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Use of rapid tests to predict quality traits of CIMMYT bread wheat genotypes grown under different environments

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ABSTRACT

At the International Maize and Wheat Improvement Center (CIMMYT), wheat quality improvement is an important goal of breeding. CIMMYT scientists develop germplasm, which is diverse for quality traits intended for use in the preparation of different wheat-based products. The integration of quality traits is complex due to the high cost of conducting traditional quality tests. One option for tackling this problem is the use of such rapid-small-scale methods as Solvent Retention Capacity (SRC), SDS Sedimentation (SDSS) and Swelling Index of Glutenin (SIG) to predict flour performance. The objectives of this study were to investigate the effect of genotypes, contrasting environmental conditions and their interactions (GxE) on different rapid-small-scale tests, and to identify their suitability for use in prediction of quality traits. A significant GxE effect was observed for all three methodologies. Overall, SIG was found to be the best predictor of gluten strength across different environments. It was also best at determining bread-making quality in some environments, followed by SDSS for bread making. SRC was found to be useful to select for gluten strength, but for extensibility and bread-making more grain data is needed.

1. Introduction

Successful adoption of new wheat varieties is largely dependent on the grain yield and grain quality demands of average consumers and industrial food manufacturers (both semi-mechanized and mechanized industrial) in a given region. Due to these complex and multifaceted needs, International Maize and Wheat Improvement Center (CIMMYT) scientists focus on the core breeding challenges of simultaneous improvement of wheat production and quality for global distribution. With the estimated growth of the bakery industry at 6% globally, a need for improved quality varieties has increased, but the integration of quality traits in a breeding program remains a challenge. The focus is often on traits with more direct importance for farmers such as grain yield or disease resistance. Additionally, high costs and time limitations restrict the use of traditional quality tests conducted with the mixograph, farinograph, alveograph, or end-use quality tests, in large breeding programs where thousands of genotypes are evaluated annually. Often there is not enough grain in early generations to conduct such analyses. The absence of quality selection tests in the early or middle generations of a breeding program could result in the development of advanced lines unsuitable for release due to related shortcomings of poor processing and end-use quality.

Small-scale, high-throughput methods for predicting flour performance, allow researchers to make a broad selection, discard lines with insufficient quality, keeping those with improved quality. The development of small scale dough testing equipment has been successful in several cases (see Bekes, Lukow, Uthayakumaran, & Mann, 2003; for a good review). Several types of equipment have been developed to work with small samples, including the 2-g mixograph (standard mixographs use 35 g of flour) (Rath, Gras, Wrigley, & Walker, 1990), the micro Z-arm mixer (4 g of flour), analogous to the farinograph (50–250 g of flour) (Haraszi, Gras, Tömösközi, Salgó, & Bekes, 2004), which shows high correlations with standard equipment. Near infrared (NIR) spectroscopy also has a great deal of potential to predict quality traits (Osborne, 2006), but it is costly, difficult for many breeding programs to afford. An economical and time saving alternative is to use simple chemical tests, which result in correlated processing and end-use quality traits. Sodium dodecyl sulfate sedimentation (SDSS), a

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commonly used traditional quality test, gives an overall idea of gluten quality and a fair prediction of bread-making (Blackman & Gill, 1980; Peña, Amaya, Rajaram, & Mujeeb-Kazi, 1990). The Swelling Index of Glutenin (SIG), developed by Wang and Kovacs (2002a), is a newer high-throughput evaluation method, based on the same principle as SDSS (glutenin swelling capacity and insoluble glutenin content) and has revealed the capacity to predict quality traits in bread wheat (Li, Wu, Hernandez-Espinosa, & Peña, 2015; Wang & Kovacs, 2002b). Finally, Solvent Retention Capacity (SRC) is another significant means of measuring quality, for which micro-methods have already been developed (Bettge, Morris, Demacon, & Kidwell, 2002; Guzman, Posadas-Romano, Hernandez-Espinosa, Morales-Dorantes, & Peña, 2015). SRC, originally developed by Slade and Levine (1994), determines the capacity of flour to hold four solvents: water, associated with the overall water holding capacity of all flours constituents; 50 g/L sodium carbonate, related to the damaged starch content of the flour; 500 g/L sucrose, associated with the concentration of arabinoxylans; and 50 g/L lactic acid, associated with the glutenin swelling capacity (Gaines, 2000). This method develops a flour–quality profile that defines the contribution of individual grain components (Kweon, Slade, & Levine, 2011). This method has been widely used in soft wheats for cookie-making (Duyvejonck, Lagrain, Pareyt, Courtin, & Delcour, 2011; Gaines (2004); Guttieri, Bowen, Gannon, Brien, & Souza, 2001; Pasha, Anjum, & Butt, 2009; Zhang, Zhang, Zhang, He, & Peña, 2007) and in hard wheat germplasm for other products (Colombo, Pérez, Ribotta, & León, 2008; Duyvejonck, Lagrain, Dornez, Delcour, & Courtin, 2012; Li et al. 2015; Xiao, Park, Chung, Caley, & Seib, 2006). However, most of the aforementioned studies, which used hard bread wheat, were undertaken with a limited number of genotypes and/or under a single set of environmental conditions. More SRC data from diverse genetic backgrounds and environmental conditions are needed to validate the value of this test in breeding programs and to understand its use relative to SDSS and SIG.

This study aimed mainly to investigate the effect of genotype (G), contrasting environmental (E) conditions and their interactions (GxE) on SDSS, SIG and SRC. It also aimed to identify the suitability of those methods for use in the prediction of quality traits in a set of CIMMYT bread wheat lines grown worldwide.

2. Materials and methods

2.1. Plant materials and field trials

A trial consisting of 54 CIMMYT bread wheat lines, including advanced lines, historical and modern varieties (Electronic Supplementary Material 1), were sown in the 2012–2013 and 2013–2014 crop seasons in Ciudad Obregon (Mexico). The trial was set up in a lattice square design with three replications and sown under six different environmental conditions: optimum irrigation with drip (control environment); flat sown with basin irrigation; reduced irrigation or moderate drought stress; severe drought stress; medium heat stress and severe heat stress. More details of the trial are illustrated in Guzmán et al. (2016).

2.2. Grain and flour parameters

Thousand kernel weight (g) and test weight (g/L) were evaluated with the digital image system SeedCount SC5000 (Next Instruments, Condell Park, Australia). Grain protein (g/kg), hardness (%) and moisture content were determined by near-infrared spectroscopy (NIR Systems 6500, Foss, Hillerød, Denmark) calibrated based on official American Association of Cereal Chemists (AACC) methods 39-10 and 46-11A (AACC, 2010). Grain samples previously conditioned at 140–160 (g/kg) of moisture were milled into flour using Brabender Quadrumat Jr (C. W. Brabender OHG, Duisburg, Germany).

Measurement of SDSS volume was carried out according to Peña et al. (1990). SIG was determined with lactic acid according to the second variant of the method used by Wang and Kovacs (2002a). SRC was carried out according to Guzman et al. (2015) with four solvents: water, sodium carbonate, sucrose and lactic acid. All data from these tests are available in Electronic Supplementary Material 1.

2.3. Rheological and baking tests

Dough development properties were determined by Mixograph of Swanson (National Mfg., Lincoln, U.S.A.) using 35 g of flour (AACC method 54-40A), obtaining dough development time and %Torque*min. The Chopin Alveograph (Trippette & Renaud, Villeneuve-la-Garenne, France) was used to determine dough tenacity, extensibility, strength (ALVW) and tenacity/extensibility ratio (ALVP/L) (AACC 54-30A) using 60 g of flour. The bread-making process was conducted using the direct dough method (AACC method 10-09) and bread loaf volume was determined by rapeseed displacement using a volumeter.

2.4. Statistical analysis

Pearson correlation coefficients (r) and the significance of each comparison in the study were obtained using SAS.

Combined analyses of variance (ANOVA) across environments for grain and other quality traits were performed using procedure Proc Anova of the SAS statistical software (SAS, 2014).

The means of genotypes in each environment throughout the two-year period during which the trials were undertaken were used in the variable selection stepwise procedure using an alpha level of 0.0001 (Proc Stepwise, SAS version 9.4, 2014). All multiple regression equations are detailed in Electronic Supplementary Material 2.

3. Results and discussion

3.1. Grain and flour characteristics

The data of both cropping cycles were quite similar (data not shown), explained by the high heritability revealed in all traits (Table 1). A wide range in grain characteristics was observed in genotypes across different environments. Test weight and particularly thousand kernel weight grain morphology parameters showed great variability, between and within each environment. The range of values for grain hardness was somewhat smaller (32–55%), without any samples showing real soft texture (>55%). For grain protein content, the variation was also important (107–175 g/kg) and larger in such highly stressed environments as severe drought stress or severe heat stress. Compared to the optimum environment (110–141 g/kg) protein content was high in severe drought (12–17.1%) and heat stress environments (121–175 g/kg). Across environments, test weight and thousand kernel weight showed a negative association with grain protein content, $r = -0.48$ and -0.52, respectively, ($p < 0.0001$), due to a dilution or concentration effect depending on grain size. In SRC tests, lactic acid SRC showed the highest variation and the lowest was shown in sodium carbonate SRC, with water SRC and sucrose SRC (also showing smaller ranges than lactic acid SRC. The range of lactic acid SRC in control environment (105–162.3%) was similar to that found by Duyvejonck et al. (2012), Li et al. (2015) and Xiao et al. (2006) (studies conducted using hard wheat). Lactic acid SRC is