactions with each other and with other wheat components (Wall, 1979; Shewry and Tatham, 1997). The properties of the gluten proteins (in the presence of water and with mechanical agitation/mixing) are described as extensible, sticky, soft, elastic, short or tough. Large extensibility in gluten causes stickiness while short extensibility in gluten causes toughness. In both these cases, these properties reflect the machining properties of dough where the gluten together with starch forms elastic, viscous and plastic properties (Hoseney and Finney, 1974).

Dough strength will affect the amount of mechanical energy required to extrude and the rate of extrusion (Levine, 2001). The cooking quality of durum wheat pasta products and the baking quality of common wheat flour, depend mainly on gluten proteins (Feillet, 1984). Protein can be a substantial, activeand thus quality determining part of the pasta structure, due to its interaction with other semolina components (Preston, 1998). It would be beneficial to know the relationship between protein components and other wheat components on functional properties. With starch comprising about 70% of the pasta, it is likely that the starch affects pasta quality (Oda *et al*., 1980). Insight into the effects of flour components on flour quality (dough strength) has been obtained by either indirect or direct methods.

The indirect method uses correlation studies in which statistically significant links are made of many wheat alleles to identify the relationships between physicochemical and biochemical componentsand functional properties (Branlard and Dardevet, 1985; Campbell *et al*., 1987). Payne *et al*. (1987) and Gupta *et al*. (1991) studied the contributions of different alleles of HMW-GS and LMW-GS to dough functionality by the indirect methods. The direct method uses the fractionation-reconstitution method which involves the separation and fractionation of the components in the flour or semolina and each separated fraction is evaluated by interchanging and reconstituting the fraction in the system (MacRitchie, 1985; Bekes and Gras, 1999) or adding them to a base flour (Preston and Tipples, 1980). Several studies (Finney, 1943; Shogren *et al*., 1969; Hoseney *et al*., 1996; MacRitchie, 1980, 1984; Pomeranz,

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1980) emphasized the functional properties of the wheat gluten proteins on quality of bread-making by solubility fractionation techniques. While a great deal of attention has been directed to the reconstitution of the components of bread dough there have been few reports using this technique in pasta dough. Sheu *et al*. (1967) were the first to apply fractionation and reconstitution techniques to pasta production. Durum semolina and Hard Red Spring (HRS) wheat farina were fractionated into their components (gluten, starch, sludgeand water extractable) and reconstituted mixtures were formed by systematic interchange of the various fractions. They found that interchange of gluten and water-soluble fractions had the most pronounced effect on macaroni color and cooking characteristics. They also found that interchange of starch and sludge fractions had no effect on color and only a small effect on cooking quality.

Durum wheat starches appear to have less compact granules than other wheat starches (Medcalf and Gilles, 1965). According to D'Egidio *et al*. (1984) amylose binds to a protein fraction and in this way contributes to the formation of protein network that avoids amylose leaching during pasta cooking. Also for some wheats an increase in the protein fraction interacting with starch rather than an increase in protein content itself leads to improved pasta quality (D'Egidio *et al*., 1984). Kulp (1973) described that wheat starch-protein interactions were different in starch-gluten dough made from small or regular wheat starch granules. On the other hand, Delcour *et al*. (2000) investigated the influence of starch granule size distribution and starch interaction behavior with other semolina components in pasta quality. They concluded that the starch surface properties do not influence the starch interaction behaviorindicating that starch-gluten interaction in raw (uncooked) pasta is mainly due to physical inclusion. Sissons *et al*. (2002) fractionated durum semolina (into its starch, gluten, water-solubleand residue fraction), freeze-dried and reconstituted them. They extruded original and reconstituted semolina samples into pasta using a small-scale extruder and found them to have similar quality. In a recent study, Sissons *et al*. (2005) concluded based on reconstitution methods that durum gluten substituted with gluten from extra strong common wheat cultivar produced the firmest pasta and the variation in protein content had a larger effect on pasta firmness and stickiness than gluten substitution. Recently, Cubadda *et al*. (2007) studied the effect of gluten proteins and drying temperature on pasta cooking quality. They fractionated gluten and starch from two durum wheat cultivars possessing good and poor gluten quality. They added these fractions back to the original base semolinas (at identical protein content). They found that there was a positive effect on cooking quality of increasing gluten fraction in the weak gluten semolinabut it was not significant in the strong gluten semolina.

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 (Bushuk, 1985). 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).

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 occurand the different flours have different responses (Hoseney and Rogers, 1986).

The glutograph is a less used (relatively new compared to the other classic rheological instruments) instrument that measures rapidly the stretching/ extensibility and elastic properties of washed wet gluten (from 10 g flour).

Therefore, the objectives of this study were: to use reconstitution studies of gluten and other biochemical constituents of selected strong and weak durum semolina gluten types for understanding gluten quality and energy requirements during pasta processing and to determine correlations between the reconstitution data and parameters of the glutograph instrument for pasta-making quality prediction.

## MATERIALS AND METHODS

Two North Dakota (ND) strong and weak durum wheat cultivars Ben and Rugby, respectively were used. Also for comparison purposes, a strong gluten desert durum cultivar, Kofa, grown in California (CA) was used.

**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 (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 durum Buhler experimental mill (Buhler Co., Minneapolis, MN) fitted with two laboratory-scale purifiers. Milling was performed according to a standard procedure of AACC (2000) approved Method 26-20.

**Fractionation of semolina samples:** Semolina from two North Dakota (ND) durum wheat cultivars (Ben strong and Rugby weak gluten types) and semolina from one California (CA) durum wheat cultivar, Kofa (very strong gluten type as classified by Clarke *et al.* (2003) were separated into four fractions (gluten, starch, water soluble and sludge) according to the procedure of Sissons *et al.* (2002) as follows: Semolina was mixed with distilled water (60%w/w) at 15°C by hand for 10 min to form a dough. After resting the dough for 5 min in a 4×8×2 inch glass Pyrex dish, 800 mL of water was added and the dough was hand-kneaded for about 10 min to wash away the starch and soluble components.

The gluten ball was separated from the liquid fraction by filtration over a nylon screen (150 μm pore size). The gluten was further washed in the Pyrex dish with nine 100 mL water washes for 5 min each time until minimal starch appeared in the wash water. The filtrate passing through the nylon screen was centrifuged at 3,000×g for 10 min to separate the starch from the water-soluble components. Some solid material remained on the nylon screen and this is called residue fraction (sludge). All fractions were stored at -20°C overnightand then were lyophilized in a freeze-dryer.

**Reconstitution studies with fractions isolated from semolina:** The freeze-dried gluten, starch, water soluble and sludge fractions isolated from Kofa, Benand Rugby durum wheat semolina were weighed followed by grinding to powders with a Falling Number Mill (Perten Instruments AB., Huddinge, Sweden).

Fractions were passed through a US#60 sieve to reduce the particles to a uniform size to improve homogeneity. Fractions were then recombined (Table 1 and 2) with the same proportion of gluten, starch or water soluble as present in the original semolina (control 2, Table 1 and 2).

Table 1: Substituting ben's fractions into Kofa and Kofa's fractions into ben

| Samples | Gluten fraction of | Starch fraction of | Water-soluble fraction of | Sludge fraction of |
|---|---|---|---|---|
| Control (1a)* | | | | |
| Control (2a) | Kofa | Kofa | Kofa | Kofa |
| 3 | Kofa | Kofa | Ben | Kofa |
| 4 | Kofa | Ben | Kofa | Kofa |
| 5 | Ben | Kofa | Kofa | Kofa |
| Control (1b)** | | | | |
| Control (2b) | Ben | Ben | Ben | Ben |
| 8 | Ben | Ben | Kofa | Ben |
| 9 | Ben | Kofa | Ben | Ben |
| 10 | Kofa | Ben | Ben | Ben |

*Non-fractionated Kofa durum wheat semolina; **Non-fractionated Ben durum wheat semolina

Table 2: Substituting Rugby's fractions into Kofa and Kofa's fractions into rugby

| Samples | Gluten fraction of | Starch fraction of | Water-soluble fraction of | Sludge fraction of |
|---|---|---|---|---|
| Control (1a)* | | | | |
| Control (2a) | Kofa | Kofa | Kofa | Kofa |
| 3 | Kofa | Kofa | Rugby | Kofa |
| 4 | Kofa | Rugby | Kofa | Kofa |
| 5 | Rugby | Kofa | Kofa | Kofa |
| Control (1c)** | | | | |
| Control (2c) | Rugby | Rugby | Rugby | Rugby |
| 8 | Rugby | Rugby | Kofa | Rugby |
| 9 | Rugby | Kofa | Rugby | Rugby |
| 10 | Kofa | Rugby | Rugby | Rugby |

*Non-fractionated Kofa durum wheat semolina; **Non-fractionated Rugby durum wheat semolina

**Physical and chemical analyses of Reconstituted semolina fractions:** AACC (2000) Approved Methods were used to determine moisture (method 44-15A); protein (method 46-30) using Leco protein analyzer (conversion factor N×5.7) and ash (method 08-01).

**Mixograph:** The 10 g bowl mixograph (National Manufacturing, TMCO Division, Lincoln, NE) (AACC, 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 the curve at 8 min after start of mixing.

**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 semolinaand 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 reconstituted fractions (800 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 timeand weight of spaghetti extruded were recorded during extrusion of each sample. Each reconstituted fraction sample was extruded in duplicate due to the limited amount of freeze-dried fractions.

**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.

**Quality evaluation of pasta made from reconstituted semolina fractions**

**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 positiveand b values measure yellowness when positive.

**Cooked weight:** Dry spaghetti (10 g) were 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 AACC (2000) approved method 66-50 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 performed in two replicates due to the limited amount of freeze-dried fractions. All statistical analyses were conducted using SAS (2003) 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

The influence of individual freeze-dried fractions (water soluble, starch and gluten) of Reconstituted Semolina (ReSem) was studied between two strong durum cultivars, Kofa (CA desert durum) and Ben (ND durum). Similarly, the strong durum cultivar Kofa and the weak durum cultivar Rugby (ND) were studied in order to determine which fraction(s) is more responsible for pasta making quality.

Table 3 shows the yields of the four freeze-dried fractions and their protein and moisture contents from semolina of the three durum wheat cultivars. The yield (recovery) percentages of fractions of Kofa, Ben and Rugby semolina were 85.6, 85.8 and 86.2%, respectively. The fractionation, centrifuging, transferring, freeze-drying and grinding are some of the processes that caused reduction of the recovery. The recovery results are consistent with results of fractionation and reconstitutions studies obtained by MacRitchie (1985) and Sissons *et al*. (2002). As expected, gluten fractions comprised almost two thirds of the total protein content while the water-soluble fractions contained 22-24% protein by weight. Delcour *et al*. (2000) reported that the gluten fraction is mainly protein with most of the remainder of the fraction likely to be starch. They also stated that the water-soluble fraction contained arabinoxylans. In the study, sludge or residue fractions were comprised mainly of protein (14-15%) and starch.

**Chemical and physical properties of reconstituted fractions isolated from semolina:** Moisture content, protein content, ash content, mixographand glutograph values of substituting Ben's fractions into Kofa and Kofa's fractions into Ben are shown in Table 4. The Non-Fractionated Ben's semolina (NFB) and the Non-Fractionated Kofa's semolina (NFK) had the highest

Table 3: Yield protein and moisture contents of Kofa, Ben and Rugby semolina components after fractionation[a,b]

| | Gluten | | | | Starch | | | | Water-soluble | | | | Sludge | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Yield | | P[c] | M[d] | Yield | | P[c] | M[d] | Yield | | P[c] | M[d] | Yield | | P[c] | M[d] |
| Types | g | % | % | % | g | % | % | % | g | % | % | % | g | % | % | % |
| Kofa | 11.6 | 13.6 | $72.1^{c}$ | $2.3^{b}$ | 62.6 | 73.1 | $1.2^{a}$ | $2.6^{a}$ | 4.7 | 5.5 | $22.2^{a}$ | $9.2^{b}$ | 6.7 | 7.8 | $14.1^{c}$ | $4.6^{c}$ |
| Ben | 11.9 | 13.9 | $74.8^{a}$ | $3.2^{a}$ | 63.6 | 74.1 | $0.9^{b}$ | $2.3^{a}$ | 5.3 | 6.2 | $24.5^{a}$ | $10.0^{a}$ | 5.0 | 5.8 | $15.6^{a}$ | $7.1^{a}$ |
| Rugby | 11.4 | 13.2 | $74.2^{b}$ | $2.4^{b}$ | 61.4 | 71.2 | $0.8^{c}$ | $2.4^{a}$ | 6.1 | 7.1 | $24.6^{a}$ | $8.5^{b}$ | 7.3 | 8.5 | $15.4^{b}$ | $4.8^{b}$ |

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$); [b]The recovery percentages were Kofa 85.6%, Ben 85.8% and Rugby 86.2%. [c]Protein content based on 14% moisture; [d]Moisture content

Table 4: Chemical and physical properties of substituting Ben's fractions into Kofa and Kofa's fractions into Ben[a]

| | Chemical properties | | | Mixograph parameters | | | Glutograph parameters | |
|---|---|---|---|---|---|---|---|---|
| Fraction[b] | Moisture (%) | Protein[c] (%) | Ash[c] (%) | PH[d] (MU) | PT[e] (min) | H-8 min[f] (MU) | Stretching (sec) | Relaxation (BU) |
| NFK | $13.8^{b}$ | $12.9^{b}$ | $0.67^{f}$ | $5.4^{a}$ | $5.5^{b}$ | $5.0^{a}$ | $125^{a}$ | $417^{b}$ |
| FK | $3.2^{c}$ | $12.0^{f}$ | $0.72^{de}$ | $5.0^{b}$ | $8.0^{a}$ | $5.0^{a}$ | $125^{a}$ | $152^{c}$ |
| Kg+Ks+Bw | $3.2^{cd}$ | $12.2^{e}$ | $0.81^{c}$ | $4.6^{c}$ | $8.0^{a}$ | $4.6^{b}$ | $125^{a}$ | $122^{c}$ |
| Kg+Kw+Bs | $3.1^{cd}$ | $12.2^{e}$ | $0.69^{ef}$ | $4.6^{c}$ | $8.0^{a}$ | $4.6^{b}$ | $125^{a}$ | $147^{c}$ |
| Ks+Kw+Bg | $3.1^{cde}$ | $12.4^{d}$ | $0.73^{d}$ | $4.6^{c}$ | $3.8^{de}$ | $4.4^{bc}$ | $121^{a}$ | $588^{a}$ |
| NFB | $14.3^{a}$ | $13.4^{a}$ | $0.81^{c}$ | $5.0^{b}$ | $3.7^{e}$ | $4.4^{b}$ | $11^{c}$ | $600^{a}$ |
| FB | $3.0^{def}$ | $12.8^{bc}$ | $0.84^{bc}$ | $4.2^{d}$ | $5.6^{b}$ | $4.1^{de}$ | $104^{b}$ | $587^{a}$ |
| Bg+Bs+Kw | $2.9^{ef}$ | $12.7^{c}$ | $0.76^{d}$ | $4.3^{d}$ | $4.2^{d}$ | $4.2^{cd}$ | $125^{a}$ | $401^{b}$ |
| Bg+Bw+Ks | $2.7^{f}$ | $12.7^{c}$ | $0.86^{ab}$ | $4.6^{c}$ | $4.8^{c}$ | $4.5^{b}$ | $119^{ab}$ | $590^{a}$ |
| Bs+Bw+Kg | $3.0^{def}$ | $12.4^{d}$ | $0.88^{a}$ | $4.0^{e}$ | $8.0^{a}$ | $4.0^{e}$ | $125^{a}$ | $88^{ca}$ |

Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$). [b]N-non, F-fractionated, K-Kofa cultivar, B-Ben cultivar, w-water-soluble fraction, s-starch fraction and g-gluten fraction; sludge fraction was incorporated into the base fractions. [c]14% moisture basis. [d]Peak height; [e]Peak time; [f]Height of curve at 8 min

moisture and protein contents. All other ReSem fractions showed much lower moisture contents (average of 3.05%) than NFK and NFB. The lower moisture content of ReSem fractions is due to the freeze-drying process. Protein content of ReSem samples in which Kofa's gluten was present showed lower protein content than those for the fractions in which Ben's gluten was present except Ks+Kw+Bg and Bs+Bw+Kg fractions. This is in agreement with data of the original semolina from Ben (NFB) that had higher protein content than semolina from Kofa (NFK). The lower protein content of ReSem fractions compared to the original semolina could also explain the recovery losses. Ash content ranged from 0.67% (NFK) to 0.88% (Bs+Bw+Kg). However, this range is consistent with the classification of Cubadda (1988) that semolina with ash content <0.9% is classified as first grade semolina. It is known from the literature that the freeze-drying process induces structural changesand the dehydration procedure may alter the rheological properties (Harmansson and Larsson, 1986; Tsiami *et al*., 1997; Bache and Donald, 1998).

The mixograph PH was significantly at the highest level for NFK. It ranged from 5.4-4.0 MU. ReSem fractions that contained Kofa's gluten fraction showed the longest (8.0 min) PT. It is most likely that the presence of the gluten fraction from Kofa increased the strength of dough by increasing mixing time. The H-8 min ranged from 5.0-4.0 MU.

The glutograph stretching of ReSem that contained Kofa's fractions showed larger values than the ReSem of Ben's Fraction (FB) and NFB. ReSem fractions that contained Kofa's gluten fraction had the lowest relaxation values. In general, these results indicate that only the gluten fraction and especially from Kofa semolina had the most pronounced effect on strength and mixing properties.

Substituting Rugby's fractions into Kofa and substituting Kofa's fractions into Rugby showed a range of chemical and physical properties (Table 5). Again, Non-Fractionated Rugby's semolina (NFR) and Non-Fractionated Kofa's semolina (NFK) had the highest moisture and protein contents. Moisture contents of ReSem fractions ranged from 3.2-2.7% while protein contents ranged from 12.0-13.0%. It was expected that ReSem fractions of Rugby substituted into Kofa's would show higher protein content because of the higher amount of protein in the original semolina from Rugby (NFR) than semolina from Kofa (NFK). Similar to protein, ash content of ReSem fractions that contained more of Rugby's fractions had the highest ash contents as a result of higher ash content of its original semolina (NFR) as mentioned earlier.

The lower mixograph, lower STR and higher RX values of NFR and other ReSem fractions that did not contain Kofa's gluten fraction, support the earlier conclusion of the previous substitution results that Kofa's gluten had the greatest influence on mixing properties compared to the other fractions.

Table 5: Chemical and physical properties of substituting Rugby's fractions into Kofa and Kofa's fractions into Rugby[a]

| | Chemical properties | | | Mixograph parameters | | | Glutograph parameters | |
|---|---|---|---|---|---|---|---|---|
| Fraction[b] | Moisture (%) | Protein[c] (%) | Ash[c] (%) | Ph[d] (MU) | PT[e] (min) | H-8 min[f] (MU) | Stretching (sec) | Relaxation (BU) |
| NFK | 13.8$^{b}$ | 12.9$^{b}$ | 0.67$^{e}$ | 5.4$^{a}$ | 5.5$^{b}$ | 5.0$^{a}$ | 125$^{a}$ | 417$^{d}$ |
| FK | 3.2$^{c}$ | 12.0$^{e}$ | 0.72$^{d}$ | 5.0$^{b}$ | 8.0$^{a}$ | 5.0$^{a}$ | 125$^{a}$ | 152$^{e}$ |
| Kg+Ks+Rw | 3.0$^{cd}$ | 12.1$^{de}$ | 0.76$^{c}$ | 4.4$^{c}$ | 8.0$^{a}$ | 4.4$^{b}$ | 125$^{a}$ | 124$^{e}$ |
| Kg+Kw+Rest | 2.7$^{ef}$ | 12.3$^{d}$ | 0.69$^{de}$ | 4.4$^{c}$ | 7.8$^{a}$ | 4.4$^{b}$ | 125$^{a}$ | 130$^{e}$ |
| Ks+Kw+Rg | 3.0$^{de}$ | 12.5$^{c}$ | 0.71$^{d}$ | 3.8$^{de}$ | 1.8$^{d}$ | 3.3$^{c}$ | 2$^{b}$ | 688$^{c}$ |
| NFR | 14.1$^{a}$ | 13.5$^{a}$ | 0.85$^{b}$ | 4.0$^{e}$ | 2.7$^{b}$ | 2.7$^{e}$ | 0$^{c}$ | 915$^{a}$ |
| FR | 2.7$^{f}$ | 12.9$^{b}$ | 0.85$^{b}$ | 3.5$^{e}$ | 2.6$^{b}$ | 3.1$^{cd}$ | 1$^{b}$ | 743$^{bc}$ |
| Rg+Rs+Kw | 2.7$^{f}$ | 13.0$^{b}$ | 0.84$^{b}$ | 3.8$^{de}$ | 2.2$^{c}$ | 3.0$^{de}$ | 2$^{b}$ | 780$^{b}$ |
| Rg+Rw+Ks | 2.8$^{ef}$ | 12.9$^{b}$ | 0.89$^{a}$ | 3.9$^{d}$ | 2.2$^{c}$ | 3.3$^{c}$ | 2$^{b}$ | 687$^{c}$ |
| Rs+Rw+Kg | 2.8$^{def}$ | 12.6$^{c}$ | 0.86$^{ab}$ | 4.4$^{c}$ | 8.0$^{a}$ | 4.4$^{b}$ | 125$^{a}$ | 137$^{e}$ |

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$). [b]N-Non, F-Fractionated, K-Kofa cultivar, R-Rugby cultivar, w-water-soluble fraction, s-starch fraction and g-gluten fraction; sludge fraction was incorporated into the base fractions.[c] 14% moisture basis. [d]Peak height; [e]Peak time; [f]Height of curve at 8 min

Table 6: Extruder operating parameters during pasta processing of substituting Ben's fractions into Kofa and Kofa's fractions into Ben[a]

| Fraction[b] | Die pressure (psi) | Temperature (°C) | Extrusion rate (g $sec^{-1}$) | ME[c] (kJ) | SME[d] (kJ $kg^{-1}$) |
|---|---|---|---|---|---|
| NFK | 470$^{d}$ | 45.3$^{b}$ | 3.1$^{bcde}$ | 0.203$^{d}$ | 64.9$^{d}$ |
| FK | 635$^{ab}$ | 47.1$^{a}$ | 3.2$^{a-d}$ | 0.295$^{a}$ | 91.3$^{a}$ |
| Kg+Ks+Bw | 668$^{a}$ | 47.6$^{a}$ | 3.0$^{cde}$ | 0.286$^{ab}$ | 95.8$^{a}$ |
| Kg+Kw+Bs | 638$^{ab}$ | 47.7$^{a}$ | 2.8$^{de}$ | 0.253$^{bc}$ | 90.6$^{a}$ |
| Ks+Kw+Bg | 638$^{ab}$ | 47.7$^{a}$ | 3.5$^{abc}$ | 0.293$^{a}$ | 84.4$^{b}$ |
| NFB | 418$^{d}$ | 44.3$^{b}$ | 3.6$^{ab}$ | 0.239$^{c}$ | 67.1$^{cd}$ |
| FB | 588$^{bc}$ | 47.7$^{a}$ | 3.7$^{ab}$ | 0.266$^{abc}$ | 72.9$^{c}$ |
| Bg+Bs+Kw | 555$^{c}$ | 47.3$^{a}$ | 3.8$^{a}$ | 0.271$^{abc}$ | 72.2$^{c}$ |
| Bg+Bw+Ks | 583$^{bc}$ | 47.2$^{a}$ | 3.3$^{a-d}$ | 0.268$^{abc}$ | 82.3$^{b}$ |
| Bs+Bw+Kg | 600$^{bc}$ | 47.5$^{a}$ | 2.7$^{e}$ | 0.241$^{c}$ | 90.8$^{a}$ |

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$). [b]N-Non, F-Fractionated, K-Kofa cultivar, B-Ben cultivar, w-water-soluble fraction, s-starch fraction and g-gluten fraction; sludge fraction was incorporated into the base fraction; [c]Mechanical energy; [d]Specific mechanical energy

Table 7: Extruder operating parameters during pasta processing of substituting Rugby's fractions into Kofa and Kofa's fractions into Rugby[a]

| Fraction[b] | Die pressure (psi) | Tempreture (°C) | Extrusion rate (g $sec^{-1}$) | ME[c] (kJ) | SME[d] (kJ $kg^{-1}$) |
|---|---|---|---|---|---|
| NFK | 470$^{e}$ | 45.3$^{b}$ | 3.1$^{cde}$ | 0.203$^{e}$ | 64.9$^{gh}$ |
| FK | 635$^{ab}$ | 47.1$^{ab}$ | 3.2$^{cde}$ | 0.295$^{a}$ | 91.3$^{ab}$ |
| Kg+Ks+Rw | 585$^{bc}$ | 47.7$^{a}$ | 2.9$^{e}$ | 0.274$^{ab}$ | 95.9$^{a}$ |
| Kg+Kw+Rs | 650$^{a}$ | 48.2$^{a}$ | 3.2$^{cde}$ | 0.276$^{ab}$ | 86.9$^{bc}$ |
| Ks+Kw+Rg | 633$^{ab}$ | 48.2$^{a}$ | 3.7$^{ab}$ | 0.274$^{ab}$ | 73.9$^{ef}$ |
| NFR | 493$^{e}$ | 45.2$^{b}$ | 4.0$^{a}$ | 0.241$^{cd}$ | 60.6$^{h}$ |
| FR | 505$^{de}$ | 48.2$^{a}$ | 3.3$^{cd}$ | 0.229$^{d}$ | 68.5$^{fg}$ |
| Rg+Rs+Kw | 495$^{e}$ | 47.8$^{a}$ | 3.4$^{bc}$ | 0.243$^{cd}$ | 72.1$^{ef}$ |
| Rg+Rw+Ks | 555$^{cd}$ | 48.1$^{a}$ | 3.2$^{cde}$ | 0.257$^{bc}$ | 79.5$^{de}$ |
| Rs+Rw+Kg | 553$^{cd}$ | 48.3$^{a}$ | 3.0$^{de}$ | 0.244$^{cd}$ | 82.5$^{cd}$ |

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$). [b]N-Non, F-Fractionated, K-Kofa cultivar, R-Rugby cultivar, w-water-soluble fraction, s-starch fraction and g-gluten fraction; sludge fraction was incorporated into the base fractions; [c]Mechanical energy; [d]Specific mechanical energy

**Evaluation of pasta processing parameters of reconstituted fractions:** Extruder operating data during pasta processing of substituting Ben's fractions into Kofa and Kofa's fractions into Ben are shown in Table 6. The highest values of extruder die pressure were found for ReSem fractions that contained Kofa's gluten fraction. Kofa's die pressure values are highest because these fractions had the greatest values of mixing properties on mixograph and glutograph (Table 4 and 5). There were no significant differences among samples in extrusion temperatures. Pasta extrusion rate varied slightly between samples by up to 1.1 g $sec^{-1}$.

ReSem fractions that contained Kofa's gluten fraction showed the slowest extrusion rate because of the stronger gluten of this fraction. Mechanical Energy (ME) ranged from 0.203 (NFK) to 0.295 kJ (FK) with no significant differences between ReSem fractions that contained Ben's gluten fraction. ReSem fractions that contained gluten fraction from Kofa had significantly the greatest values in Specific Mechanical Energy (SME). NFK and NFB had the lowest SME which could be related to the higher initial moisture content.

In the case of substituting Rugby's fractions into Kofa and Kofa's fractions into Rugby (Table 7), ReSem fractions that contained more of Kofa's fractions had significantly the highest die pressure. There were no major differences between samples in extrusion temperatures. Extrusion rate ranged from 4.0-2.9 g $sec^{-1}$ with the same slight variation of 1.1 g $sec^{-1}$ in extrusion rate as the previous data (Table 6). ReSem fractions that

Table 8: Pasta quality characteristics of substituting Ben's fractions into Kofa and Kofa's fractions into Ben[a]

| Fraction[b] | Color values (Hunter)[c] L | a | B | Cooked weight (g) | Cooking loss (%) | Cooking Firmness (g-cm) |
|---|---|---|---|---|---|---|
| NFK | $53.7^{bc}$ | $2.43^{d}$ | $23.7^{bc}$ | $30.4^{a}$ | $6.2^{d}$ | $5.0^{a}$ |
| FK | $55.7^{a}$ | $1.86^{f}$ | $23.3^{cde}$ | $30.0^{ab}$ | $8.9^{b}$ | $4.2^{b}$ |
| Kg+Ks+Bw | $54.3^{b}$ | $2.46^{d}$ | $23.2^{de}$ | $29.4^{bc}$ | $11.5^{a}$ | $3.5^{c}$ |
| Kg+Kw+Bs | $54.1^{b}$ | $2.12^{e}$ | $23.9^{ab}$ | $29.1^{c}$ | $11.2^{a}$ | $3.5^{c}$ |
| Ks+Kw+Bg | $55.4^{a}$ | $1.49^{g}$ | $24.2^{a}$ | $29.6^{abc}$ | $8.0^{bc}$ | $4.1^{b}$ |
| NFB | $52.7^{cd}$ | 2.99 | 23.0 | 30.0 | 7.0 | 5.1 |
| FB | $52.4^{d}$ | $2.94^{b}$ | $23.1^{e}$ | $30.3^{a}$ | $8.5^{bc}$ | $4.1^{b}$ |
| Bg+Bs+Kw | $52.7^{cd}$ | $2.34^{d}$ | $23.5^{bcd}$ | $29.8^{abc}$ | $8.4^{bc}$ | $4.0^{b}$ |
| Bg+Bw+Ks | $53.1^{cd}$ | $2.71^{c}$ | $22.9^{e}$ | $30.0^{ab}$ | $8.4^{bc}$ | $4.0^{b}$ |
| Bs+Bw+Kg | $52.4^{d}$ | $3.14^{a}$ | $22.5^{f}$ | $29.2^{bc}$ | $11.9^{a}$ | $3.3^{c}$ |

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$). [b]N-non, F-fractionated, K-Kofa cultivar, B-Ben cultivar, w-water-soluble fraction, s-starch fraction and g-gluten fraction; sludge fraction was incorporated into the base fractions. [c]L-values measure black to white (0-100), a-values measure redness when positive and b-values measure yellowness when positive

contained more of Kofa's fractions showed the greatest ME while those that contained Kofa's gluten fractions had the greatest SME values. In conclusion, those ReSem fractions that contained Kofa's strong gluten exhibited the best processing values and the most energy requirements during pasta extrusion followed by those ReSem fractions that contained Ben's gluten fractions. The weak gluten fraction from Rugby in ReSem exhibited the poorest pasta processing values during extrusion.

**Evaluation of pasta quality of reconstituted fractions:** Pasta color values and cooking quality characteristics when Ben's fractions were substituted into Kofa and Kofa's fractions into Ben are shown in Table 8. Brightness (L) was higher with ReSem fractions in which Ben's fractions were substituted into Kofa than in which Kofa's fractions were substituted into Ben. ReSem fractions that contained more of Ben's fractions showed higher redness (a) than other ReSem fractions. There was minimal variation between samples in yellowness (b). These L, a and b color results are in accordance with the color results of original semolina from Kofa and Ben (NFK and NFB).

ReSem fractions that contained Kofa's gluten fractions (Kg+Ks+Bw, Kg+Kw+Bsand Bs+Bw+Kg) had the lowest cooked weight. Cooked weight values of all other ReSem fractions were not significantly different. There were higher cooking loss values and lower firmness values when Kofa's gluten fraction was substituted into Ben or incorporated in the ReSem fractions. A high cooking loss percentage reflects a protein-starch matrix that easily allows leaching of amylose from pasta during cooking (Lintas and D'Appolonia, 1973) and other carbohydrates (Bangur *et al*., 1999). It is also possible that during the fractionation procedure where one of the first steps is to form a dough by hand-kneading followed by washing the dough to obtained gluten, the isolated gluten may still contain some non-protein materials trapped in it. These materials may have leached out during cooking. Also, the overall higher cooking loss values of ReSem fractions compared to the original semolina is most likely due to the smaller particle size of the isolated fractions due to grinding of fractions after freeze-drying. Matsuo and Dexter (1980) illustrated that particles of semolina that are relatively smaller are high in damaged starch which increases the loss of solids into cooking water during pasta cooking. Another factor could be that interaction properties of the reconstituted fractions are not the same as in the original semolina thus resulting in higher cooking losses.

Similarly, pasta color values of substituting Rugby's fractions into Kofa had higher L and lower a values than that of substituting Kofa's fractions into Rugby (Table 9). The variations in b value were <2.3 among samples. Similar to the earlier results with Ben, pasta cooking quality characteristics showed a higher cooking loss, lower cooked weightbut higher firmness when Kofa's gluten fraction was substituted or incorporated in the ReSem fractions. These results indicate that starch structure and composition are more important specifically in cooking loss than protein content. Gianibelli *et al*. (2005) stated that starch has the major effect on cooking loss percentage. However, cooking quality of weak durum cultivar is positively affected by adding strong gluten fraction (Cubadda *et al*., 2007).

In these reconstitution studies it has clearly been shown that the gluten fractions are mainly responsible for differences in pasta-making quality. Kofa's gluten fraction had the most marked influence on the ReSem fractions followed by Ben's gluten fraction whereas Rugby's gluten fraction had the least influence on the ReSem fractions. Water-soluble and starch fractions of fractionated semolina had no significant effects on physical parameters, pasta operating and pasta quality parameters of ReSem samples.

Table 9: Pasta quality characteristics of substituting Rugby's fractions into Kofa and Kofa's fractions into rugby[a]

| | Color values (Hunter)[c] | | | | | |
|---|---|---|---|---|---|---|
| Cooking | L | a | B | Cooked weight (g) | Cooking loss (%) | Cooking Firmness (g-cm) |
| NFK | 53.7[bc] | 2.43[c] | 23.7[b] | 30.4[ab] | 6.2[c] | 5.0[a] |
| FK | 55.7[a] | 1.86[e] | 23.3[bcd] | 30.0[ab] | 8.9[b] | 4.2[b] |
| Kg+Ks+Rw | 54.4[ab] | 2.22[d] | 23.1[bcd] | 29.2[bc] | 10.5[a] | 3.7[c] |
| Kg+Kw+Rs | 54.5[ab] | 2.11[d] | 23.7[b] | 28.4[c] | 11.0[a] | 3.5[c] |
| Ks+Kw+Rg | 54.8[ab] | 1.13[f] | 24.6[a] | 30.1[ab] | 7.7[b] | 3.1[de] |
| NFR | 52.5[cd] | 2.73[b] | 23.1[bcd] | 30.6[a] | 7.6[b] | 4.1[b] |
| FR | 51.5[d] | 2.53[c] | 22.9[cde] | 30.1[ab] | 8.9[b] | 3.3[cde] |
| Rg+Rs+Kw | 51.9[d] | 2.17[d] | 23.4[bc] | 29.8[ab] | 8.5[b] | 3.0[e] |
| Rg+Rw+Ks | 52.0[d] | 2.44[c] | 22.7[de] | 29.9[ab] | 8.2[b] | 3.3[cde] |
| Rs+Rw+Kg | 51.6[d] | 3.06[a] | 22.3[e] | 29.4[bc] | 11.1[a] | 3.5[cd] |

[a]Values followed by the same letter in the same column are not significantly different from each other ($p<0.05$).[b]N-non, F-fractionated, K-Kofa cultivar, R-Rugby cultivar, w-water-soluble fraction, s-starch fraction and g-gluten fraction; sludge fraction was incorporated into the base fractions. [c]L-values measure black to white (0-100), a-values measure redness when positive and b-values measure yellowness when positive

It should be noted that the durum wheat semolina samples used in this study were not defatted. This may raise the question that the lipids may have influenced results of this study. However it is unlikely that the lipids would have influenced the results since, for all semolina samples, only gluten was isolated by the same procedure. Gluten was not fractionated into protein sub-fractions in which lipids components would be differentially distributed. It is the differential distribution of the polar and non-polar lipids in protein sub-fractions that would influence results in reconstitution studies (MacRitchie and Gras, 1973).

Table 10: Correlation coefficients between glutograph parameters and pasta-making quality characteristics of reconstituted durum wheat fractions[a]

| Quality characteristics of reconstitution semolina | Glutograph parameters stretching (sec) | Relaxation (BU) |
|---|---|---|
| Extrusion die pressure | 0.491**[b] | -0.521*** |
| Extrusion rate | -0.418** | 0.689*** |
| Mechanical energy | 0.188 | -0.282 |
| Specific mechanical energy | 0.442* | -0.763*** |
| Cooked weight | -0.355* | 0.625*** |
| Cooking loss | 0.346* | -0.673*** |
| Cooked firmness | 0.136 | 0.086 |

[a]See tables for reconstitution of fractions. [b]*,** and *** indicate significance at $p<0.05$, $p<0.01$ and $p<0.001$, respectively

**Relationship between parameters of glutograph and pasta-making quality characteristics of reconstituted fractions:** Correlation coefficients between STR and RX of the glutograph and different pasta quality and operating parameters of ReSem fractions are shown in Table 10. Extruder die pressure showed positive and negative correlations at highly significant levels with STR and RX parameters, respectively of the glutograph. Extrusion rate was negatively non-significantly associated with STR but it was positively and highly significantly associated with RX. The ME exhibited positive and negative correlation coefficients with STR and RX, respectively but none of the correlations were significant. Specific Mechanical Energy (SME) was correlated positively and significantly with STR while it was correlated negatively and highly significantly with RX. It seems logical that the higher mechanical energy required for processing pasta is associated with the higher STR of dough while the opposite is true with the higher RX of dough.

Cooking quality characteristics showed a mixture of positive and negative relationships with glutograph parameters. Cooked weight showed negative correlation with STR and positive significant correlations with RX. In contrast, cooking loss and firmness showed positive correlation with STR whereas only cooking loss was negatively correlated with RX.

These correlation coefficients showed that there were relationships between glutograph parameters and pasta quality characteristics. The STR parameter of the glutograph an indicator of dough strength was positively correlated with good pasta extrusion parameters during processing such as extrusion die pressure and SME.

However, the STR parameter had a lower correlation with cooking quality such as cooking loss. Also, STR parameter did not correlate with ME and firmness. The opposite was true for the RX parameter of the glutograph, an indicator of dough extensibility. It showed positive and highly significant correlation coefficients with extrusion rate and cooked weight. In contrast, RX parameter showed negative and highly significant correlations with extrusion die pressure, SME and cooking loss.

These correlation results justify that the glutograph can be used to predict pasta-making quality and pasta extrusion operating parameters throughout mixing properties of semolina.

## CONCLUSION

The use of reconstitution methods of gluten, starch, sludge and water-soluble components fractionated from durum semolina of selected strong and weak gluten types for understanding gluten quality and energy requirements during pasta processing. The results of this study showed that the gluten fraction, compared to other biochemical componentsis mainly responsible for differences in pasta-making quality. Substituting Kofa's gluten fraction into ReSem fractions had the most positive effect and contribution on mixing properties and pasta operating parameters than gluten from Ben and Rugby durum wheat cultivars. Water-soluble and starch fractions had no significant effects on physical, pasta operating and pasta quality parameters of ReSem samples. This research demonstrated the contribution of individual semolina components to pasta quality by interchanging proteins and starches from different cultivars.

The rheological properties of the reconstituted semolina fractions showed positive associations between stretching of glutograph and mechanical energy requirements, die pressure during pasta extrusionand spaghetti cooking loss. However, negative associations were found between relaxation of glutograph and mechanical energy requirements, die pressure during pasta extrusionand spaghetti cooking loss. Therefore, the glutograph can be used to predict pasta-making quality and pasta extrusion operating parameters at mixing evaluation stage of semolina.

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