Genotypic variation of spring wheats for solvent retention capacities in relation to end-use quality

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1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world and Pakistan is one of the top ten wheat-producing countries, accounting for 2% of the world’s total wheat production i.e. 21,109,000 tonnes from an area of 8,330,000 hectares (GOP, 2005). Major determinant of the end-use quality of wheat is endosperm texture, or in other words, whether the grain is soft or hard. Several methods (phenotypic) have been used to measure grain hardness. These include particle size index of flours (PSI), resistance to grinding (Pearling value), near infrared reflectance (NIR) spectroscopy of whole-grain meals (Pomeranz & Williams, 1990), and to some extent sodium carbonate retention capacity (one of the solvent retention capacities tests) as an indicator of starch damage and indirectly of hardness (Gaines, 2000).

Cereal scientists are seeking some rapid and predictive tests for the assessment of end-use quality of wheat and flour. It is a dire need of the wheat breeders to test hundreds of lines/varieties and there is an interest in saving money and time. Rapid tests that are well suited to estimate end-use quality of small wheat samples are very effective in a sense that they save time and cost and require only small quantities of sample. These types of tests can be used to eliminate inferior lines saving time and money. Many small scale predictive tests for assessment of wheat quality are being used, like the SDS-sed volume test (uses 1 g flour), flour swelling volume test (0.45 g flour) and the NIR spectroscopy (uses 10–15 g flour) for grain texture, moisture, protein and water absorption.

Biscuits (cookies) are one of the important products of the baking industry and biscuit quality is normally evaluated by measuring the diameter and spread ratio of special test cookies. Larger cookie diameters and higher spread ratios are used as the main quality characteristics for soft wheats (Yamamoto, Worthington, Hou, & Ng, 1996). Cookie quality depends on the chemical constituents in the flour responsible for water holding and quality and quantity of gluten proteins. Generally, soft wheats with weak gluten content and low protein content are preferred for biscuit making (Souza, Kruk, & Sundarman, 1994). Slade and Levine (1994) developed a new small scale test; the solvent retention capacity test that quantifies soft wheat flour quality (Gaines, 2000) and was then adopted by the American Association of Cereal Chemists International (AACC, 2000) as method 56-11. Solvent retention capacity (SRC) is the weight of solvent held by flour after centrifugation and is expressed as a percentage of the flour weight. In this test, four different solutions, i.e. lactic acid, sodium carbonate, sucrose, and water are used to predict some of the chemical and physical properties of a wheat sample. Generally, lactic acid SRC (LASRC) is associated with glutenin characteristics (an indicator of gluten quality), sodium carbonate SRC (SOCSRc) is associated with starch damage (indirectly hardness), and sucrose SRC (SUCSRC) is
associated with pentosan content and gliadin characteristics, while water SRC (WSRC) is associated with all the four constituents (Gaines, 2000; Guttiere, Bowen, Gannon, O’Brien, & Souza, 2001). The characterization of wheat on the basis of SRC provides additional complementary information to the alkaline water retention capacity (AWRC) and highlights wheat flour chemical, rheological and baking aspects.

The present study was designed to determine the solvent retention capacities of different Pakistani wheat varieties and to observe the relationship of SRC to different chemical parameters and cookie baking quality. The findings of this study will be helpful to plant breeders for quick analysis of wheat lines as well as for bakers to assess proper mixing and baking behavior of flours coming from different wheat varieties.

2. Materials and methods

2.1. Collection and milling of wheat varieties

Fifty different spring wheat varieties (including two hard varieties) released from 1933 to 2004 were grown for 2 consecutive years, i.e. 2003–2004 and 2004–2005, at the wheat Research Institute, Faisalabad and were included in the present study. The wheat varieties were grown at the same location under identical conditions, applying similar inputs both the years. The wheat varieties were cultivated on 10–15 November each year and fertilizer was applied as NPK at the rate of 100:75:50 kg/ha with four irrigations each year during the whole crop cycle and were harvested during the last week of April. Grain samples of each wheat variety were collected in triplicate for different analysis. The whole wheat flour was prepared with a UDY cyclone mill (Seedburo Equipment Co., 1022 W. Jackson Blvd., Chicago, IL) fitted with 0.5-mm sieve. The mill was carefully cleaned after each sample to avoid mixing the samples.

2.2. Analytical tests

The moisture, crude protein, and ash contents were determined according to approved methods 44–16 (Using Inframatic 9100 i.e. IM 9100), 46-10, & 08-01 (AACC, 2000), respectively. AWRC was determined according to AACC method 56-10. Flour (1 g) was suspended in 5 mL of 0.1 N NaHCO3, hydrated for 20 min, and centrifuged at 1000g for 15 min at room temperature. The precipitate obtained was weighed, and AWRC was calculated. The SRC of all flours was measured using the four water-based solvents i.e. deionized water, 5% sodium carbonate, 50% sucrose, and 5% lactic acid according to approved method 56-11 with minor modification (Ram & Singh, 2004). The SRC tests were conducted using 1 g whole wheat flour instead of 5 g (AACC 56-11) in 15 mL tubes with conical bottoms. The material was dispersed in 5 mL solvent and kept for 20 min with intermittent agitation on a vortex mixer at 5, 10, 15, and 20 min, followed by 15 min centrifugation at 100g at room temperature. The solvent retention capacities were calculated according to AACC (2000) adopted by Guttiere et al. (2001) and Ram, Dawar, Singh, and Shorain (2005). Dry and wet gluten contents for each whole wheat flour sample were estimated by method 38-10 as described in AACC (2000). The water absorption capacity of each wheat variety was determined using the NIR analyzer Inframatic 8620 (Perten Instruments, Inc., Springfield, IL). Grain hardness of each wheat variety was determined using Inframatic 8620 according to method 39-70 A (AACC, 2000). About 10–15 g of ground sample was fed in the instrument after grinding using a Laboratory mill 3100 (Perten Instruments, Inc., Springfield, IL), a hammer type cyclone mill fitted with a 0.8-mm sieve. The SDS-sed volume for each spring wheat variety was determined following the method described by Williams, El-Haramein, Nakkoul, and Riharwi (1986). The SDS-sed volume for Durum wheat was estimated by method 56-70 (AACC, 2000). The Zeleny sedimentation value of each wheat variety was determined using Inframatic 8620 according to method 39-70 A (AACC, 2000) adopted by Guttieri et al. (2001) and Ram & Singh, 2004. The SRC tests were conducted using 1 g whole meal flour. The characterization of wheat on the basis of SRC provides additional complementary information to the alkaline water retention capacity (AWRC) and highlights wheat flour chemical, rheological and baking aspects.

Pearson’s linear correlation coefficients among different quality parameters were calculated by genotype means. Step-wise multiple regression analysis was conducted on the parameters analyzed where solvent retention capacity tests were considered as dependent variables, whereas the remaining quality characteristics were regarded as independent variables. Cluster analysis (Ward’s method) was performed on the basis of Euclidean distances using nearest centroid sorting (Centroid method), where the samples were allowed to segregate themselves arbitrarily into three clusters. The clusters were made using five independent variables i.e. AWRC, SOCSR, SUCSRC, LASRC, and WSRC of whole meal flour. The distribution of SRC and cookie spread ratio among different clusters was also evaluated.

2.3. Statistical analysis

The data collected were analyzed according to standard statistical procedures (Steel, Torrie, & Dickey, 1996) using various software packages including SPSS (Statistical Package for the Social Sciences, version 10.0.1, 1999) for cluster analysis and Minitab (version 11.12, 1996). Analysis of variance was carried out on the data for 50 spring wheat varieties grown during 2 consecutive crop years (Gomes & Gomez, 1984). Triplicate analysis for different parameters was conducted on each wheat variety drawn from same batch of flour.

### Table 2

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Mean</th>
<th>Min</th>
<th>Max</th>
<th>Std. error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture NIR (g/100 g)</td>
<td>9.81</td>
<td>9.10</td>
<td>10.53</td>
<td>0.05</td>
</tr>
<tr>
<td>Hardness NIR</td>
<td>67.58</td>
<td>63.83</td>
<td>71.33</td>
<td>0.22</td>
</tr>
<tr>
<td>Total ash (g/100 g)</td>
<td>1.41</td>
<td>1.17</td>
<td>1.65</td>
<td>0.01</td>
</tr>
<tr>
<td>Protein content (g/100 g)</td>
<td>11.70</td>
<td>10.00</td>
<td>13.40</td>
<td>0.07</td>
</tr>
<tr>
<td>Water absorption (ml/100 g)</td>
<td>61.64</td>
<td>59.64</td>
<td>63.64</td>
<td>0.12</td>
</tr>
<tr>
<td>Dry gluten (g/100 g)</td>
<td>8.56</td>
<td>2.58</td>
<td>14.35</td>
<td>0.16</td>
</tr>
<tr>
<td>Wet gluten (g/100 g)</td>
<td>25.61</td>
<td>8.09</td>
<td>43.13</td>
<td>0.46</td>
</tr>
<tr>
<td>SDS-sed (ml)</td>
<td>27.41</td>
<td>18.83</td>
<td>36.00</td>
<td>0.23</td>
</tr>
<tr>
<td>Zeleny value (ml)</td>
<td>65.50</td>
<td>50.67</td>
<td>80.34</td>
<td>0.49</td>
</tr>
<tr>
<td>Cookie diameter (mm)</td>
<td>44.17</td>
<td>42.90</td>
<td>45.45</td>
<td>0.12</td>
</tr>
<tr>
<td>Cookie thickness (mm)</td>
<td>8.00</td>
<td>6.76</td>
<td>9.25</td>
<td>0.06</td>
</tr>
<tr>
<td>Cookie spread ratio</td>
<td>5.47</td>
<td>4.43</td>
<td>6.52</td>
<td>0.35</td>
</tr>
</tbody>
</table>

SOV: source of variation; d.f.: degree of freedom; WSRC: water SRC; LASRC: lactic acid SRC; SOCSR: sodium carbonate SRC; SUCSRC: sucrose SRC; SDS-sed: sodium dodecyl sulfate sedimentation volume; SRC: solvent retention capacity; AWRC: alkaline water retention capacity.
3. Results and discussion

3.1. Effect of environment and genotype on chemical characteristics of flour

The effect of crop years and wheat variety on the NIR hardness, WSRC, and SUCSRC was found to be highly significant while the interaction of wheat varieties × crop years was non-significant. SOCSRC and LASRC were significantly affected by crop years, wheat varieties and interaction between wheat varieties × crop years (Table 1). Crude protein content was significantly affected by wheat variety and the interaction between crop year and variety while the affect of crop year was non-significant.

3.2. Chemical characteristics

The data regarding different chemical characteristics of spring wheats have been presented in Table 2. The moisture content is extremely important in any measurement of wheat kernel texture (Pomeranz & Williams, 1990), whereas protein content is an important criterion while considering wheat quality. It has been reported to be influenced by genetic as well as by non-genetic factors like soil, climatic conditions, and use of fertilizer (Kent & Evers, 1994; Subda, 1991). Crude protein content ranged from 10.00 to 13.40 g/100 g while wet and dry gluten content ranged from 8.09 to 43.13 and 2.58 to 14.55 g/100 g, respectively. The ranges of values for wet gluten obtained in these studies are in line with those of Curic (2001), Miralbes (2003) and Palival and Singh (1985) who reported the similar ranges of wet and dry gluten in wheat varieties.

The Zeleny sedimentation values ranged from 50.67 to 80.34 mL. Hruskova and Famera (2003) evaluated 318 wheat samples for Zeleny sedimentation value through an NIR technique and found they ranged from 17 to 66 mL. The SDS-sed test is an estimate of the strength of the wheat (gluten quality) and it depends upon the degree of hydration of the proteins in the wheat and on their degree of oxidation. The higher the SDS-sed volume (more than 30 mL), the greater will be the protein strength.
(Williams et al., 1986), which will be better for bread preparation. The wheat varieties possessing low SDS-sed values may be considered to be more suitable for cakes and cookies. Water absorption and NIR hardness values were found to be significantly different in spring wheat varieties. Maghirang and Dowell (2003) found that NIR grain hardness ranged from 63.83 to 71.13. The present study revealed that four wheat varieties fell in the category of fairly soft (in the range of 57–64) while all other 46 varieties fell in the category of soft (in the range of 65–72) according to the NIR hardness scale given by Williams et al. (1986).

3.3. Solvent retention capacities of wheat varieties

AWRC was found to be ranged from 59.06 to 77.96 g/100 g (Table 2). AWRC has been used to make selections between wheats having soft and hard characteristics (Finney & Andrews, 1986). The results from the present study are in line with earlier work conducted by Ram and Singh (2004) who reported the range of AWRC in different wheat varieties as 57–80 g/100 g.

The results regarding SRC (WSRC, SOCSR, LASRC and SUCSRC) of different spring wheats have been presented in Table 3. WSRC ranged from 78.0 to 98.0 g/100 g and was found to be the highest in Iqbal-2000 (Sr. 38) and C 591 (Sr. 21), while the lowest in Iqbal-2000 (Sr. 38) and Punjab 85 (Sr. 30). The lowest LASRC values were found in the wheat varieties Lyallpur 73 (Sr. 6) and Pak 81 (Sr. 14). Ram et al. (2005) reported a range in LASRC of 72.0–122.8 g/100 g across 150 wheat varieties. Guttier and Souza (2003) reported that the LASRC is an indicator of gluten strength and that it varies due to genotypic differences in different wheat varieties. They observed LASRC ranging from 81.6 to 108.0 g/100 g. The results of the present study are high as compared to other reported results, because of varietal differences.

SUCSRC ranged from 125.0 to 163.0 g/100 g and was found to be highest in Iqbal-2000 (Sr. 38) and C 591 (Sr. 21), while the lowest in Iqbal-2000 (Sr. 38) and Lyallpur 73 (Sr. 6). Ram and Singh (2004) observed the range in SUCSRC of 77.0–109.0 g/100 g in different wheat varieties.

3.4. Cookie diameter

Cookie diameter and thickness ranged from 42.9 to 45.45 and 6.76 to 9.25 mm, respectively (Table 2). Spread ratio ranged from 4.43 to 6.52, the highest for wheat varieties Perwaz 94 and the lowest in Uqab 2000. Cookie diameter is a function of the rate of spreading and the setting point of the cookie dough (Ram & Singh, 2004). The rate of spreading was greater and expansion time was longer for good quality (soft wheat) cookie doughs as compared to poor quality (hard wheat) cookie doughs. Haque, Shams-Ud-Din, and Haque (2002) reported that diameter, thickness, and spread ratio of cookies ranged from 31.0 to 41.1 mm, 4.4 to 5.5 mm and 7.06 to 7.49, respectively. Igrejas et al. (2002) reported length, diameter and thickness of cookies ranged from 68.1 to 70.1 mm, 57.2 to 58.2 mm, and 4.6 to 5.9 mm, respectively.

3.5. Correlation between SRC and other quality parameters

A correlation was developed between SRC and other wheat quality and cookie quality parameters (Table 4). WSRC showed a significant positive correlation with SOCSR, SUCSRC, AWRC and cookie diameter and spread ratio of cookies while negative correlation coefficients were observed in WSRC and NIR Hardness, NIR protein, wet and dry gluten, water absorption, SDS-sed value, Zeleny value and cookie thickness. Similar results were also observed by other research workers. This high correlation of WSRC with SOCSR and SUCSRC indicated that the major factors for determining water absorption in wheat flour are damaged starch and pentosan content. Water is necessary for gluten development and plays an important role in all types of chemical reactions that occur during mixing and baking (Ram et al., 2005). WSRC was found to be positively correlated with SOCSR, SUCSRC, AWRC and cookie spread ratio. Water SRC was independent of sodium carbonate, sucrose, or lactic acid SRC (Guttieri et al., 2001). Ram and Singh (2004) found a strong negative correlation between cookie diameter and WSRC (r = −0.63, p < 0.001) while positive relationship between WSRC and Zeleny value.

LASRC was found to be positively correlated with ash content, SOCSR, SUCSRC, AWRC, NIR Hardness, water absorption and cookie thickness while negatively correlated with wet gluten, SDS-sed value, cookie diameter and spread ratio of cookies. It was significantly correlated with grain protein content (r = 0.35, p < 0.001) and SDS-sed value (r = 0.44, p < 0.001). LASRC is associated with gluten strength and was, therefore, expected to be associated with protein content and SDS-sed value. The results of present investigation are well justified by other researchers. Ram and Singh (2004) found that the whole meal LASRC was significantly correlated with SOCSR (r = −0.83), SUCSRC (r = 0.81) and WSRC (r = 0.74). The negative correlation found in another study between LASRC and cookie diameter is an indication that some soft wheats with stronger gluten have less cookie baking potential, although...
they are more suitable for some other products e.g. crackers, flat breads (Gaines, 2004).

SOC SRC showed highly significant correlation with WSRC, SUC SRC and AWRC while it was negatively correlated with cookie diameter and spread ratio. The findings of the present study are in accordance with the findings of other researchers who also found SOCSR C to be positively correlated with SUC SRC, AWRC and WSRC ($r = 0.86$) while no correlation with grain protein content ($r = 0.03$) and LASRC ($r = 0.18$) (Gaines, 2000; Guttieri et al., 2004).

SOC SRC was found to be negatively correlated with cookie diameter and cookie spread ratio (Ram et al., 2005). Therefore, the wheat meal SOCSR C test may be an effective tool for selecting genotypes with greater flour extraction and larger sugar snap cookie diameter.

SUC SRC was found to be significantly correlated with WSRC, SOCSR C, LASRC, AWRC, water absorption, NIR Hardness and cookie thickness while it showed negative correlation with SDS-sed value and spread ratio of cookies. Previous studies indicated that SUC SRC was linearly correlated with AWRC, NIR hardness, cookie thickness, SOCSR C ($r = 0.56$), WSRC ($r = 0.56$) and LASRC ($r = 0.55$) while SUC SRC was found to be negatively correlated with SDS-sed volume and cookie spread ratio (Gaines, 2000; Guttieri et al., 2001; Ram et al., 2005).

Step-wise multiple regression analysis depicted a unit increase in cookie diameter which was associated with 1.89 unit increase in WSRC while keeping the effect of all other variables constant. Unit increase in wet gluten gives 0.14 unit decrease in WSRC while keeping all other variables constant. LASRC decreased by 0.51 units with unit increase in cookie spread ratio and 0.46 units with unit increase in wet gluten. SOCSR C declined 0.18 units with unit increase in cookie spread ratio, SUC SRC increased by 2.66 units with unit increase in water absorption.

Fig. 1. Dendrogram showing clustering of different spring wheat varieties for solvent retention capacities. *Code Seq: code sequence used for wheat varieties in Table 3.
3.6. Cluster analysis

SRC profile developed by whole wheat flour was used for the clustering of wheat varieties (Fig. 1). The three clusters formed, contained 20, 19 and 11 wheat varieties, respectively. The distances between cluster centroids were 21.897 (between I and II), 15.686 (between II and III) and 18.504 (between I and III). Cluster I of wheat flour attained significantly (p < 0.001) lower SRC for all the solvents while obtained comparatively higher values for LASRC and AWRC. Cluster III having higher LASRC and AWRC got lowest spread ratio among three clusters made. There were non-significant differences in average values for cookie spread ratio of the corresponding clusters.

4. Conclusion

SRC profile explained large amount of genetic variability in cookie making quality among all the spring wheat varieties. Solvent retention capacities of whole wheat flour differed significantly among spring wheat varieties. LASRC, SUCSRC and NIR hardness positively while WSRC negatively correlated with cookie thickness. Cluster I of wheat flour attained significantly lower SRC values for all the solvents while obtained comparatively higher values for cookie spread ratio. The data very clearly demonstrated that SRC test for whole wheat flour can be used efficiently in addition to other quality parameters and improving end-product quality of spring wheats.