Reduced-tillering wheat lines maintain kernel weight in dry environments

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Abstract

Water stress, particularly after anthesis, provides a major limitation to wheat production, particularly in the northern wheat belt of Australia where crops are largely grown on stored soil moisture. Combined with rising temperatures during grain-filling, water stress often leads to the development of small or shrivelled kernels ('screenings'). While drought-affected yield directly limits farm profit, the value of the crop is further reduced when percent screenings is high.

In a series of dryland field experiments we investigated the value of the tiller inhibition (*tin*) gene to maintain greater kernel weight under water stress. From two genetically contrasting backgrounds (Kite and Banks) pairs of near isogenic lines that were freely-tillering or contained the *tin* gene were established at three densities (20, 50, 100 plants/m^2). The aim was to identify whether, for a given spike number/m^2, kernel weight is greater in *tin* than freely-tillering lines. An evaluation trial, conducted in a terminal water stress environment, examined sister lines derived from three contrasting genetic backgrounds incorporating the *tin* gene, and which consequently contrasted for high and low tiller potential.

Under a severe pre-anthesis water stress (-3.4MPa), Kite+*tin* maintained a greater kernel weight (40mg) and similar grain yield (214g/m^2) compared to free-tillering Kite (35mg and 221g/m^2). The expression of the *tin* gene was less in Kite+*tin* (max. of 5 stems/plant) compared with Banks+*tin* (max. of 3.5 stems/plant). Preliminary results from the evaluation trial indicate that reduced-tillering lines have potential to maintain kernel weight and reduce grain screenings under terminal water stress conditions. On average there was a reduction in yield due to low grain number, however selection for grain yield in material incorporating the *tin* gene may result in simultaneous improvements in grain yield and kernel weight.

Key Words

drought, spike number, *tin* gene, screenings

Introduction

In cereals, selection for increased grain yield has largely been associated with increased grain number per unit area, due to the high genetic variability of grain number and its strong genetic correlation with grain yield. In contrast, kernel weight is considered a relatively stable yield component with small genotypic variation (Fischer and HilleRisLambers 1978). Following many years of selection, especially in higher input environments, there has been a tendency for modern wheat varieties to produce a large number of grain, which tend to have a smaller kernel weight even under non-limiting conditions. When these lines are exposed to a water deficit, particularly a post-anthesis terminal water stress, as often experienced in the northern region, small kernels commonly result. A negative relationship exists between kernel weight and screenings (Sharma and Anderson 2004). Hence, high screenings can be a problem in these environments. van Herwaarden et al (1998) suggested that there may be value in incorporating the reduced-tillering *tin* gene into adapted germplasm with the aim of maintaining large kernel size and reducing the incidence of screenings. The *tin* gene tends to result in larger stems, higher harvest index and increased kernel weight (Richards 1998; Duggan et al 2005).

Methods

Physiological study

A dryland experiment was conducted at Gatton (elevation 91m, 27?33'S, 152^{o}20'E), SE Queensland to assess the performance of two genetically contrasting sets (Kite and Banks) of near-isogenic lines containing the *tin* gene. Seed was machine sown on May 27 2005 in 6m long plots (22 cm row spacing ? 8 rows) in a randomised complete block design with three replications and thinned to establish three plant densities (20, 50, and 100 plants/m^2). Quadrats (0.125 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. Leaf water potential measurements were taken to assess the degree of water stress.

Evaluation trial

A dryland evaluation trial was sown on July 11 2005 at Kingsthorpe (27?28'S, 151^{o}49'E) near Toowoomba, to examine the performance of 98 sister lines segregating for tiller production based on back-crossing the *tin* gene in three genetic backgrounds (Silverstar, Chara and Sunco). Plots were 6m long with 25cm row spacing, and were sown to establish a target plant population of 100 plants/m^2. Several quadrat cuts were taken through the season and machine harvesting occurred at maturity. Yield and yield components including screening data were obtained.

Results

Environments

The timing and pattern of water stress in relation to crop development is critical. Two contrasting environments were encountered. The Gatton trial experienced a severe pre-anthesis water stress so that it was only possible to obtain LWP readings from the lower density treatments at anthesis (-3MPa mean LWP at anthesis). Due to pre-anthesis stress there was considerable head tipping (upper spikelet sterility) and consequently reduced grain number. There had been no rain between 35 and 99 days after sowing. During mid to late grain-fill (September) 50mm rain assisted filling of grain that had set, resulting in a relatively large kernel weight and small percentage screenings.

In contrast, the Kingsthorpe trial was sown relatively late, on a full profile of water, and the crop was able to set a large number of grain. However, rising temperatures, the lack of spring rainfall and the large number of grain set resulted in this sowing producing relatively small grain and high screenings. This crop experienced a typical post-anthesis terminal water stress.

Density trial

As expected, freely-tillering lines increased their stems per plant to a maximum of 7 (Banks) or 8.5 (Kite) prior to anthesis and declined thereafter (Figure 1). The *tin* lines followed a similar pattern but not to the same extent as the free-tillering lines. The expression of the *tin* gene in Kite was less than that of Banks. Kite+*tin* was able to produce a maximum of five stems, whilst Banks+*tin* produced only 3.5. This genetic control of stem number per plant, through the incorporation of the *tin* gene, was maintained at all densities (data not shown).

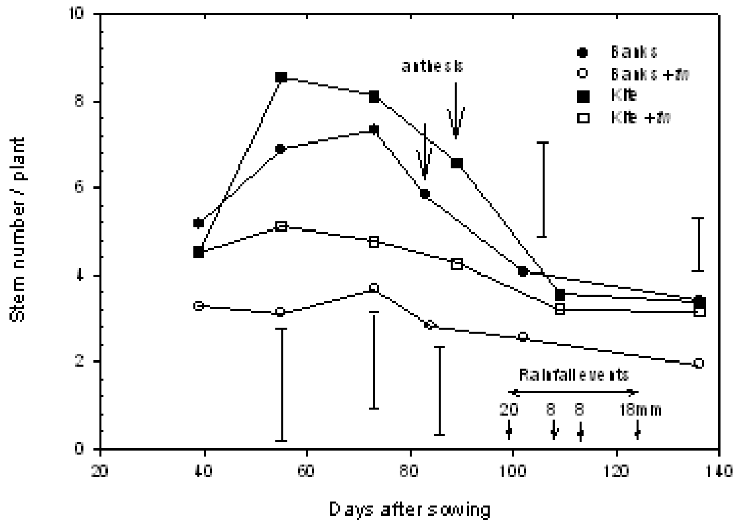

Figure 1. Stem number per plant for *tin* (+*tin*) and freely-tillering lines of Banks and Kite throughout the season at a density of 100 plants per m^2 at Gatton (anthesis and rainfall events indicated by arrows).

With increase in plant density, grain yield increased in reduced-tillering lines, but decreased in free-tillering lines (Figure 2a). The latter result was due to the fact that the freely-tillering lines in the high density treatments experienced a more severe degree of pre-anthesis water stress (as reflected in LWP values < -4MPa) and this reduced grain number relative to the lower densities (from high to low density, Banks: 9578, 11145, 11433 grains/m2, Kite: 4459, 6379, 8250). Consequently, high density treatments resulted in lower grain yield. This did not occur in the *tin* lines (Banks+*tin*: 8934, 8149, 3343 grains/m2, Kite+*tin*: 6430, 6029, 3997). Rather the lowest density treatment was unable to maintain grain number because of the low spike number per m^2.

Line and line ? density effects were significant for kernel weight. Kite+*tin* maintained the highest kernel weight across all densities while Banks had consistently low kernel weight (Figure 2b). The *tin* lines had high kernel weight relative to their freely-tillering counterparts and this was associated with fewer grain number per m^2, particularly at the low density treatment.

Although not significant, evidence exists that Kite was able to maintain a higher kernel weight for a given spike number than free-tillering Kite (Figure 3). Banks+*tin* produced so few tillers that it was not possible to make this comparison with Banks freely-tillering counterpart for a comparable spike number.

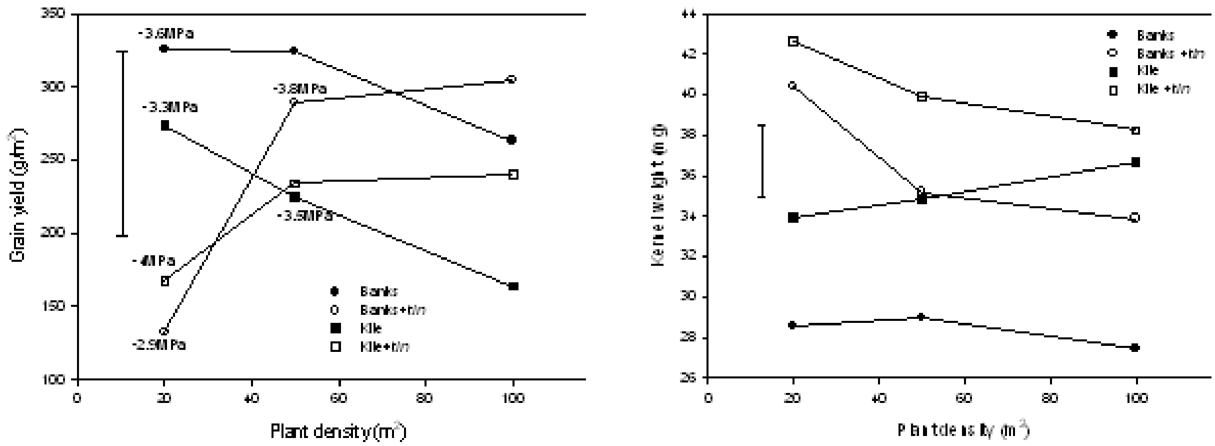

Figure 2: a) Grain yield (g/m^2) and anthesis LWP readings and b) Kernel weight (mg) for *tin* (+*tin*) and freely-tillering lines of Banks and Kite at 20, 50 and 100 plants per m^2 grown under dryland conditions (pre-anthesis stress) at Gatton 2005.

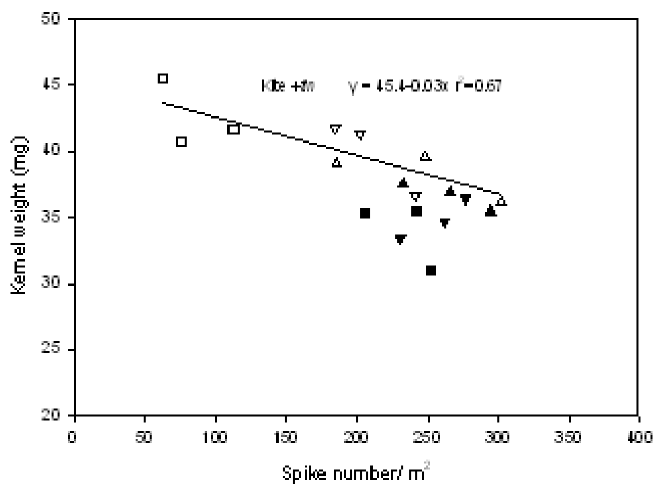

Figure 3: The relationship between kernel weight and spike number per m^2 for *tin* (+*tin;* open symbols*)* and freely tillering (closed symbols) lines of Kite at 20 (■), 50(▼) and 100 (▲) plants per m^2 grown under dryland conditions (pre-anthesis stress) at Gatton 2005.

Head-tipping contributed to maintenance of kernel weight. As a result of reduced fertile grain (tip of head sterile), combined with rainfall events mid grain-filling (*c.* 50mm) those grain that remained in the central and lower portion of the spike could fill increasing average kernel weight. This compensatory ability of grain within the spike was observed by Rawson and Evans (1970) in which sterilization of individual florets in the central spiklets resulted in complete compensation in grain number and weight per spike through the successful development of third and fourth grains in the spikelet. In *tin* lines, the lowermost spikelets, which are usually sterile, often bore some grains. As a result of large kernel weight from post-anthesis rains, screenings were at a minimum. Banks produced between 3.5 and 5.2% screenings, while Banks+*tin*, Kite and Kite+*tin* were all below 1%.

Evaluation trial

There was significant variation in kernel weight among lines grown at Kingsthorpe (Table 1). There was a tendency for +*tin* lines to produce higher kernel weights; this increase reflecting a reduction in spike and kernel number per m^2. The +*tin* lines produced only *c.* 70% of the grain number of the free-tillering lines. The increase in kernel weight with *tin* could not compensate for reduced grain number and therefore grain yield was reduced markedly. However, percent screenings were nearly halved from 16% to 9% through the increase in kernel weight with the *tin* gene. The +*tin* lines may have achieved higher yield had they been sown at a higher plant density to increase spike number per m^2 .The trial was sown late and consequently the freely-tillering lines did not produce as many tillers as they potentially may have with a longer growing season. Nevertheless the value of the +*tin* lines was quite substantial in reduction in screenings. Data from additional trial sites in NSW and South and Western Australia are being analysed.

Table 1: Mean grain yield (Gy, g m^{-2}); kernel grain weight (Kgw, mg), maturity head number (Mhn, m^{-2}), grain number (Gn, m^{-2}), screenings (Scr, %), stem number per plant (Snp, no. $plant^{-1}$), grain number per stem (Gps, no. stem-1), anthesis (ANT, days after sowing(DAS)), maturity total dry matter (MTDM, g/m^2) ? standard error for sister lines grown at Kingsthorpe.

Trait	Check lines (n=22) (including parents)	*tin* lines (n=21)	Free-tillering lines (n=25)
Gy (g/m^2)	283 ? 6.8	215 ? 13.2	281 ? 7.4
Kgw (mg)	20.0 ? 0.5	21.1 ? 0.5	18.7 ? 0.5
Mhn (m^2)	445 ? 16	311 ? 19	428 ? 15
Gn (m^2)	14256 ? 365	10431 ? 736	15284 ? 529
Scr (%)	10.7 ? 1.2	8.8 ? 0.6	16.0 ? 1.1
Snp (no./plant)	6.9 ? 0.4	5.0 ? 0.4	6.1 ? 0.2
Gps (no./stem)	35.5 ? 1.6	36.1 ? 1.9	39.3 ? 1.6
ANT (DAS)	86 ? 1.2	84 ? 0.9	83.0 ? 0.6
MTDM (g/m^2)	864 ? 26	783 ? 27	859 ? 30

Conclusion

There is good evidence from these experiments that the *tin* gene can assist the maintenance of kernel weight in pre-anthesis and post-anthesis water stress environments, but the effects of *tin* on yield are highly variable, and may depend on the timing of water stress. The density treatments generated environments that differed in the degree of pre-anthesis water stress. The +*tin* lines maintained larger kernel weight at all densities and, except for the low density treatment (least stressed environment), at least equivalent grain yield to free-tillering lines. Thus, with water stress beginning well before anthesis, there was strong evidence that +*tin* lines grown at appropriate plant densities will achieve a similar grain yield to free-tillering lines, whilst maintaining a larger kernel weight. The Evaluation Trial, sown late in the season, encountered post-anthesis, terminal water stress. In this environment, +*tin* lines again had greater kernel weight than free-tillering lines but their average yield was much less because they failed to generate sufficient grain number. There is the possibility that selection for grain yield in material incorporating the *tin* gene may result in simultaneous improvements in grain yield and kernel weight. Results from these trials indicate that the expression of the *tin* gene is genotype-dependent, being stronger in some backgrounds than others. It has been suggested that a possible target for breeding could be +*tin* lines that produce 4-6 stems per plant, as opposed to more extreme uniculm or biculm morphotypes, as this may enable the potential for maintaining grain number in the absence of pre-anthesis stress at the plant densities used in Australian wheat production. This suggestion is not strongly supported by the preliminary results of the Evaluation trial, analysis including other environments will provide more conclusive results.

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