CURRENT ADVANCES IN GENETIC IMPROVEMENT IN WHEAT

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ABSTRACT

The wheat breeding program at UC Davis includes subprograms in common wheat (white and red) and durum wheat. Every year hundreds of crosses are produced and thousands of headrows and yield plots are evaluated for agronomic traits, disease resistance and quality. During the last 17 years average yields have increased 1100 lb/ac for common wheat and 500 lb/ac for durum wheat documenting a continuous increase in productivity. The traditional field-based breeding efforts are complemented by marker assisted selection strategies to improve disease resistance, quality, abiotic stress resistance and nutritional value. Molecular markers have been used successfully to develop commercial varieties with improved resistance to stripe rust, increased grain protein content, and reduced cadmium content. The UC Davis program is also deploying genes for improved salt tolerance in durum wheat and improved draught tolerance in common wheat. Extensive research efforts continue to map and clone additional genes to improve resistance to biotic and abiotic stresses and to improve quality and nutritional value of wheat. In addition to the breeding efforts, the UCD program conducts cereal evaluation tests in 15 locations in the Sacramento, San Joaquin, and Imperial Valleys; the intermountain valleys of northern California and in the south central coastal region. Results from these trials are summarized at http://smallgrains.ucdavis.edu/.

Key Words: wheat, barley, breeding

INTRODUCTION

Wheat is an important component of the winter cropping system in the California, providing needed alternatives in crop rotations and economic viability with relatively low input. The California small grain crop in 2012 consisted of 737,000 acres of wheat (including 137,000 acres of durum), 120,000 acres of barley, and 230,000 acres of oat (http://quickstats.nass.usda.gov/).

The overall objective of the UC Wheat Breeding Program is to improve yield potential, disease resistance and quality of white and red bread wheat and durum wheat germplasm adapted to different California environments. A continuous breeding effort is required to maintain an adequate supply of varieties resistant to new pathogens (e.g. stripe and leaf rust) and adapted to growers and industry needs. The continuous evolution of new races of several diseases also requires a continuous research effort to identify and incorporate new resistance genes to be prepared for future race changes. The incorporation of disease resistance genes into the wheat germplasm adapted to California is essential to maintain a viable crop.

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In addition, permanent efforts are required to improve what quality to maintain the competitive advantage of California wheat. One important trait for both breadmaking and pasta quality is grain protein content. Our laboratory has discovered a gene from wild wheats that increase grain protein content by 5-10 % depending on the varieties (Uauy et al. 2006, Brevis et al. 2010a, b). We are currently deploying this gene in both our durum and common wheat programs.

In the durum wheat, lower cadmium levels required by the European Union have prompted urgent efforts to reduce cadmium levels. The soils in the desert valleys and lowlands of Southern California are rich in Cd, and the intensive use of phosphate fertilizer may increase these levels even further. Cd is a non-essential heavy metal that is easily absorbed and translocated in plants, particularly in durum wheat, which is not as efficient as bread wheat in limiting Cd translocation from the roots to the grains. Currently, more than 90% of the durum wheat acreage planted in California consisted of high-Cd varieties. This high proportion of high-Cd varieties jeopardizes future exports to the European Union and other international markets.

Improvements in disease resistance and quality need to be incorporated into high yielding lines that are competitive with existent varieties. To test the potential of these lines, a regional testing program is required to compare public and private wheat potential varieties in the different wheat growing areas in California. Efforts in these different areas are described below.

PROCEDURES

Traditional breeding program*:* To incorporate new diversity and new traits, approximately 150-200 crosses are made every year in the greenhouse during the winter and are planted at Tulelake to produce F_2 seeds in the summer. The new F_2 populations are planted in the field in November at UC Davis. Individual heads from selected plants are harvested and planted as F_3 families. The subsequent F_{4-6} families are handled using the modified pedigree method and the best F_6 and F_7 lines are harvested in bulk and advanced to a small observation plot.

Observation plots are selected by agronomic characteristics and yield. The best lines are analyzed for protein content and the selected lines are tested for HMW-GS analysis to eliminate the poorest quality lines. Approximately 200 lines are selected and advanced to preliminary yield trials. A preliminary screening of gluten strength by SDS sedimentation is performed to eliminate lines with low gluten strength.

"Preliminary" and "Advanced" yield trials are then grown at UC Davis and the best lines are advanced to "Elite" experiments for common and durum wheats (4 replications) at Davis, Colusa and Kings Counties. Lines selected from the Elite trials are then evaluated in the statewide Regional Evaluation trials for potential release together with advanced lines from private breeding companies. Selection of the more advanced yield trials is complemented by quality tests performed at the California Wheat Commission. For the lines selected for variety release we produce Breeder's Seed, and send that seed to the Foundation Seed Program (FSP) for increase and distribution to seed companies.

Traditional breeding efforts in California during the last 17 years have resulted in average yields increases of 1,100 lb/ac for common wheat (~65 lb/ac per year) and 500 lb/ac for durum wheat (~30 lb/ac per year) documenting a continuous increase in productivity.

Marker assisted selection*:* We are currently deploying multiple stripe rust resistance genes using molecular markers for major resistance genes *Yr5, Yr15, Yr17* and for slow rusting genes *Yr48, Yr18,* and *Yr36*. In the area of septoria tritici blotch resistance we use molecular markers to introgress resistance genes *Stb3, Stb4,* and *Stb7.* Our laboratory recently cloned the first slow rusting gene (*Yr36*) and released germplasm and commercial varieties including this novel stripe rust resistance gene (Fu et al. 2009; Hale et. al 2012)

In 2012 we are releasing the new variety Patwin 515, which incorporates stripe rust resistance genes *Yr5* and *Yr15* in the resistant variety Patwin (*Yr17* plus other unknown genes). Pyramiding of multiple resistance genes is expected to increase the durability of the resistance found in this variety. Patwin-515 shows very good breadmaking quality characteristics. Patwin 515 performs well agronomically in all areas where it has been evaluated in California and is well suited for the Sacramento, San Joaquin and Imperial Valleys.

In durum wheat, we incorporated the high grain protein content *GPC-B1* into our variety Desert King and developed the new variety Desert King-High Protein (DK-HP) that shows a 10% increase in protein content relative to Desert King. DK-HP combines a high yield potential, good pasta quality, and resistance to the major wheat pathogens found in California. DK-HP performs well agronomically in all areas where it has been evaluated in California. DK-HP is well suited for the San Joaquin and Imperial Valley, the main durum producing areas in California, but has also the potential to expand the durum growing area in California to the Sacramento Valley, an area were previous varieties were unable to reach the high grain protein content levels required for high-quality pasta varieties.

In the area of reduced Cadmium, we are converting our breeding program into a low-cadmium breeding program by using extensively markers assisted selection for the *CDU1* gene, which explains ~80% of the variation in Cadmium content. The UC Davis breeding program is releasing Miwok (UC1690) in 2013, the first UC Davis low-cadmium variety. Breeder seed was produced in 2012 and Foundation seed will be available in 2013. This variety shows excellent yield potential and low levels of Cadmium due to the incorporation of the *CDU-1* gene. This line was evaluated for pasta quality by the California Wheat Commission quality laboratory and by milling companies in the Collaborative Quality Evaluation Program in 2012 with excellent results.

Discovery of new markers and genes*:* In addition to deploying current markers a continuous research effort is required to discover new resistance genes and to identify new markers and genes to increase the value and productivity of California wheat varieties.

In common wheat, we are using a new technology known as Association Mapping to find new chromosome regions associated to disease resistance and drought tolerance. These screening of 1000 lines for stripe rust resistance has already identified several promising chromosome regions associated with resistance. In the area of drought tolerance, we have identified a segment from rye chromosome 1RS that confers improved resistance to drought. We are currently combining this draught tolerance gene with the stripe rust resistance gene *Yr15* and a gene for strong gluten (7Bx over-expressor) which are all located on chromosome 1B from common wheat. Once the three genes are combined, this engineered chromosome will be deployed in our breeding program.

In durum wheat, we have done extensive research in pasta quality (Zhang et al. 2008) and the genes identified for improved pasta color (pigment content and color stability) are currently being deployed in our breeding lines. We have also introgressed the salt tolerance gene NAX2 into durum lines and we are currently doing experiment with near isogenic lines to test the effectiveness of this gene in California environments. Finally, we have initiated research in additional genes regulating Cadmium (different from *CDU1*) to further reduce Cadmium levels.

Regional testing program*:* In addition to the breeding efforts, the UCD program conducts evaluation trials of common wheat, durum wheat, triticale, and barley trials in the major small grain-producing areas of California (~15 locations). The Regional Cereal Evaluation Program includes evaluation nurseries of advanced breeding lines and new and standard cultivars obtained from public and private breeding programs. Trials are located at representative environments in the Sacramento, San Joaquin, Imperial, and northern intermountain valleys, and south-central coastal foothills. Nurseries are using production practices appropriate for each environment. The performances (yield, agronomic characteristics, diseases and pest reactions, grain quality) of the entries is documented and summarized in the Agronomy Progress Reports. The resulting information is useful for growers to identify areas where new cultivars are best adapted and as supporting data for justifying the release of advanced breeding lines from both public and private breeding programs. Results from these trials for each year are summarized at http://smallgrains.ucdavis.edu/.

CONCLUSION

The pubic wheat breeding program at the University of California Davis has provided commercial wheat varieties to the wheat growers and helped private breeding programs to incorporate marker assisted selection techniques. For example, California wheat varieties Westmore, Expresso, Blanca Grande 515, and Summit 515 were all developed in collaboration between UCD and private companies breeding wheat varieties for California. The UCD program has successfully incorporated modern marker assisted selection approaches and used them to control the devastating stripe rust epidemic that started in the year 2000. Markers have been also used successfully to increase grain protein content and reduce Cadmium levels. The breeding efforts have been complemented with a broad wheat research program that has resulted in more than 170 scientific publications describing useful genes for wheat improvement. Finally, an integrated Regional Testing Program continues to provide the California wheat growers the information required to select the better varieties for their regions.

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