

# Spring wheat lines contrasting in stem water soluble carbohydrate concentration: growth, nitrogen absorption and partitioning

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## ABSTRACT

We studied a small set of recombinant inbred lines contrasting in stem water soluble carbohydrates (WSC) concentration across a range of environments ranging from moderate water stress to fully irrigated. The aim was to check for consistency in genotypic rankings and potential trade-offs between WSC storage, grain number and yield. The pattern of WSC concentration was modulated by water availability, with rainfed trials reaching maximum levels before anthesis. Early sown irrigated trials seemed the best option to discriminate lines for WSC concentration for selection purposes since genotypic differences were already detectable at anthesis and observed until late grain filling.

High WSC lines achieved similar or greater yields than their low WSC counterparts; their relative advantage was larger in irrigated compared to rainfed trials. High WSC lines had a lower grain number per unit area linked to a lower number of spikes and stems per unit area, fewer but heavier spikes and lower grain number per unit spike weight. The observed changes in plant type behind the high WSC phenotype were accompanied by higher potential and attainable individual grain weight.

## INTRODUCTION

In wheat, water soluble carbohydrates (WSC) stored in the stems have been acknowledged as contributing to maintenance of grain filling rate when photosynthesis declines due to various stresses, e.g. drought (Palta et al., 1994), heat stress (Blum et al., 1994) and possibly disease (Blum, 1998). Genetic variation exists for WSC accumulation in the stems at anthesis and it has been suggested that breeding for high WSC should be possible due to its high heritability (Ruuska et al, 2006).

In the context of selection, it is important to determine if there would be any negative consequences to yield or its components if stem WSC concentration was positively selected for. In this study we investigated potential trade-offs between WSC storage, grain number and yield. We monitored biomass, N and WSC concentration (WSCc, mg WSC g<sup>-1</sup> dry weight) and amount (WSCa, g m<sup>-2</sup>) in a small set of recombinant inbred lines (RILs) contrasting in stem WSC level, across a broad range of

environments ranging from moderate water stress to fully irrigated.

## MATERIAL AND METHODS

The RILs were part of the Seri/Babax population described by Olivares-Villegas et al. (2007) and had shown transgressive segregation for stem WSCc at anthesis (SB003 and SB010: low WSCc, SB062 and SB169: high WSCc) but otherwise similar anthesis date and height. Genetic map and QTL information (McIntyre et al., 2006) was used to select the two lines of each group such that they were as genetically diverse as possible.

In 2006, six field trials were conducted at the CSIRO experimental station in Gatton (Queensland, 27.55°S lat, 152.33°E long) at several planting dates and combinations of irrigation and nitrogen supply (Table 1). Individual seed weights were used to target 150 plants m<sup>-2</sup> for each genotype. Bordered biomass cuts were made during the crop cycle, depending on the trial, at the start of stem elongation, booting, anthesis or 100°Cd after anthesis, early grain filling, mid-late grain filling (ca. 450°Cd after anthesis) and maturity. Plants were dissected in organs, green leaf area measured, and harvest index calculated on a dry weight basis at maturity. At heading, individual spikes from main stems or first cohort tillers were tagged. These were used to collect data on the number of fertile florets, grain set and grain growth rate. Light interception was calculated from radiation measurements with a ceptometer. In the rainout-shelter experiments soil water was measured with a neutron moisture meter. The levels of total water soluble were determined as in van Herwaarden et al. (1998). Nitrogen was determined by combustion analysis.

The potential maximum contribution of WSC to grain was calculated as the maximum stem WSCa minus WSCa at maturity. Remobilisation efficiency was calculated as '1 - WSCaMaturity / WSCaMaximum'. An estimate of structural biomass in the stems at anthesis was calculated as the anthesis stem biomass minus the protein and the WSCa.

Table 1. Trials, treatments and experimental design

Trials	Sowing date	Watering regime	Treatments	Design
ROS-1SD	6 <sup>th</sup> June, 2006	Initial soil water; rain-out shelter	Genotypes: SB003 (low WSC) and SB062 (high WSC)	RBD, 4 reps.
ROS-2SD	17 <sup>th</sup> July, 2006	Initial soil water; rain-out shelter	Genotypes: SB003 and SB062	RBD, 4 reps.
IRR-1SD	6 <sup>th</sup> June, 2006	Fully irrigated	Genotypes: SB003 and SB062	RBD, 3 reps.
IRR-2SD	17 <sup>th</sup> July, 2006	Fully irrigated	Genotypes: SB003 and SB062	RBD, 3 reps.
NRFED	14 <sup>th</sup> June, 2006	Rain fed	Genotypes: SB003, SB10, SB062, SB169 Nitrogen: 176 (high) and 90 (low) kg ha <sup>-1</sup>	RBD, 3 reps.
NIRR	23 <sup>rd</sup> May, 2006	Rain plus tactical irrigations	Genotypes: SB003, SB10, SB062, SB169 Nitrogen: 262 (high) and 158 (low) kg ha <sup>-1</sup>	RBD, 4 reps.

Figure 1. Grain number per m<sup>-2</sup> vs. WSC concentration in stems plus sheaths around anthesis (a) and WSC concentration in stems plus sheaths around anthesis vs. stem number m<sup>-2</sup> at the same time. In (b) arrows point from SB062 to SB003, dashed arrow indicates NIRR and full arrow is for IRR-2SD.

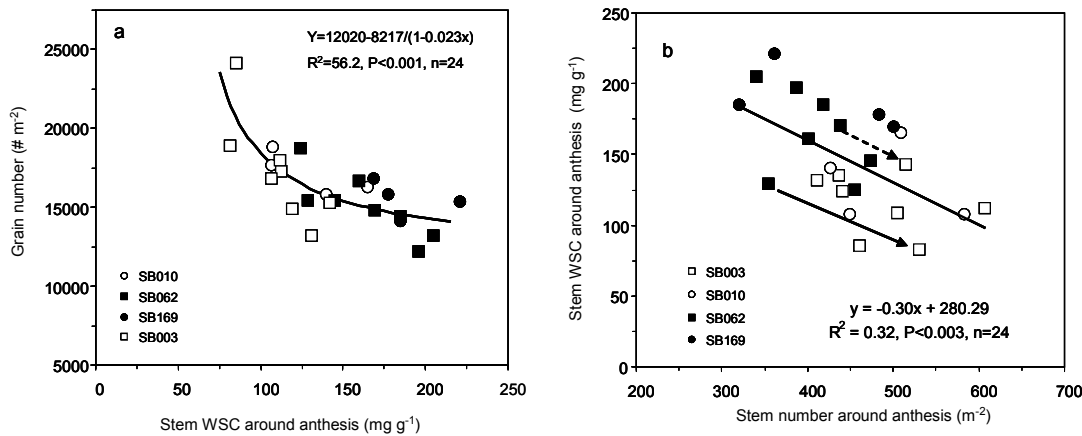
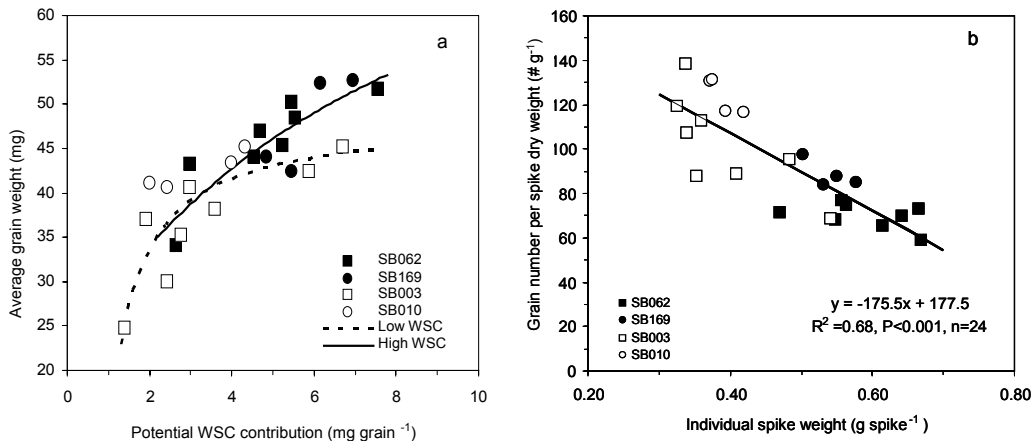


Figure 2. Potential contribution of WSC per grain to average individual grain weight (a) grouped regression n=22, R<sup>2</sup>=76.4, P<0.001; grain number per spike weight vs individual spike dry weight (a).



## RESULTS AND DISCUSSION

The WSCc in stems around anthesis was lower in SB003 and SB010 than in SB062 and SB169, consistent with previous observations. The pattern of WSC deposition was modulated by water availability. Rainfed crops reached the peak of WSCc before anthesis, when some internodes were still elongating, as observed by Goggin

and Setter (2004). In irrigated crops, the stem WSCc peak was generally reached during grain filling, up to 400 °Cd (Tb=0°C) after anthesis. Early sown irrigated field experiments can be used to extend the window of sampling opportunities to establish genotypic rankings for WSCc for up to ca. 20 days after anthesis in our environments.

The classification of genotypes according to WSCc had significant effects for the majority of yield related attributes. Yields spanned from ca. 4.6 to 8.5 t ha<sup>-1</sup>, with high WSC lines yielding similarly or up to 18% more than low WSC lines. This trend was not based on differences in total biomass production but in harvest index. Consistently across trials, high WSC lines had 8 to 22% lower grain number per unit area and 17 to 51% higher average individual grain weight compared to low WSC lines. The lower number of grains per unit area in high WSC lines was a result of the lower number of spikes per unit area, which was not compensated by their slightly higher number of grains per individual spike as calculated at maturity.

Features of stem WSC deposition that could have compromised grain number determination are, its timing with respect to the spike growth period and the accumulation of WSC in the peduncle. We found no evidence of a trade off between WSC accumulation (g m<sup>-2</sup>) and attainable or potential yield, despite the negative association between the grain number per m<sup>2</sup> and stem WSCc at anthesis (Figure 1a). Each spike in high WSC lines was not necessarily C or N limited because (a) high WSC lines also had a lower number of stems per m<sup>2</sup> (Figure 1b) and (b) on a per stem basis, high WSC lines had both higher WSCa, heavier spikes with higher N amount and concentration, and more fertile florets and grains per spike (data not shown). The lower tiller number range observed in the high WSC lines could be interpreted as a conservative strategy that maximises the amount of resources per stem and results in a cascade of effects, such as higher WSC per stem (Figure 1b) and more grains per spike. The degree of variation in stem WSCc observed at a particular stem number per m<sup>2</sup> at anthesis was expected, not only because of the range of environments involved but also because by anthesis, remobilisation was already underway in rainfed trials (examples of irrigated trials illustrated with arrows in Figure 1b). While differences in tillering may not be the only mechanism involved (Xue et al., 2008), its stability makes it a candidate to help explain the observed high heritability of stem WSCc (Ruuska et al., 2006). A similar phenotype, high stem WSCc-few stems has been reported to perform well under drought (Dreccer et al., 2008) or maintains high grain filling rates (Triboi and Ollier, 1991).

The potential contribution of WSC to grain yield was greater in high WSC lines and in early sown irrigated trials (data not shown); high WSC lines had both higher WSCa and remobilisation efficiency. The observed changes in plant type behind the high WSC phenotype were accompanied by higher potential and attainable individual grain weight. Individual grain weight, from the average pool or at particular positions within central spikelets (data not shown), was greater in high WSC lines (Figure 2a). Interestingly, low WSC lines attained a lower final grain weight compared to high WSC ones at greater levels (>5 mg grain<sup>-1</sup>) of potential WSC contribution per grain (Figure 2b). This supports the

hypothesis that high WSC lines may have a higher potential grain weight per se, hence able to translate WSC into higher grain weight. High WSC lines had a lower grain number per unit spike weight at anthesis (Figure 2b). Whether this could account for structural differences in the spike, such as larger vascular bundles, allowing larger or faster delivery of sugars to the grains is worth testing. Trials are being conducted to determine if the WSCc varies genetically with planting density.

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