Maximizing Canopy Conductance to Enhance Spring Wheat Yield Potential in the Upper Midwest

M. Walid Sadok, Dept. of Agronomy & Plant Genetics, U of M

Research Questions

Background. Increasing wheat canopy conductance has great potential to enhance productivity of wheat cropping systems. This is because canopy conductance controls the plants efficiency in trading water for fixing atmospheric CO_2, which is necessary to fill the grain with carbohydrates and protein. In wheat, we have shown in two different production environments (Australia and Minnesota) that increases in canopy conductance are associated with historic yield increases from 1890-2008 and 1992-2016 respectively. This makes this trait uniquely valuable for breeding programs, because it has a greater chance of increasing yield potential of varieties released to farmers. The long-term objective of this research is to identify all major genetic loci associated with this complex trait and pyramid them in the pipeline of the University of Minnesota wheat breeding program to deliver to producers varieties with higher yield potential. **Goals.** To this end, the proposed research had 4 goals: 1) develop a high-throughput phenotyping approach to screen canopy conductance within the Minnesota Nested Association Mapping Population (MNAMP), a highly diverse group of wheat lines consisting of RB07 and 25 other exotic lines, 2) select from this group parents of families to be evaluated for canopy conductance, 3) phenotype a family of recombinant inbred lines (RILs) resulting from the mating of recurrent parent RB07 and the parent with the most extreme conductance and 4) identify genetic markers associated with enhanced canopy conductance.

Results

Goal 1). Dr. Sadok's team successfully developed and adapted a unique phenotyping system (the GPS Platform) for high-throughput screening of canopy conductance of the 26 parents of the MNAMP. This phenotyping effort was undertaken twice, confirming the initial results, and revealing highly stable conductance values across experiments. The team discovered an unexpectedly large variability in canopy conductance within the panel which is a positive outcome, since genetic analyses are far more reliable for diverse traits. In fact, in this panel, the highest canopy conductance was approx. 300% the level of the lowest conductance identified (Figure 1). **Goal 2).** Based on the data, we selected 3 genotypes in addition to RB07 as parents of the MNAMP families to be phenotyped for future genetic analyses. **Goal 3).** The number of available progeny lines from the Steffenson lab was limited to approx. 50 to 90 for each family. As a result, instead of phenotyping one family as initially planned, we successfully screened 3 families, totaling 150 genotypes, which is more than the initial number of genotypes we initially proposed.

Application and Use

Increasing canopy conductance can lead to numerous yield-related benefits for Minnesota wheat. Higher canopy conductance is associated with increased ability of the plant for water and nitrogen uptake from the soil. This in turn may decrease risks of nitrogen leaching and waterlogging. In addition, higher canopy conductance is associated with increased fixation of CO_2 and other mobile nutrients needed for filling the grain and with protecting the canopy from heat stress during the summer, via evaporative cooling. The proposed research aims at maximizing all of these benefits by identifying genetic markers associated with increased canopy conductance. Those genes will be integrated into the University of Minnesota wheat breeding program to deliver new cultivars with maximized canopy conductance and increased yield potential.

Materials and Methods

For this research, the plants were grown under naturally fluctuating conditions in a well-maintained greenhouse at the University of Minnesota. Plants were grown in a setting that mimic field conditions (large pots, fertilized top soil, high density) in where where key environmental conditions were carefully monitored (light, temperature, relative humidity, watering regime). After 4-5 weeks, plants were transferred in a precision phenotyping platform deployed inside three walk-in environment chambers. This platform tracks canopy conductance as a function of whole-plant transpiration response –measured gravimetrically – to increasing atmospheric vapor pressure deficit. This allows for a very precise estimation of whole-plant canopy conductance which is very difficult to accurately measure in the field because of the confounding influence of uncontrollable variations in light, temperature and wind speed. The experiment was replicated twice to characterize diversity in canopy conductance among the 26 parents of the MNAMP. After identifying the target parents, the system was then deployed to phenotype three families selected from the MNAMP, totaling 150 lines.

Economic Benefit to a Typical 500 Acre Wheat Enterprise

In temperate production environments such as Minnesota, increasing canopy conductance would lead to enhanced yields as suggested by our work showing correlation between increases in canopy conductance and yield increases in historic Minnesota wheat lines. In this regard, data from the first year showed great promise. For instance, we have identified genotypes with maximal canopy conductance values that were up to 42% higher than the high-yielding cultivar RB07 (Figure 1). Potentially, this represents an untapped possibility to enhance wheat yields in Minnesota by further increasing canopy conductance of new cultivars. Since we know what trait to look for, we can reasonably assume that yield increases resulting from enhanced canopy conductance could be achieved over a period significantly shorter than 15 years, which is the duration over which we were able to correlate yield increases and canopy conductance in historic wheat lines. However, although much shorter, it is important to note that this pre-breeding project requires a time horizon of 4 to 6 years to integrate beneficial canopy conductance genes into advanced breeding lines.

Related Research

Matching canopy conductance to the resources offered by the production environment is now a major goal for wheat breeding programs across the globe. In well-watered environments such as Minnesota, increasing canopy conductance provides an opportunity for enhancing yield potential, by increasing water, nutrient and CO_2 uptake. Indeed, over a given day, desired genotypes for Minnesota would be those that maintain a maximal conductance during most of the day. However, in water-limited environments such as the western part of the U.S. spring wheat region, our research showed that genotypes that decrease their canopy conductance at midday would increase yields through a water-saving strategy. Since our screening method allows us to identify favorable canopy responses under well-watered (i.e., high conductance) and water-limited (i.e., low conductance) environments, the research conducted in this project will be valuable not only for Minnesota but also to wheat breeding programs of more drought-prone neighboring states such as the North Dakota and South Dakota HRSW breeding programs. This research is also relevant to address future water-deficit events that are predicted to occur in certain regions in Minnesota. As a result of these benefits, Dr. Sadok's research program in this area has expanded to include collaborations with colleagues in Tunisia, Morocco and Australia with the goal of helping breeders develop cultivars with canopy conductance that maximize yield potential in various production environments.

Recommended Future Research

In this first year, we expect fulfilling the goal of the proposal, which is the identification – for the first time – of quantitative trait loci (QTL) controlling canopy conductance in wheat within a Minnesota Nested Association Mapping Population. Such a goal is typically achieved after 3-5 years of field phenotyping for a single mapping population, considering the difficulty of measuring canopy conductance. In our case, we have successfully screened 3 families within a single year. However, because of the complexity of this trait, we expect to detect several QTL associated with this trait that need to be confirmed in more populations and experiments before integration in the breeding program. In addition, the structure of the MNAMP itself requires phenotyping as many families as possible to maximize the precision of the detection and chances of capturing favorable genes to be pyramided in the U of M wheat breeding program. For this to be achieved, we have set the following timetable:

- End of 2017: analyze data, identify QTL for the first time.
- 2018: phenotype a second group of 3 new families, replicate phenotyping of first 3 populations, confirm QTL in an independent mapping population, analyze data, identify new QTL.
- 2019: replicate phenotyping of the second group of 3 families, replicate phenotyping of the independent mapping population, analyze data, perform joint QTL analysis to identify major genes, write up manuscripts, release genetic markers to wheat breeders.

Appendix

Figure 1.

Variation in maximal canopy conductance among the 26 parents of the Minnesota Nested Association Mapping Population (MNAMP). The value for the recurrent parent (RB07) is represented by the gray bar. Data is based on two independent experiments.