Breeding of weed-competitive wheat

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Abstract
Weeds are estimated to cost Australian agriculture $4.3 billion a year. In Australia herbicide-resistant weeds are identified with increasing frequency, challenging current weed control methods. Competitive crop varieties are a little used weed control tool despite being low cost and easy to implement with other weed control approaches. Traditionally, Australian wheat varieties have not shown good early vigour, a trait representing more rapid leaf area development through wide leaves and greater biomass at stem elongation. Early vigour is a common mechanism of competition in natural plant communities and could be useful in managed farming systems. This paper describes a pre-breeding approach to develop Australian competitive wheat varieties. Overseas wheats with great early vigour were sourced and the vigour combined in one vigour-donor, which was crossed traditionally with adapted commercial varieties. The developed advanced breeding lines were assessed for agronomic parameters in rows in the field and then distributed amongst Australian commercial breeding companies. To date, ~5000 advanced main-season breeding lines have been distributed to Australian commercial breeding companies and evaluated by commercial breeders for uptake in their breeding programs. A further ~4000 advanced breeding lines including long-season types are under development for release in 2019-20. The feedback from commercial breeders on distributed advanced breeding lines has been positive.

Key Words
Pre-breeding, weed-competition, early vigour, integrated weed management

Introduction

The impact of weeds on Australian agriculture costs growers an estimated $4.3 billion a year (Mcleod 2018). No-till management with no integrated weed management (IWM) has increased pressure on herbicides with development of resistant weeds. Ryegrass, wild oats and wild radish contribute to significant reductions in wheat yields (Llewellyn et al 2016) and are amongst the 50 resistant weed species identified in Australia (Heap 2019). With the issue of herbicide resistance, it is pertinent to expand our IWM toolbox to maintain the longevity of new and existing herbicides and reduce the cost of herbicide management to increase grower profitability. Competitive crop varieties is one non-herbicide IWM control tool and is easily implemented with other approaches and moreover with low cost and low risk.

Greater early vigour, representing a more rapid leaf area development through wide leaves and greater biomass at stem elongation, is known to be a common mechanism in competition in natural plant communities (Aerts 1999). Vigorous wheat varieties should provide an equally effective ideotype to improve crop competition in managed farming system. Unfortunately, few competitive wheat varieties have been released commercially and available vigorous breeding lines do not possess suitable agronomic and grain quality, and are not well-adapted to Australian farming systems.

Few studies have assessed weed-competitive abilities of Australian wheat varieties (Lemerle et al 2001, Vandeleur & Gill 2004). These studies confirm early vigour as an important factor in weed competition and highlight the need to introduce greater early vigour in modern wheat varieties.

A wheat breeding line developed with great early vigour is C6-2. C6-2 is a selection from a recurrent selection population representing an aggregation of 28 diverse wheat lines including overseas sources with greater early vigour (Rebetzke and Richards 1999). Figure 1 shows how total leaf area increased significantly with the recurrent selection. The recurrent selection was based on width of leaves 1, 2 and 3 to increase total early leaf area. The results showed that flag leaf also increased in both width and length despite not being targeted by selection. In contrast, the Australian variety Westonia produced approximately half the leaf area of the most vigorous cycle 6 selection (cf. 51.2 versus. 87.3cm^2).

The C6-2 genotype is a tall, short-seasoned wheat with few tillers and tight glumes and with exotic germplasm, and it does not contain desirable agronomic or quality characteristics. Through traditional breeding techniques, C6-2 was crossed with commercially adapted Australian wheat varieties with the aim to combine greater early vigour with desired commercial agronomic and quality wheat traits in numerous advanced breeding lines.

Since the discovery of gibberellic acid-insensitive dwarfing genes *Rht1* and *Rht2*, they have been used to reduce plant height, however, *Rht1* and *Rht2* have also been shown to reduce crop vigour (Rebetzke et al 2001). In the last years several gibberellin-sensitive dwarfing genes have been identified, they limit plant height but not crop vigour. To further secure high vigour in the advanced breeding lines, the commercial variety used as a parent was enriched with the alternative dwarfing genes *Rht13* or *Rht18* instead of *Rht1* or *Rht2*.

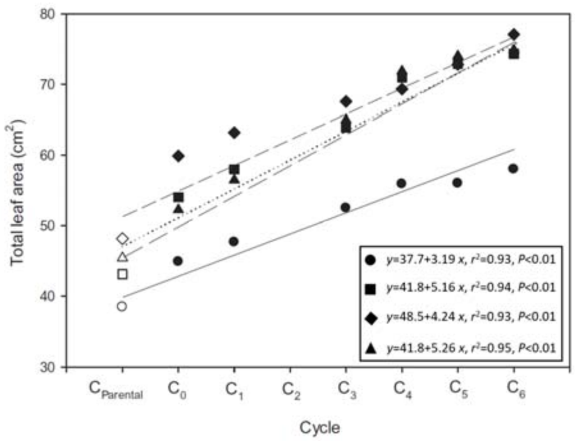

Figure 1. Recurrent selection developing C6-2 (progeny of C_6). Relationship between starting lines ($C_{Parental}$) and selection cycle zero to six (C_0-C_6) and mean total leaf area of leaves 1 to 3 measured in four environments: Sowing 1 (●); Sowing 2 (■); Sowing 3 (♦); and Sowing 4 (▲). Between each selection cycle progenies were randomly intermated and total leaf are measured on F3 progeny, for full details please see Zhang et al (2015).

Methods

Plant material

The donor of greater early vigour was the CSIRO developed C6-2 (Rebetzke and Richards 1999, Zhang et al. 2015) either backcrossed or topcrossed to Australian adapted commercial varieties enriched with either *Rht13* or *Rht18* dwarfing genes (Figure 2). Choosing which adapted commercial backgrounds to include was agreed through dialogue with commercial Australian breeding companies.

The F1s were generated through back- or top-crossing to increase the frequency of favourable 'commercial' alleles, and populations then self-fertilised through five generations in 2017 and four generations in 2018 via single seed descent. Resulting F2-derived F5:6 or F4:5 lines were assessed for agronomic characteristics under field conditions.

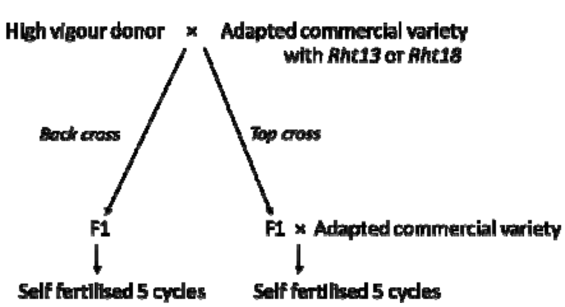

Figure 2. Schematic crossing scheme followed in development of weed-competitive advanced breeding lines.

Agronomic assessment

Agronomic assessment was predominantly performed on seed from the last cycle of single seed descent carried out in the greenhouse. Only plant height was assessed in the greenhouse. In the field seeds of individual plants from the greenhouse were sown in one meter rows. One row for each individual advanced breeding line. Each 6-row plot consisted of 4 rows of weed-competitive advanced breeding lines bordered by the commercial adapted parent (backcross) or parents (topcross) for direct comparison.

In 2017, 6943 individual advanced breeding lines were sown in the field representing 18 different genetic backgrounds of Australian adapted varieties. In 2018 the field sown nursery contained 2044 advanced breeding lines including new genetic backgrounds. Each year 21-28 checks were included comprising vigour donor C6-2, the commercial varieties enriched with *Rht13* and *Rht18*, and a selection of commercial varieties. The check varieties were repeated in four to 26 rows randomly throughout the nursery. The advanced breeding lines and checks were visually assessed for early vigour (leaf area of the first 4-5 leaves), late vigour (post flowering biomass), flowering time and mature plant height. At maturity rows were hand harvested, threshed and distributed to commercial breeding companies.

Distribution to commercial breeding companies
The large number of advanced breeding lines were developed to deliver a unique set of genotypes to each commercial breeding company every year, meaning no line was distributed to more than one breeding company. Further, the advanced breeding lines were allocated in accordance to each commercial breeding companies' confidential interest in the genetic backgrounds.

Through these large populations it was possible to cater to the individual needs of each breeding program and most likely increasing the chance of the material actively being used in crossing and population development in the programs and the competitive trait making its way to the grower's paddock.

From the advanced breeding lines grown in 2017, 4313 were distributed amongst commercial breeding companies and from the advanced breeding lines grown in 2018, 1015 lines were distributed amongst commercial breeding companies. Advanced breeding lines were distributed in quantities of 40-50g of seed per line.

Results
As expected, C6-2 showed greater vigour than commercial varieties at vegetative stages, and this translated to greater vigour in advanced breeding lines (Figure 3). There was an association between plant height in the greenhouse and under field conditions. However, this association was not strong enough to confidently select for variation in plant height in the greenhouse environment. The agronomic assessment was only performed in one year on plants grown in a one metre row, necessitating caution with the measured performance. Further, due to delays with seed maturation in the greenhouse, the 2017 trial was sown very late (early August) further reducing confidence in selection for agronomic quality in the field. Selected breeding lines are now being assessed in other experiments to establish the value proposition with competitiveness and traits responsible.

Figure 3. Visual presentation of (left) early vigour in C6-2 compared to commercially adapted parents, and (right) variation in four advanced breeding lines from a Gregory background in the four middle rows compared with the commercial variety Gregory in the top and bottom rows.

In the 2019 field season we have sown 4033 advanced breeding lines for agronomic assessment with weed-competitive CSIRO donors W470201 and W670704. W470201 is Yitpi derived and W670704 is a Wyalkatchem derivative developed in 2007 and since confirmed as strongly weed-competitive. In the 2020 field season we will grow advanced breeding lines derived from vigorous donors and the longer-season commercial adapted varieties Coolah, Flanker, Kittyhawk and Pascal.

Conclusion

The development of weed-competitive wheats and their high-throughput assessment is ongoing. Up until now, ~5000 weed-competitive advanced breeding lines have been distributed as unique sets among commercial breeding companies with further advanced breeding lines to be distributed from the 2019 and 2020 field season. The advanced breeding lines distributed in 2018 have already been assessed in one season by the breeders with feedback being positive.

In this field season we have attained enough seed of the individual advanced breeding lines and a selected set of 100 have been sown to determine their weed-competitive ability.

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