Water-soluble carbohydrates and yield in wheat

Anthony van Herwaarden[1], Richard Richards[2] and John Angus[2]

[1]CSIRO Plant Industry, 120 Meiers Road, Indooroopilly, QLD 4068 www.pi.csiro.au Email Anthony.van.Herwaarden@csiro.au
2 CSIRO Plant Industry, GPO Box 1600, Canberra, ACT 2601 www.pi.csiro.au Email Richard.Richards@csiro.au , John.Angus@csiro.au

Abstract

Pre-anthesis accumulated water-soluble carbohydrates (WSC) in wheat provide an alternative source of assimilates to current photosynthesis for grain filling. When photosynthesis is reduced during terminal drought, pre-anthesis WSC can contribute significantly to grain yield. Field experiments were conducted at 8 sites in southeastern Australia to investigate factors affecting accumulation and mobilisation of water-soluble carbohydrates in Janz wheat. The largest single environmental or management factor contributing to variation in WSC accumulation was tissue protein concentration. Other factors that affected WSC in these experiments, were general standard of crop health and nutrition, but no assessment of genetic variation was made . In another experiment at Ginninderra Experiment Station, genetic variation in the accumulation of WSC was assessed under non water-limiting conditions in 80 spring wheat cultivars from Australia and overseas. The level of WSC at anthesis ranged from 150 g/m^2 to 350g/m^2, or 15 to 25% of the above-ground biomass. There was no association between WSC and anthesis date. In another series of 6 experiments across south-eastern Australia over 3 years, reduce-tillering breeding lines were compared with commercial freely tillering cultivars at yield levels ranging from 1.5 to 7.0 tonnes/ha. Reduced tillering genotypes accumulated 20% more WSC and outyielded locally adapted varieties, on average, by 10%, with a corresponding increase in kernel weight of 25 %. Genotypes with high stem WSC at anthesis are currently being used in the CSIRO wheat-breeding program to improve grain yield under water-limited conditions.

Key Words

Triticum aestivum, non-structural carbohydrate, fructan, stem reserves, storage, nitrogen

Introduction

Remobilisation of pre-anthesis assimilates is an important source of carbohydrate for grain filling of wheat (1) because post-anthesis drought and the low water-holding capacity of many cropping soils (2; 3) limit post-anthesis assimilation. Crops of high-N status have increased risk of haying-off due to higher water use and lower WSC reserves than crops of low-N status (1). Breeding for higher WSC has potential for increased yield under terminal drought (4; 5; 6). Studies comparing wheat cultivars (7) or cereal species (8) support this view. There is little information on the affect of crop management on the accumulation of WSC or the genetic variation for this trait in wheat. This paper describes the results of experiments undertaken to investigate management strategies to maximise WSC accumulation and to assess the genetic variation in WSC accumulation in wheat.

Methods

Field experiments to investigate the carbohydrate and protein dynamics in wheat crops were conducted during the 1990s throughout southeastern Australia at locations shown on the Figure captions. The experiments followed canola breakcrops (9) to minimise the detrimental effects of soil-borne disease on wheat growth and were managed as for high yielding commercial crops. Crop sampling was related to the decimal code (DC) of Zadoks et al. (10). From stem elongation onwards, crops were sprayed every 14 to 21 days with triadamefon fungicide to prevent the development of foliar disease. As each crop flowered (DC 65) a random sample of 40-70 culms was taken from crops according to the methods of van Herwaarden et al (11). Subsamples were counted for fertile spikes, dried at 70?C and the samples ground in a Wiley mill to pass a 1 mm sieve. N and WSC concentration were determined by the methods of van Herwaarden et al (1). Yield and yield components at maturity were determined by the methods of van Herwaarden et al (11).

Results and discussion

Management factors

Over 8 experiments, a low level of pre-anthesis water-soluble carbohydrate (WSC) reserves was the greatest single factor responsible for haying-off and concomitant high screenings of high-nitrogen wheat crops experiencing terminal drought (1). The lack of WSC in crops of high-N status can be explained by the negative association between protein concentration and WSC concentration in the above-ground biomass at anthesis (Fig. 1). This relationship is a result of the effects of nitrogen leading to greater investment into structural biomass due to increased tillering (12), stimulation of respiration due to additional protein (13), to inefficiencies within the denser canopies (5) and the use of carbon skeletons otherwise bound for storage in the stem for reduction of ammonium (1).

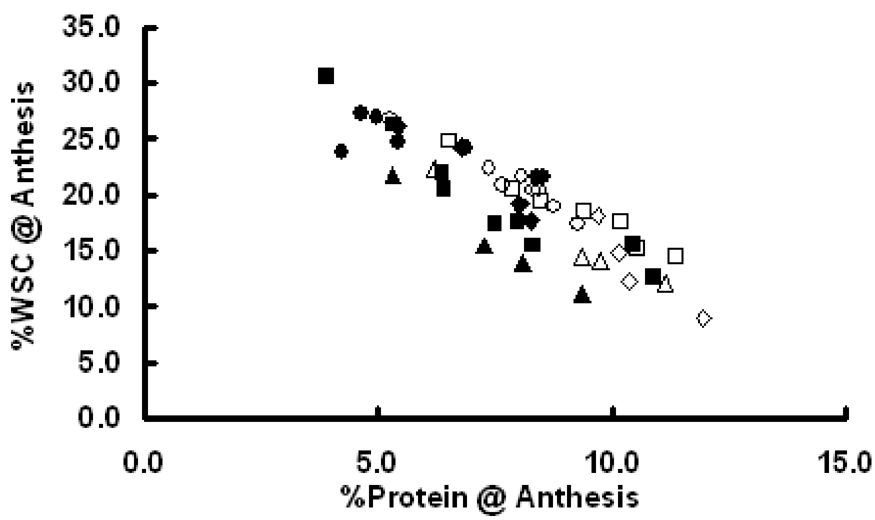

Fig. 1. Trade-off between WSC concentration and protein concentration in the above-ground biomass of Janz at anthesis for (□) Ginninderra 1991, (■)Ginninderra 1992, (○) Barellan 1991, (●) Barellan 1992, (Δ) Pucawan 1991, (▲) Wagga Wagga 1991, (◊) Harden-Murrumburrah 1996 and (♦) Ariah Park 1996.

Across the same environments as in Fig 1, when WSC and protein in the above-ground biomass at anthesis are summed together then they constitute 27?2.0% of the above-ground biomass (Fig. 2). This result suggests there is a direct substitution of assimilates between carbohydrate and protein.

Provided there is little or no water deficit, a dense, high-nitrogen crop can fill grain from current photosynthesis and need only call on WSC reserves during the periods of peak assimilate demand (12). However, in the event of post-anthesis drought and reduced current photosynthesis, the lack of WSC reserves results in haying-off. A low-nitrogen crop does not face the same severity of drought because lower anthesis biomass has resulted in reduced water use than for a high-nitrogen crop. Greater yield at low nitrogen is therefore achieved through longer duration of photosynthesis and greater reserves of pre-anthesis WSC (5). These results indicate that for crops targeting higher protein segregations management strategies and tactics which conserve soil water for the grain filling period and maximise the accumulation of pre-anthesis WSC will reduce the incidence of haying-off.

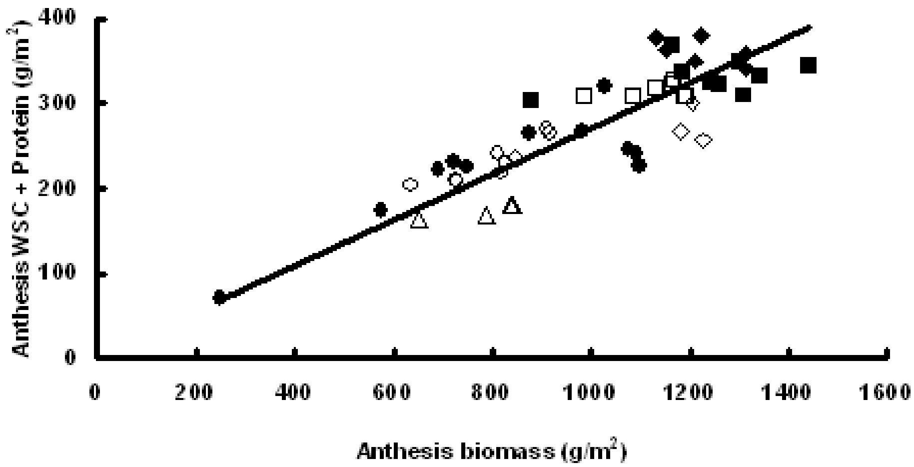

Fig. 2. Relationship between anthesis biomass and soluble reserves (WSC + protein) at anthesis for experiments grown in contrasting environments in south-eastern Australia 1991-96. y =0.27x r^2 =0.74. Relationship is forced through the origin, symbols as for Fig. 1.

Breeding strategies

Variation in the accumulation of WSC was assessed at anthesis in 80 spring wheats from Australian and overseas. The accumulation of WSC to anthesis varied from 150 g/m^2 to 350g/m^2 or 15 to 25% of the above-ground biomass (Fig. 3). The association between accumulation of WSC and anthesis date (-1.6 g/m^2/day) was not significant. In contrast, Foulkes et al (7) found a positive trend between accumulation of WSC and anthesis date. Phenotyping for WSC is time consuming and labour intensive so breeding populations have been made with the aim of developing molecular markers to streamline the breeding for high WSC accumulation.

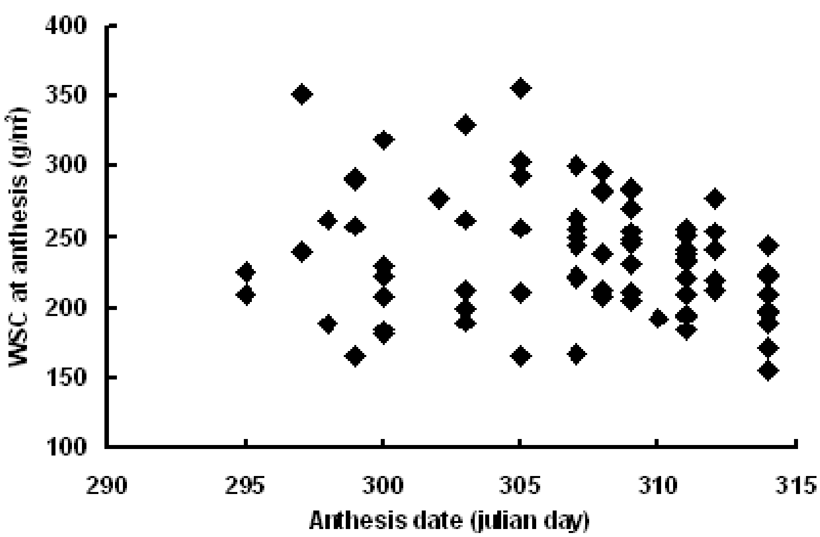

Fig. 3. Variation in accumulation of water-soluble carbohydrate to anthesis with date of anthesis for a collection of 80 wheats from Australia and overseas grown at Ginninderra, ACT in 1998.

van Herwaarden et al (5) proposed that the incidence of haying-off could be reduced by increasing the storage of WSC through reduction in the amount of structural biomass produced to flowering by incorporating genes for reduced tillering (14). When reduced tillering wheats were compared to locally adapted freely tillering commercial cultivars in contrasting environments across south-eastern Australia reduced tillering wheats had increased grain yield and kernel weight and this was associated with greater accumulation of WSC to anthesis (Table 1).

Table 1. Comparion of locally adapted, freely tillering cultivars s and reduced tillering breeding lines of wheat grown in 6 contrasting environments in southeastern Australia between 1996-98. Experiments were conducted in 1996 at Condobolin, NSW, in 1997 at Harden-Murrumburrah, NSW and in 1998 at Balaklava, SA, Birchip, Vic., Moombooldool, NSW and Stockinbingal, NSW.

Crop attribute	Wheat line		
	Freely tillering	Reduced tillering	P value
Grain yield (t/ha)	3.45	3.71	0.10
Kernel weight (mg)	33.7	39.5	0.01
Kernel number (‘000/m^2)	13.0	11.8	0.07
WSC at anthesis (t/ha)	1.88	2.26	0.08

Experiments are continuing to further investigate genotype-by-environment interaction for WSC accumulation, the most appropriate timing of sampling to screen for high WSC and the use of NIR to speed up phenotyping. The results of this of field experiments illustrate how increased physiological understanding of the constraints to yield can lead to new avenues for genetic improvement and improved crop management of current cultivars.

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References

(1) van Herwaarden, A.F., Angus, J.F., Richards, R.A. and Farquhar, G.D. (1998b) Aust. J. Agric. Res., 49: 1083-1093.

(2) Asseng, S., Keating, B.A., Fillery, I.R.P., Gregory, P.J., Bowden, J.W., Turner, N.C., Palta, J.A. and Abrecht, D.G. (1998) Field Crops Res., 57: 163-179.

(3) Sadras, V., Roget, D. and O’Leary, G. (2002) Aust. J. Agric. Res., 53: 587-598.

(4) Blum. A., Mayer, J., and Gozlan, G. (1983) Plant, Cell and Envir. 6: 219-225.

(5) van Herwaarden, A.F., Richards, R.A., Farquhar, G.D. and Angus, J.F. (1998c) Aust. J. Agric. Res., 49, 1095-1110.

(6) Asseng, S. and van Herwaarden, A.F. (2002) Plant Soil (In press)

(7) Foulkes, M.J., Scott, R.K. and Sylvester-Bradley, R. (2002) J Agric. Sci., 138: 153-169.

(8) Richards, R.A., Rebetzke, G.J., Condon, A.G. and van Herwaarden, A.F. (2002) Crop Sci. 42: 111-121.

(9) Angus, J.F., van Herwaarden, A.F. and Howe, G.N. (1991) Aust. J. Exp. Agric., 31: 669-677.

(10) Zadoks, J.C., Chang T.T., Konzak C.F. (1974) Weeds Res. 14: 415-421.

(11) van Herwaarden, A.F., Farquhar, G.D., Angus, J.F., Richards, R.A. and Howe, G.N. (1998a) Aust. J. Agric. Res., 49: 1067-1081.

(12) Spiertz, J.H.J. and Ellen, J. (1978). Neth. .J Agric. Sci. 26, 210-231.

(13) Amthor, J. S. (1989) Respiration and Crop Productivity. Springer-Verlag: New York.

(14) Richards, R.A. (1988). Aust. J. Agric. Res. 39, 749-757.