Yield formation of wheat in the high rainfall zone of south-western Australia

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Abstract

We examined the phenology, dry-matter accumulation and partitioning, and yield of five wheat genotypes in the high-rainfall zone of south-western Australia in two contrasting years (2006-a dry year and 2007- an average year). The genotypes differed in flowering date by up to 10 days in 2006 and 20 days in 2007. No clear relationships were found between grain yield and grains/ear, ear/m^2, and grains/m^2 in either year except kernel weight. Spike dry weight is positively correlated to the duration of spike growth period in both years. Pre-anthesis dry matter (DW_a) increased but post-anthesis dry matter (DW_{pa}) decreased with increased number of days to anthesis. With delayed flowering, grain yield declined in 2006 but no trend was detected in 2007. The number of grains per unit area was correlated to the duration of spike growth (r^2 = 0.98) and to spike dry weight at anthesis (r^2 = 0.52) in 2006. Grain yield was positively related to the spike dry weight at anthesis but not to the relative partitioning of dry matter to spikes at anthesis. Harvest index was significantly related to DW_{pa} in 2006, but not in 2007 as a result of limited sink sizes of Wyalkatchem and Calingiri. It is proposed that increasing sink size may provide opportunities to improve harvest index of wheat in the high-rainfall zone.

Key Words

High-rainfall zone, wheat, WSC, harvest index, spike growth

Introduction

The high-rainfall zones (HRZ) of southern Australia have high yield potential as a result of high and more reliable rainfall and a longer growing season compared with the traditional wheat-growing regions of low- and medium-rainfall zones (Zhang et al. 2006). However, actual on-farm yields are only about 50% of the water-limited potential yield (Zhang et al. 2006; Anderson 2010). Lack of adapted wheat cultivars for the HRZ and the low harvest index (HI) achieved are considered to be major constraints to achieving the potential yield in the HRZ (Zhang et al. 2006; Zhang et al. 2007). In this paper we report a study of the performance of five wheat genotypes and the relationships between grain yield and phenology, the duration of spike growth period, pre- and post-anthesis dry matter, WSC at anthesis, and HI in the HRZ of south-western Australia.

Methods

The experiments were conducted in 2006 and 2007 near Kojonup in Western Australia (33°55'S, 116°54'E). The soil was a sandy duplex soil with 0.4 m of gritty loamy sand overlaying clay. Four commercial spring wheat (*Triticum aestivum* L.) cultivars Calingiri, Wyalkatchem, Chara, Wedgetail and two breeding lines HRZ216, and HRZ203 were used. Wheat was sown at a rate of 100 kg/ha on 23 June 2006 and 23 May 2007. A randomized complete block design was used with four replicates. Three N applications were made: 20 kg/ha at sowing, 50 kg/ha at tillering, and 50 kg/ha at stem elongation. Phosphorus was applied at 17kg/ha at sowing as MAP and 50 kg K/ha as muriate of potash was top-dressed at tillering. Growth stages were scored using the Zadoks scale. Terminal spikelet initiation was determined by microscopic dissection every 3-4 days during tillering. The duration of spike growth was defined as the period from terminal spikelet initiation to DC 65. Crops were sampled using a quadrat of 0.54 m^2 and dry weight measured. Grain yield and ears/m^2 were determined from 1.08 m^2 quadrats at maturity. Five plants from the samples at anthesis and physiological maturity were randomly selected and separated into leaf blade, stems with leaf sheath, and spikes for WSC analysis. Ten plants were randomly taken from the maturity sample and threshed by hand to determine grains/ear and thousand kernel weight. The number of grains per m^2 was calculated by dividing the grain yield by the thousand kernel weight. WSC concentration in the stem and leaf sheath was determined at anthesis and maturity. Samples were ground to pass through a 1 mm sieve. A 0.1 g sample was extracted with 8 ml of 80% ethanol at 80°C followed by 2 extractions with 8 ml distilled water at 60°C for 60 min. The three washes obtained were centrifuged at room temperature for 10 min at 3400 rpm and combined. Carbohydrate was analysed by the anthrone method. The amount of WSC in stem and leaf sheath were calculated from the concentration of WSC and dry weight of stem and leaf sheath.

Results

In 2006, drought delayed sowing until late June. Growing-season rainfall was 296 mm (25th percentile). The 2007 season was an average year with annual rainfall of 540 mm and growing-season rainfall of 396 mm with an even distribution.

Wyalkatchem reached terminal spikelet initiation first and also flowered earliest. Wedgetail reached terminal spikelet initiation 20 days later than Wyalkatchem and reached anthesis 10 days and 13 days later than Wyalkatchem in 2006 and 2007, respectively. Wedgetail had the shortest duration of spike growth of 45 days. The duration of spike growth was 65 days for Wyalkatchem and 74 days for HRZ203.

No clear relationships were found between grain yield and grains/ear, ear/m^2, and grains/m^2 (Fig. 1a) in either year. There was a stronger relationship between grain yield and kernel weight (Fig. 1b). Grain yield was positively related to the sum of DW_{pa} and WSC in 2006 (r^2 =0.96) and but was less correlated in 2007 (r^2 = 0.42) because the yield of Wyalkatchem and Calingiri was lower than the potential sources (Fig. 1c). Grain yield decreased with increased days to anthesis in 2006, but showed no trends in 2007 except significant yield reductions in Wedgetail with late flowering (Fig. 1d). Although there were significant differences between genotypes in partitioning of dry matter to spikes at anthesis, no relationship was observed between the partitioning and grain yield in either year.

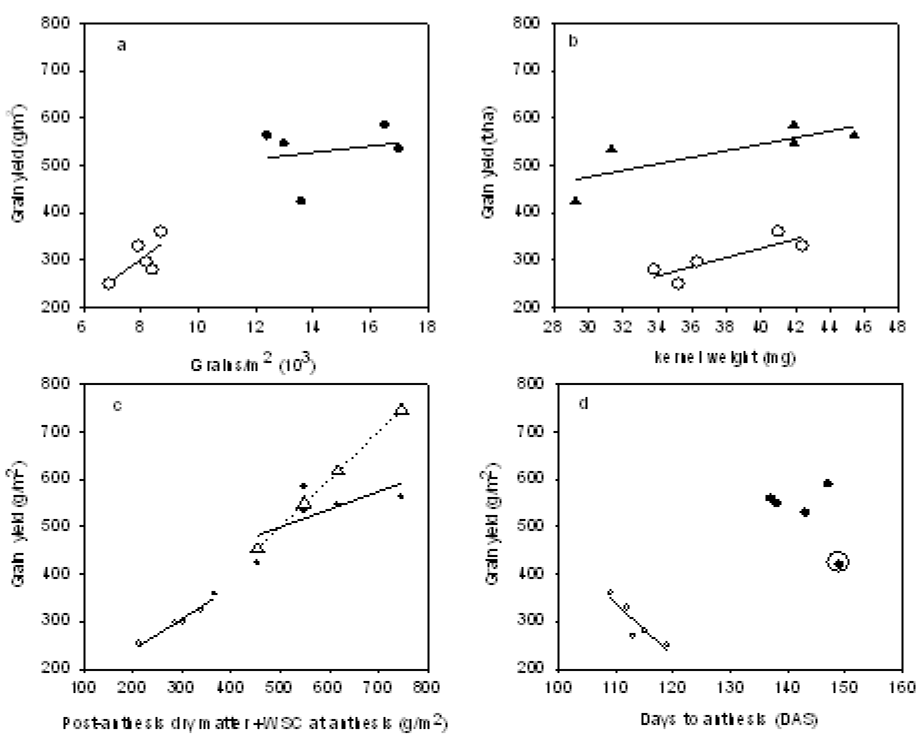

Figure 1. Relationships between grain yield and (a) grains/m^2, (b) kernel weight, (c) the sum of post-anthesis dry matter plus water soluble carbohydrate (WSC) at anthesis, (d) days to anthesis in 2006 (™) and 2007 (˜).The circled point in (d) represents Wedgetail in 207. The triangle points indicate the potential source available for grain filling.

Pre-anthesis dry matter increased linearly with the increased days to anthesis in both years except for Wedgetail (r^2 = 0.42 in 2006 and 0.93 in 2007) (Fig. 2a). However, post-anthesis dry matter decreased with delayed flowering (Fig. 2a). The number of grains/m^2 increased with the increased duration of spike growth period in 2006 (r^2 = 0.98) and no clear pattern in 2007 (Fig. 2b). Grain yield was also positively related to the duration of spike growth period (Fig.2c).

In 2006, HI was positively related to DW_{pa} (r^2 = 0.79), the total available sources for grain filling (r^2 = 0.87), but negatively related to the days to flowering (r^2 = 0.75) (Fig. 3a). The relationship between the HI and WSC was not significant. In 2007, none of the above relationships were significant. Assuming that 5% of WSC is left in stems at maturity under full remobilisation, we could estimate the potential yield as the sum of total available WSC and DW_{pa} and consequently derive a potential HI. The relationship between the potential HI and the total available sources for grain filling was significantly improved (Fig. 3b).

Wyalkatchem had the highest WSC at anthesis as a result of a significantly higher WSC concentration compared with the other genotypes (Zhang et al. 2010). The apparent contribution of WSC to yield averaged 34% across the season and cultivars, and was higher (*P* < 0.01) in 2006 than in 2007. The contribution of WSC to grain yield appeared to be negatively related to post-anthesis dry matter. The proportion of grain yield from WSC remobilization was higher in Chara, Wyalkatchem, and HRZ216 than Calingiri and Wedgetail.

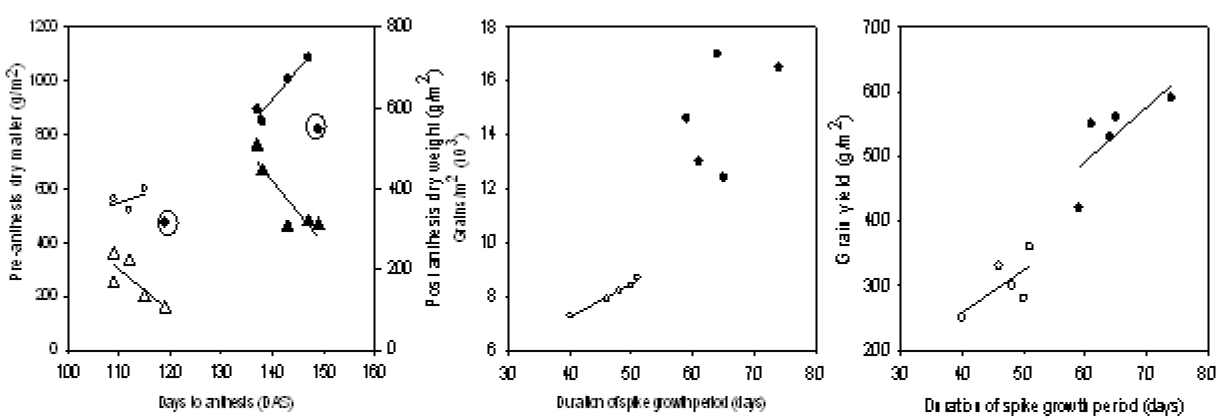

Figure 2 Relationships between (a) pre- (circles) and post-anthesis (triangles) dry matter and days to anthesis, (b) between the number of grains/m^2, and (c) grain yield and the duration of spike growth period in 2006 (™,r) and 2007 (˜,p). The circle points represent Wedgetail.

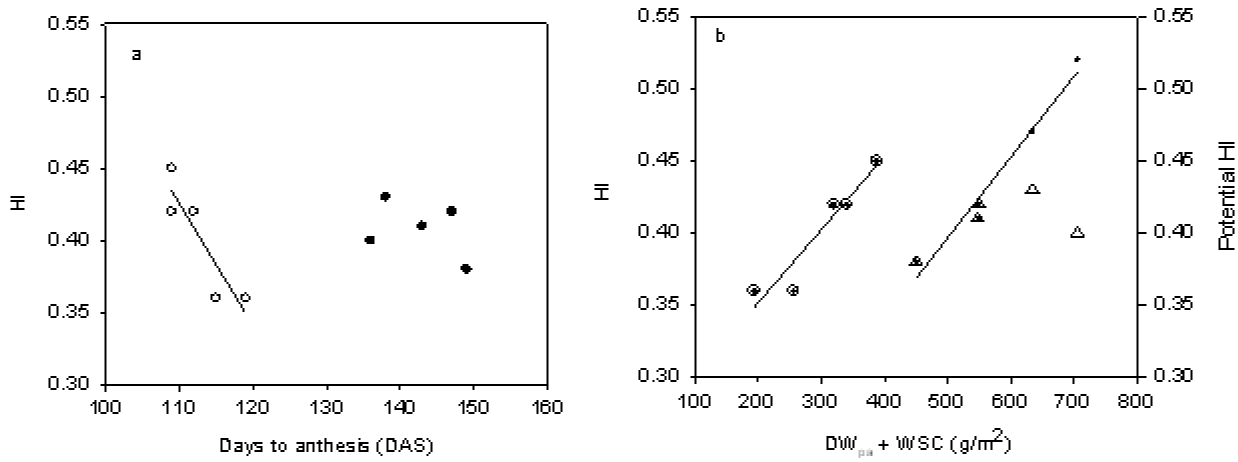

Figure 3 Relationships between harvest index (HI) and (a) days to anthesis after sowing, (b) the sum of post-anthesis dry matter (DW_{pa})and WSC at anthesis and between the potential HI and the sum of DW_{pa} and WSC in 2006 (™) and 2007 (˜). The HI is indicated in open and solid circles and the potential HI is shown in crosses and triangles in 2006 and 2007, respectively, in b).

Discussion

Extending spike growing period has been suggested as an avenue to improve yield potential of wheat because it allows the wheat crop to produce more grains/m^2 (Fischer 2007; Miralles and Slafer 2007). This study showed that the spike dry weight at anthesis, pre-anthesis dry matter, grains/m^2 and grain yield were positively related to the duration of spike growth period. Based on the water availability during grain filling period, Zhang et al. (2007) proposed that anthesis date may be extended 10 days compared with Wyalkatchem without putting the crop under severe water stress during grain filling. HRZ203 initiated as early as Wyalkatchem and flowered about 10 days later than Wyalkatchem in 2007. It produced as many ears/m^2 as Wyalkatchem with more grains per ear and resulted in more grains/m^2. Consequently, HRZ203 yielded about 5% higher than Wyalkatchem. Since DW_{pa} decreases with delaying of anthesis, the option for delaying flowering date is limited. It is necessary to extend spike growth period by moving spike initiation forward in order to allow the wheat crop achieve a large sink size (Foulkes et al. 2007; Miralles and Slafer 2007).

A combination of early flowering with large above-ground dry matter at anthesis is a desirable trait for high yielding. This combination allows the crop to produce large biomass to set up a large number of grains and provide the crop with enough resources to accumulate greater DW_{pa} (Fig. 2a) and remobilise stored WSC to fill grains. However, there are trade-offs between increasing DW_a and DW_{pa} accumulation. Early flowering tends to be associated with undesirable low dry matter at anthesis (Fig. 2a). This undesirable trait might be compensated for by greater dry-matter accumulation during the post-anthesis period as shown in Wyalkatchem (Fig. 2a).

Both high WSC at anthesis and greater DW_{pa} are expected to contribute to higher grain yield and therefore higher HI. However, the HI can be affected by the water availability during grain filling, source available to fill grains, and the sink size of the crops. In 2006, the HI increased with increased WSC at anthesis and DW_{pa} when the source for grain filling was limited (Fig. 3b), indicating that the crops converted most of available WSC and DW_{pa} into grain yield. This relationship did not hold in an average rainfall year 2007 (Fig. 3b). The sink size of Wyalkatchem and Calingiri was showed to be limited and unable to fully remobilize the available sources in 2007 as a result of limited number of grains/m^2 (Zhang et al. 2010). It was unlikely that the kernel weight in these two cultivars was a limiting factor because their kernel weights were the highest among the tested genotypes. This unused WSC may have contributed to lower HI and constrained these crops from achieving potential HI. If one assumes that these crops with sink limitations had enough sink to accommodate the available sources and convert them into grain yield, the relationships between the estimated potential HI and the sum of WSC at anthesis and DW_{pa} would have significantly improved ($r^2 = 0.80$, $P < 0.01$) in 2007 (Fig. 3b). Therefore, increasing the sink size of the crop may provide an avenue to lift HI of the wheat in the HRZ of southern Australia.

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