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Wheat quality improvement at CIMMYT and the use of genomic selection on it

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ABSTRACT

The International Center for Maize and Wheat Improvement (CIMMYT) leads the Global Wheat Program, whose main objective is to increase the productivity of wheat cropping systems to reduce poverty in developing countries. The priorities of the program are high grain yield, disease resistance, tolerance to abiotic stresses (drought and heat), and desirable quality. The Wheat Chemistry and Quality Laboratory has been continuously evolving to be able to analyze the largest number of samples possible, in the shortest time, at lowest cost, in order to deliver data on diverse quality traits on time to the breeders for making selections for advancement in the breeding pipeline. The participation of wheat quality analysis/selection is carried out in two stages of the breeding process: evaluation of the parental lines for new crosses and advanced lines in preliminary and elite yield trials. Thousands of lines are analyzed which requires a big investment in resources. Genomic selection has been proposed to assist in selecting for quality and other traits in breeding programs. Genomic selection can predict quantitative traits and is applicable to multiple quantitative traits in a breeding pipeline by attaining historical phenotypes and adding high-density genotypic information. Due to advances in sequencing technology, genome-wide single nucleotide polymorphism markers are available through genotyping-by-sequencing at a cost conducive to application for genomic selection. At CIMMYT, genomic selection has been applied to predict all of the processing and end-use quality traits regularly tested in the spring wheat breeding program. These traits have variable levels of prediction accuracy, however, they demonstrated that most expensive traits, dough rheology and baking final product, can be predicted with a high degree of confidence. Currently it is being explored how to combine both phenotypic and genomic selection to make more efficient the genetic improvement for quality traits at CIMMYT spring wheat breeding program.

Contents

1. Understanding wheat quality - quality and what it means to different people

Wheat quality is a very wide subject that will be defined differently by the different stakeholders of the wheat chain, which makes it an extremely complex and variable concept. For farmers in some countries wheat quality is considered what allows them to allocate their harvested grain at the grain market and get the highest price for it. This is usually different among countries, where each one has different regulations that may prime farmers for producing better grain quality or not. Good morphological characteristics (grain size and density through test weight) and absence of grain damage are some of the most common traits considered at grain markets to determine the grade and

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sometimes the prize of the produced wheat. In other countries such as Australia or Canada there are more complex grading systems, in which protein content is usually an important trait (Blakeney et al., 2009). In other countries subsistence farmers will mill and process the wheat to feed their families and in these cases farmers consider wheat quality what allows them to produce a good product with desirable organoleptic properties.

For millers, wheat quality is the ability of a wheat variety to produce high levels of flour or semolina during the extraction process. In this process the level of contamination of the flour/semolina with bran fractions is also important and is linked in most cases to undesirable characteristics for the end-use quality of the product. For milling quality the traits probably most important are the grain morphology, grain density (test weight) (Matsuo and Dexter, 1980) and grain hardness (Edwards et al., 2010). Millers prefer large grain with plump shape which is well filled and not shriveled. These characteristics are also targets for breeders to increase grain yield in the field. On the other hand, food manufactures are more focused on processing quality, the ability of a wheat variety to be processed with minimum cost to give a uniform product, and end-use quality, the ability of a wheat variety to produce a specific product according to the consumers' preferences. For both types of quality, grain hardness and gluten quality and quantity are critical. Nutritional quality, the ability of a food to supply nutrients for a complete physical and mental development and a healthy life, is becoming also a big priority for food manufacturers due to the interest of consumers in that issue.

Last, but not least, consumers could have very different ideas of what wheat quality means. Some of them will think about the end-use quality of the product, while others could think about the processing conditions (artisanal or handmade vs. mechanized or industrial) or the nutritional quality of food products. End-use consumers vary in terms of quality demands, although there are several traits well identified among consumers as desired for specific products (soft crumb for bread, yellow color in pasta, shelf life of products, etc.). Having all this in mind breeding for quality to satisfy the demands of all the mentioned stakeholders is no simple task.

2. Bread wheat quality improvement at CIMMYT

The International Center for Maize and Wheat Improvement (CIMMYT) leads the Global Wheat Program of the Consultative Group on International Agriculture Research (CGIAR), whose main objective is to increase the productivity of wheat cropping systems to reduce poverty in developing countries. For this purpose CIMMYT works in the development of new wheat germplasm that can be used by national partners to improve their own germplasm or be released directly as varieties when appropriate. The priorities of the breeding program of CIMMYT are high grain yield, disease resistance, tolerance to abiotic stresses such as drought and heat, and desirable quality. Thousands of new breeding lines are evaluated annually in the three main field stations of the Program (Ciudad Obregon and Toluca in Mexico, and Njoro in Kenya). These evaluations lead to the formation of a set of best lines targeted to different environments (irrigated, semi-arid, high rain fed, etc.), which are distributed to national partners as international nurseries. Following this approach CIMMYT germplasm is extensively used worldwide, particularly in developing countries (Lantican et al., 2016).

As above mentioned, wheat quality is an integral part of this breeding process. Wheat Chemistry and Quality Laboratory has been an important component of the Global Wheat Program since its creation. As CIMMYT has a global mission and end-use quality of all bread wheat products developed worldwide are diverse, the strategy of the program has been mainly to guarantee good gluten quality (diverse levels of gluten strength combined with good extensibility) at medium protein content levels, in semi-hard or hard grains. This set of quality parameters is preferred for most products in developing countries. The laboratory has been continuously evolving to be able to analyze the largest number of samples possible, in the shortest time, at lowest cost, in order to deliver data on diverse quality traits on time to the breeders for making selections for advancement in the breeding pipeline. Currently for bread wheat, the following analyses and traits are routinely tested for the samples of the breeding program: grain image analysis (test weight and thousand kernel weight), visual grain inspection (color), grain analysis by NIR (hardness, protein and moisture content), milling (flour yield), flour analysis by NIR (protein, ash and moisture content; water absorption for mixograph, alveograph and bread-making based in Guzman et al., 2015), SDS-sedimentation, dough rheology (mixograph for optimum mixing time and torque, and alveograph for gluten strength and extensibility) and end-use product testing (baking pup loaf for volume and crumb structure). The methodologies used for these analysis are based on the official protocols of the AACC (American Association of Cereal Chemists, 2010), although several modifications have been implemented in both equipment and procedures to gain higher throughput and greater genetic diversity (Peña et al., 1990; Guzman et al., 2015, 2016a). This is necessary to characterize around 2500 samples in five months' time, deliver data on time, and allow breeders to select based in both field and quality traits.

For a better understanding and use of the wheat quality data generated, samples are classified in five different potential end-use types (1–5), using an index of the phenotypic data (Table 1). In each type there can be also subtypes based on protein content (*a* for medium-high and *b* for medium-low). An overview of the typical uses for each category is found in Table 2. Briefly, type 1 are the white and red grain lines suitable for pan type breads in mechanized industry; type 2a (above 11.5% of protein content) are for leavened breads produced in semi-mechanized industry (baguette, supermarket breads, etc.), two-layer flat breads (baladi), and dry & fresh noodles (alkaline, white, instant), while type 2b are for single-layer flat breads (chapatti) and steamed bread (North-China style); type 3 are for lines used to develop handmade products including dense and flat breads and some kind of noodles; type 4a (above 11.5% of protein content) are for steamed bread (South-China style) and white-salted noodles while type 4b are for

Table 1
Bread wheat gluten and end-use type classification to facilitate BW breeding at CIMMYT.

Hardness class & grain color	Gluten type[a]	End-use type[b]
Hard wheat		
Hard-white and hard-red	Strong (W > 300; P/L < 1.3)	1a, 1b
Hard-white and hard-red	Medium strong (W = 200–300; P/L < 1.2)	2a, 2b
Hard-white and hard-red	Medium weak (W = 150–200; P/L < 1.1)	3a, 3b
Soft wheat		
Soft-white	Strong and medium-strong	4a
Soft-white and soft-red	Weak	4b
Household or utility wheat[c]		
Hard- or soft- white or red	Tenacious (P/L > 1.3) or weak in not soft endosperm (W < 150)	5

Type 1a should have grain protein above 12.5% (12.5% M. B.).
Types 2a and 3a should have grain protein above 11.5% (12.5% M. B.).
Type 4a should have grain protein above 11.0% (12.5% M. B.).
Type 5 has no differentiation regarding protein content.

[a] Alveograph parameters. W, dough strength value J × 10^{-4}; P/L, tenacity extensibility ratio.

[b] End-use type number followed by letter "a" has higher protein content than the same followed by the letter "b".

[c] Quality types marked as "*Household (or utility) wheat*" have tenacious or weak (in not soft endosperm) gluten character, which is generally undesirable for most of the end-use types requiring a minimum of processing and end product quality attributes. This wheat is used mainly for home consumption, as whole meal flour or refined flour, used to prepare dense-leavened and flat breads or traditional dishes. Main quality attributes: taste, aroma.

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