Increased stability of kernel weight under drought through selection of a reduced-tillering gene in wheat

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Abstract

Australian wheat production environments are typically water-limited and characterised by terminal drought. Post-anthesis drought contributes to a high incidence of small or shriveled wheat kernels (screenings) that reduce crop value. It was hypothesised that the incorporation of the tiller inhibition (*tin*) gene into wheat germplasm may contribute to the maintenance of large kernel weight (KW) and reduction in screenings (SCR), particularly in terminal water stress environments. One irrigated and six dryland field experiments (2005 & 2006) and two rainout shelter experiments with an irrigated control (2007) were utilized to investigate the value of the *tin* gene in maintenance of KW under variable water supply in Queensland. Twenty two (2005 & 2006) and six (2007) Silverstar near-isogenic lines (NILs) contrasting for reduced tillering (tin_1) and wild type (Tin_1) alleles were utilised. Averaged across experiments, the KW of *tin* lines was 11% greater than free-tillering lines. Reduced-tillering lines produced up to 53% fewer SCR than free-tillering lines. The KW advantage was largely associated with reduced spike number/m^2 (r^2=0.27 to 0.79), with kernel number per spike being less important. On average grain yield (GY), which ranged from 2.0-6.1 t/ha, tended to be lower (-9%) in *tin* lines, particularly in high-yielding environments with high spike density. However, at moderate spike density (≈300 spike/m^2) in all environments, particular *tin* lines could be identified which achieved high KW, low SCR and relatively high GY. There exists potential for selection among *tin* progeny to achieve simultaneous GY and KW improvement and reduction in SCR for terminal stress environments. Consequently, considerable increases in crop value (eg $45-313/ha) can be achieved with the use of *tin* lines in terminal stress environments.

Keywords

grain weight, *tin* gene, water stress, dryland agriculture, northern region, cereal

Introduction

It is well documented that increased yield of modern wheat varieties, as with other cereals, has largely been achieved through selection for increased kernel number per unit area (Fischer 2008; Sayre et al. 1997). In contrast, KW is considered a relatively stable yield component across years and locations with small genotypic variation (Fischer and Hillerislambers 1978). However, following many years of selection, especially under higher input conditions, there has been a tendency for modern wheat varieties to produce a substantial proportion of low weight kernels (Acreche and Slafer 2006) even under non water-limiting conditions. Furthermore, when lines are exposed to a water deficit, particularly a post-anthesis terminal water stress, as often experienced in the northern and western growing regions of the Australian wheat belt, small or 'pinched and shriveled' kernels result. Growers wish to minimize screenings, as the value of the crop is reduced when the percentage of screenings is above 5%.

Selection for the reduced-tillering *tin* gene has been shown to result in larger stems, higher harvest index and increased kernel weight (Duggan et al. 2005; Richards 1988) with minimal reduction in GY in southern environments. It may be in the northern region, where the target plant density is relatively low and crops are reliant on stored soil moisture with terminal water stress being frequent (Chenu et al. 2009), that the greatest benefit of *tin* germplasm may exist. Thus, a series of field experiments were conducted in the northern region to evaluate the performance of reduced and free-tillering Silverstar sister lines. It was hypothesised that the incorporation of the *tin* gene into wheat germplasm may contribute to the maintenance of KW and reduction in SCR.

Methods

Near-isogenic lines (NILs) varying in tiller number were developed by twice back-crossing the *tin* gene into the free-tillering, high-screenings variety, Silverstar (Rebetzke pers.comm.). Lines containing the *tin1* allele, as identified by molecular marker Xgwm136 (Spielmeyer and Richards 2004), were classed as reduced tillering (*tin*), whereas those with the alternative wild-type allele were free-tillering (W). Seven field experiments were conducted at Gatton (-27.55,152.33), Kingsthorpe (-27.47,151.83) and Emerald (-23.47,148.15), QLD in 2005 and 2006. Each experiment evaluated 22 Silverstar NILs (11 Silverstar *tin* and 11 W lines) for which variation in height and days required to reach anthesis date were minimized, to reduce the confounding effect of these two major traits. A subset of 6 lines was used in 2007 Rainout shelter experiments. All plots were machine planted and harvested (with trimmed ends and plot lengths measured) averaging 6 m long and 7 rows wide with a row spacing of 0.25 m. Rainout shelter experiments were manually harvested at maturity. Quadrats (0.125-0.5 m^2) for biomass and tiller counts were taken at various developmental stages throughout the season. Anthesis dates, grain yield and yield components, and grain screenings based on industry standards (40 shakes on Agtator with 2mm slotted sieve) were determined. For each line, kernel weight was determined for a random sample of 300 grain.

Established plant density ranged from 74 to 157 plants / m^2. Apart from 2005 experiments which were augmented design all other experiments were randomised complete block designs with two (2006) and three (2007) replications. Sown into dry soil the Gatton and Kingsthorpe experiments were irrigated (41-63 mm) to ensure good plant establishment. The Gatton irrigated trial received an additional 54mm irrigation between rainfall events (34mm) pre-anthesis, with 107 mm rainfall occurring post-anthesis.

Results

Head Number

The incorporation of the *tin* gene reduced head number per unit area in Silverstar lines, in all experiments (Table 1). On average, Silverstar free-tillering lines produced between 305 and 542 heads/ m^2 depending on experiment; in contrast *tin* lines produced between 197 and 385 heads/ m^2. Therefore, Silverstar *tin* lines produced between 23% to 50% less heads per unit area than free-tillering lines.

Table 1: Experiment code, year, locations, post-anthesis stress type and head number per unit area of free-tillering (W) and reduced (*tin*) tillering Silverstar lines grown in 10 Queensland field experiments between 2005-2007.

?	?	?	Post-anthesis	Head number per m^2		
Experiment code	Year	Location	Stress	W	*tin*	Reduction due to *tin*(%)
05GAT	2005	Gatton	None	337 ? 24.8	258 ? 18.7	23
06GATI	2006	Gatton	None	477 ? 15.0	261 ? 21.1	45
06GATS	2006	Gatton	None	521 ? 18.7	383 ? 20.2	27

07C	2007	Gatton	None	542 ? 35.1	385 ? 39.2	29
06EMN	2006	Emerald	mild	363 ? 10.9	252 ? 17.4	30
06EMW	2006	Emerald(WR)	mild	305 ? 12.0	197 ? 12.6	35
07MS	2007	Gatton	mild	485 ? 24.3	315 ? 19.5	35
05KIN	2005	Kingsthorpe	Severe	401 ? 21.5	281 ? 21.8	30
06KIN	2006	Kingsthorpe	Severe	463 ? 13.5	230 ? 28.8	50
07SS	2007	Gatton	Severe	384 ? 23.0	285 ? 24.5	26
Mean all				428	285	33
Mean stress experiments		?	?	400	260	35

WR indicates wide row spacing (0.5m)

Kernel weight, screenings and grain yield

In the experiments that suffered post-anthesis water stress, the KW advantage of *tin* lines ranged from 3 to 36% (Table 2). The larger kernel weight of *tin* lines translated to between 13 and 53% reduction in screenings produced compared with free-tillering lines. A negative genotypic relationship exists between KW and SCR (Mitchell *et al.* 2008; Sharma and Anderson 2004). Under mild stress conditions there was no difference in average GY of *tin* and free-tillering Silverstar lines; an observation also made in southern and western regions (Duggan *et al.* 2005; Whan 1988). However, under severe stress conditions in Kingsthorpe the GY reduction due to *tin* lines was 23 and 26%. This was due in part to low head number of *tin* lines relative to free-tillering lines. This GY penalty was not observed in 2007 Gatton severe terminal stress trial where *tin* lines achieved head number around 300 heads/m^2.

Table 2: Kernel weight (mg), screenings (%) and grain yield (t/ha) of free-tillering (W) and reduced (*tin*) tillering Silverstar lines grown in 10 Queensland field experiments between 2005-2007.

?	Kernel weight (mg)			Screenings (%)			Grain yield (t/ha)		
Experiment	W	*tin*	Advantage of *tin* (%)	W	*tin*	Advantage of *tin* (%)	W	*tin*	Advantage of *tin* (%)
05GAT	31.0 ? 2.3	30.9 ? 2.5	-3	7.4	8.3	12	3.6 ? 0.6	3.7 ? 0.7	3

06GATI	30.9 ? 1.1	33.8 ? 1.1	10	4.1	4.3	6	6.0 ? 0.7	4.9 ? 0.7	-18
06GATS	29.4 ? 1.0	32.1 ? 1.0	9	6.7	5.1	-24	5.2 ? 0.3	4.6 ? 0.3	-11
07C	31.3 ? 0.5	31.6 ? 0.7	1	3.6	5.7	58	6.1 ? 0.2	5.0 ? 0.2	-18
06EMN	22.8 ? 1.5	23.6 ? 1.4	3	21.7	18.9	-13	2.6 ? 0.2	2.7 ? 0.2	3
06EMW	22.9 ? 1.0	25.9 ? 1.0	13	21.2	17.7	-17	2.1 ? 0.1	2.2 ? 0.1	4
07MS	23.5 ? 0.4	26.4 ? 0.8	12	13.0	8.9	-32	4.1 ? 0.2	4.1 ? 0.2	1
05KIN	18.3 ? 0.9	20.9 ? 0.9	14	16.4	8.9	-46	2.7 ? 0.2	2.0 ? 0.2	-26
06KIN	20.4 ? 1.5	27.6 ? 1.5	36	24.9	11.8	-53	2.7 ? 0.3	2.0 ? 0.3	-23
07SS	21.8 ? 0.5	24.9 ? 1.0	14	14.5	10.6	-27	2.9 ? 0.3	2.7 ? 0.3	-6
Mean all	25.3	27.8	11	13.4	10	-14	3.8	3.4	-9
Mean stress	21.6	24.9	15	18.6	12.8	-31	2.8	2.6	-8

Averaged across the experiments, a negative association (r^2=0.41) existed between mean KW and GY, with *tin* lines tending to maintain higher KW and lower GY compared to free-tillering lines. However, a number of *tin* lines consistently performed well and maintained a high KW with relatively high GY.

Crop value – cost/benefit analysis

The estimated crop value was determined for the top yielding line from each group (*tin* and free-tillering) in the 2007 control, mild and severe stress experiments. These experiments were utilised for this purpose because terminal stress developed which resulted in the production of SCR, and GY achieved by *tin* lines was comparable to free-tillering lines with relatively high established head number (≈300 heads/m^2). Crop value was determined using the Base Rates from the AWB Golden Rewards Pool pricing (www.awb.com.au/growers) and the increments /decrements based on SCR, protein and moisture percent (Table 3). Base Rates were moderately high ($448.35/t) from 2007/2008 and relatively low ($216.50/t) from 2004/2005 seasons.

In the high yielding favourable conditions (2007 control), lower SCR (3 vs. 9%) and the 1.0 t/ha yield advantage of free-tillering lines results in a $583 and $332/ha advantage in crop value at high and low base rates respectively. In contrast, under mild stress conditions when there was essentially no GY difference, and SCR generated by free-tillering lines result in a downgrading from Australian Prime Hard (APH) to Australian Utility Hard (AUH), the *tin* lines produced an $ 87 and $45/ha advantage in crop value at high and low base rates respectively. This crop value advantage of *tin* lines became even greater, up to $313 and $126/ha, when under severe stress conditions where free-tillering lines are downgraded to feed quality as a result of >15% SCR. When GY potential for a given environment was not realized eg *tin* lines in 2005 and 2006 Kingsthorpe experiments, due to low head number (257 and 192 heads/m^2), free-tillering lines achieved higher crop values (data not shown). In the 2005 and 2006 Kingsthorpe experiments the price reduction due to SCR was not offset by the yield advantage of free-tillering lines. Generally, a GY advantage and therefore economic advantage was also observed for free-tillering lines in favourable environments.

Conclusion

In the Silverstar material there appears to be a distinct advantage of *tin* in maintenance of KW and subsequent reduction in SCR in terminal stress environments, such as those often experienced in the northern and western Australian production environments. There was evidence to suggest that *tin* was associated with a GY penalty when less than ≈300 heads per m^2 was achieved. However, in all environments tested particular *tin* lines were found to achieve high KW with the maintenance of high GY. From the results of the simple cost/benefit analysis it would appear that the use of *tin* lines in the northern region, where terminal water stress is frequently encountered, could be of considerable value to the farmer, provided that similar GY to that of free-tillering lines can be achieved.

Table 3: Grain yield; grain protein; and screenings (and based on these); pool pay grade with base rate; and increment adjustments (based on protein, screenings and moisture); Providing estimated pool return per tonne; and overall crop value, for the highest yielding *tin* and W Silverstar lines in 2007 control, mild and severe terminal stress experiments.

Experiment	Control		Mild stress		Severe stress	
Group	*tin*	W	*tin*	W	*tin*	W
Line	SsrT65	SsrW35	SsrT65	SsrW35	SsrT17	SsrW35
Grain yield (t/ha)	5.7	6.7	4.9	5	4.1	4.4
Grain protein (%)	11.4	11.5	13	12.5	13.4	14
Screenings (%)	9	3	8	14	10	15

Pool Pay Grade#	APH	APH	APH	AUH	APH	FEED
Base rate (2007/2008 Season)	448.35	448.35	448.35	432.85	448.35	352.4
+/- Protein, Moisture & Screening Increment	-24.5	-9.5	-6.5	-19	-6	0
Estimated Pool Return ($/t)	423.85	438.85	441.85	413.85	442.35	352.4
Crop Value ($/ha)	2711	3293	2400	2313	2041	1729
Base rate (2004/2005 Season)	216.5	216.5	216.5	204	216.5	170
+/- Protein, Moisture & Screening Increment	-19	-4	-6.5	-8	-8.5	0
Estimated Pool Return ($/t)	197.5	212.5	210	196	208	170
Crop Value ($/ha)	1263	1595	1141	1095	960	834

APH, Australian Prime Hard; AUH, Australian Utility Hard; FEED, feed quality

References

Acreche MM and Slafer GA 2006. Grain weight response to increases in number of grains in wheat in a mediterranean area. Field Crops Research 98, 52-9.

Chenu K, Hammer GL, Dreccer F and Chapman SC 2009. Environment characterisation as an aid to wheat improvement in north east Australia. 14th Australasian Plant Breeding & 11th SABRAO Conference, Cairns, Australia, 10-13 August 2009.

Duggan BL, Richard, RA, van Herwaarden AF and Fettell NA 2005. Agronomic evaluation of a tiller inhibition gene (tin) in wheat. I. Effect on yield, yield components, and grain protein. Australian Journal of Agricultural Research 56, 169-78.

Fischer RA 2008. The importance of grain or kernel number in wheat: A reply to sinclair and jamieson', Field Crops Research 105, 15-21.

Fischer RA and Hillerislambers D 1978. Effect of environment and cultivar on source limitation to grain weight in wheat', Australian Journal of Agricultural Research 29, 443-58.

Mitchell JH, Chapman S, Rebetzke GJ and Fukai S 2008. Increasing grain size and reducing screenings in wheat using a tiller inhibition gene - investigating grain morphology by image analysis. In Global Issues: Paddock Action. Proceedings of the 14th ASA Conference, Adelaide, South Australia, 21-25 September 2008.

Richard, RA 1988. A tiller inhibitor gene in wheat and its effect on plant-growth. Australian Journal of Agricultural Research 39, 749-57.

Sayre KD, Rajaram S and Fischer RA 1997. Yield potential progress in short bread wheats in northwest mexico', Crop Science 37, 36-42.

Sharma DL and Anderson WK 2004. Small grain screenings in wheat: Interactions of cultivars with season, site, and management practices. Australian Journal of Agricultural Research 55, 797-809.

Spielmeyer W and Richards RA 2004. Comparative mapping of wheat chromosome 1as which contains the tiller inhibition gene (tin) with rice chromosome 5s. Theoretical and Applied Genetics 109, 1303-10.

Whan BR, Delane R. and Gilmour R 1988. The potential of reduced tillering wheats in dry environments. Seventh International Wheat Genetics Symposium, Cambridge, England, 13-19 July.