Evaluation of harvest index as an indirect early generation selection trait for yield in winter wheat

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Abstract

Early generation selection (EGS) in wheat (*Triticum aestivum* L.) aims to accelerate genetic yield gain by identifying lines with high potential yield in the F2 or F3 generation. Three experiments were conducted near Birchip in northwest Victoria to evaluate EGS in spaced single F3 winter wheat plants using harvest index (HI; single plant yield/plant weight). In 2018, 440 F3 single winter wheat plants and 10 plots of pooled family seed were planted. 21 single plant lines were selected for high HI and 52 were selected randomly; 25 culms were selected from plots based on visual characteristics. These lines were planted in a partially replicated plot experiment at Birchip in 2019. In 2019, lines selected for HI had a higher plot yield (457 g/m^2) than lines selected visually (375 g/m^2) or randomly (368 g/m^2). There was moderate correlation between F3 single plant HI and F4 plot yield (r^2 = 0.17). The seven highest-yielding lines from each selection treatment were sown in a replicated plot experiment at Curyo in 2020 and there was no difference in yield between selection groups. Results suggest that applying high selection pressure for HI in early generations can accelerate yield gain in winter wheat.

Keywords

Wheat breeding; early generation selection; visual selection; early sowing

Introduction

Early generation selection (EGS) aims to apply selection pressure at the F2 and F3 generation to accelerate genetic yield gain in breeding programs. A lack of seed and high heterozygosity means EGS needs to occur in single plants or in low plant densities. The yield of wheat (*Triticum aestivum* L.) at these densities is not well-correlated with yield in homogenous crop stands(Donald and Hamblin, 1976), so selection traits must be indirect indicators of yield.

Fischer and Rebetzke (2018) recommend harvest index (HI; grain yield divided by total plant biomass) as a potential indirect selection trait in wheat. HI is well-correlated with yield in Australian spring wheat and has been linked to historical increases in Australian spring wheat potential yield – due in part to a reduction in plant height (Sadras and Lawson, 2011; Flohr et al., 2018). Successful implementation of indirect EGS would increase the rate of genetic yield gain and accelerate the release of high-yielding wheat cultivars to growers.

Previous attempts to incorporate HI into EGS breeding programs have not been successful enough to warrant the supersession of conventional breeding methods. Quail et al. (1989) found moderate to high correlation between F3 HI and F7-F8 plot yield, while Sharma and Smith (1986) found that selecting for high HI was effective in increasing HI in subsequent generations, but not yield. The purpose of this study was to evaluate the suitability of HI as an EGS trait in a segregating population of winter wheat lines, measured on single plants and compared to both a random sample across the entire population and a sample of lines selected for visual characteristics. It was hypothesized that lines selected for high HI as single plants would produce higher-yielding progeny than lines selected visually or randomly.

Methods

Nine families of winter wheat lines were derived from crosses involving high-yielding Australian spring wheat cultivars. Lines were phenotyped as winter on growth habit in the glasshouse at the F2 generation, vernalised at 8°C for 28 days and returned to glasshouse before F3 seed was harvested.

2018 field experiment – HI and random selection groups
A field experiment was conducted at Narraport, in northwest Victoria. The site had been fallowed in 2017. On 15 April, 44 seeds per family were planted on 0.75 m row spacings, with 0.50 m between seeds along the crop row. The experiment was a partially replicated block design, with lines sown in family blocks with four check cultivars (Illabo, Longsword, CSIROW007, Mace). Seeds were irrigated at sowing with 30 mm of water, with 35 mm on 6 August and 80 mm on 6 September. April – October rainfall was 138 mm.

Heading date was measured as the day on which the most developed spike emerged fully from the flag leaf sheath. At maturity, single plants were harvested, dried at 50°C for 48 hours before weighing and threshing. HI was calculated by dividing yield by single plant weight. 21 of the lines with the highest single plant HI were selected for a plot experiment the following year. To represent the mean yield of the population across all families, 52 lines were selected randomly.

2018 field experiment – visual selection group
One 6 row, 12 m^2 plot of pooled F3 seed per family was sown on 15 April at the same site as the single plants, and received 10 mm of irrigation. 25 single culms were selected from each of the plots of pooled seed based on visual appearance at both anthesis (Z65; Zadoks et al., 1974) and maturity (Z89). Criteria were suitable phenology, erect stature and leaf angle, large and consistent spike size and the absence of any defects such as physiological yellowing or disease. Following harvest, one seed per culm was planted in the glasshouse, vernalised, grown to maturity to collect seed for 2019.

2019 field experiment
Selected lines were sown in 6 row, 12 m^2 plots at Karyrie, northwest Victoria on 30 April. The experiment was a randomised partially replicated row:column design, with no replicates of selected lines, but five replicates of three elite winter wheat cultivars (Illabo, Longsword, LRPB Kittyhawk). April – October rainfall was 197 mm.

Heading date was recorded when 50% of spikes had fully emerged from the flag leaf sheath (Z55; Zadoks et al., 1974). At maturity (Z89), a hand-cut biomass sample of 0.5 m from the 4 inside rows was taken (1.2 m^2). Spikelet number and floret sterility were counted on 10 random spikes. Samples were dried at 70°C for 48 hours before being weighed and threshed. HI was calculated by dividing grain yield by harvest biomass. 250 kernels were sampled for kernel weight and number.

2020 field experiment
The 7 highest-yielding lines in each treatment from 2019 were sown in 6 row, 12 m^2 plots at Curyo, northwest Victoria on 9 April 2020. The experiment was a randomised complete block experiment with four replicates of all lines, including Illabo, Longsword and LRPB Kittyhawk. Growing season (April – October) rainfall was 373 mm. All measurements were the same as in 2019.

Statistical analyses
Measurements were analysed with linear mixed models using residual maximum likelihood (REML) with GenStat 19 (VSN International, 2019). Results from each year were analysed separately. Line number was a fixed effect, while block, row and column were random effects. Means obtained from the REML output were used in an analysis of variance (ANOVA) to compare traits from each selection treatment in 2019. A Tukey range test was used to determine whether trait means for different treatments were significantly different ($p < 0.05$). Predicted means were also used in Type II regression analyses which were conducted to compare single plant traits and plot traits (Legendre, 2014).

Results and discussion
There was no significant difference in heading date between selection groups in 2019 (Table 1). The HI-selection group yielded more (457 g/m^2) than both the random (368 g/m^2) and visual selection (375 g/m^2) treatment. The yield increase in HI-selected lines relative to population mean (24%) was

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higher than seen in Quail et al. (1989) (9% at one site) and Sharma and Smith (1986) (18% in high HI-selections relative to low-HI selections). The yield advantage of was driven by an increase in HI compared to the random group, and an in biomass relative to the visual selection group.

Table 1. Mean trait values for treatments in 2019. Superscript letters note significant groups according to a Tukey HSD test ($p < 0.05$). Values without superscript letters were not significantly different.

Selection treatment	Heading (Z55) date	Grain yield (g/m^2)	Harvest biomass (g/m^2)	HI	Kernel weight (mg)	Kernel number/m^2	Spikelets per spike
HI	22 Sep	457 ^{a}	1207 ^{a}	0.39 ^{a}	33	14162	15.4 ^{a}
Visual	27 Sep	375 ^{b}	1001 ^{b}	0.38 ^{ab}	32	11745	16.8 ^{a}
Random	26 Sep	368 ^{b}	1095 ^{ab}	0.34 ^{b}	32	11982	15.6 ^{b}

Yield variation was also less in the HI- and visual selection treatments than in the random group (Figure 2). One HI-selected line (5%) yielded less than 350 g/m^2; in comparison, 40% of randomly selected and 32% of visually selected lines yielded below this level.

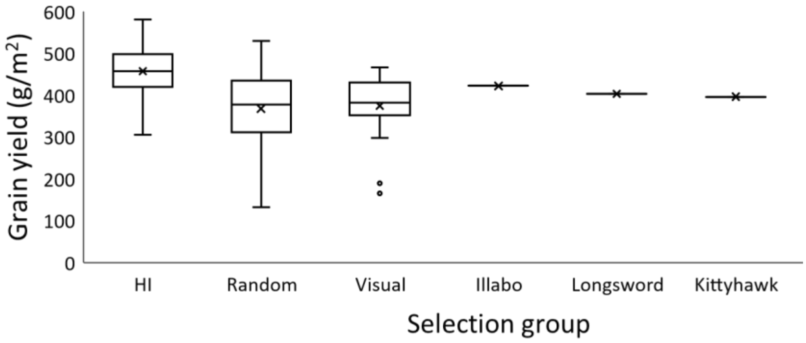

Figure 2. Box and whisker plot depicting average and range of plot grain yield for selection treatments in 2019. Values for Illabo, LRPB Kittyhawk and Longsword are the predicted means from five replicates.

The correlation between single F3 plant HI and F4 plot yield was only moderate ($r^2 = 0.17$, Figure 3a). This is comparable to Quail et al. (1989), where average correlation coefficient (r) values for the relationship between F3 HI and F7-F8 plot yield was 0.326. However, in the one setting where selecting for HI increased plot yield, $r = 0.508$, higher than seen here. The relationship between single F3 plant HI and F4 plot HI was similar in strength ($r^2 = 0.20$) to the HI-yield relationship (Figure 3b).

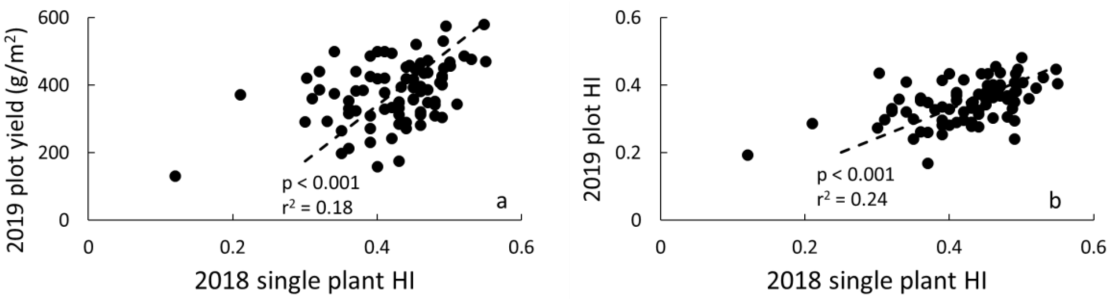

Figure 3. Relationship between F3 single plant HI and traits measured in plots in 2019.

When the 7 highest yielding lines from each treatment were grown in 2020, there was no difference in yield between selection groups (Table 2). Lines selected for HI had a higher HI than those visually selected, and a higher kernel weight but lower kernel number than the random treatment. Applying a high level of selection pressure for HI did not exclude any lines with higher potential yield than those selected, negating one of the risks of EGS (Fischer and Rebetzke, 2018). If the strategy of applying high selection pressure for HI to unenriched material was expanded to the scale of commercial breeding programmes, larger populations could be screened at the F3 generation, ensuring population mean yield is higher when direct selection for yield commences in later generations.

Table 2. Mean trait values for treatments in 2020. Superscript letters note significant groups according to a Tukey HSD test ($p < 0.05$). Values without superscript letters were not significantly different.

Selection treatment	Heading (Z55) date	Grain yield (g/m^2)	Harvest biomass (g/m^2)	HI	Kernel weight (mg)	Kernel number/m^2	Sterility (%)
HI	14 Sep	522	1278	0.41 [a]	42 [a]	12631 [b]	15 [ab]
Visual	15 Sep	502	1316	0.38 [b]	40 [b]	12778 [b]	18 [a]
Random	16 Sep	528	1318	0.40 [a]	40 [b]	13369 [a]	14 [b]

There is currently no way to measure HI affordably and rapidly in single plants. There has been success in using photogrammetry to estimate HI from breeding plots (Walter et al., 2018), but several minutes to over an hour are required to process the requisite number of images for each plot. However, considering the speed at which high-throughput phenotyping technology has advanced in recent years, the ability to estimate HI in single plants can reasonably be expected in coming years.

Conclusion

Selecting for HI in a winter wheat population of F3 single plants increased plot yield and HI in the following generation compared to the population mean. While breeders do not currently have access to high-throughput phenotyping tools to measure HI rapidly enough to warrant immediate widespread uptake, rapid advancements in high-throughput field phenotyping are predicted, and selecting for HI in early generation single plants holds promise as a breeding strategy in the near future.

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