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Influence of BVP on grain size and yield in southern Australia.

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Abstract

Key physiological characteristics influencing grain plumpness were studied in a population developed from a cross between a tall, large grained barley genotype well adapted to southern Australia, and a semidwarf European malting cultivar with inherently smaller grain size. The parents also differed in the length of the Basic Vegetative Phase of development, and the population segregated for this trait. Within this population, grain plumpness was strongly, negatively correlated with anthesis date, date of physiological maturity and peduncle length. Pathway analysis indicated a strong, negative influence of kernel number per spike on grain plumpness. Despite a strong positive correlation between the duration of the BVP and kernel number under conditions of extended daylength, this relationship was much weaker when kernel number per spike was measured for plants grown under daylengths experienced by crops sown in late June. Under these conditions, the correlation between the duration of the BVP and grain plumpness was not significant. Plant height and peduncle length were positively correlated, whilst duration of the BVP and peduncle length were negatively correlated. In trials grown in the Wimmera, grain yield was negatively correlated with both plant height and peduncle length, whilst under unfavourable seasonal conditions in the Mallee environment these correlations were positive. The influence of the duration of the BVP on grain yield was dependent on the environment, with a negative association in drought stressed Mallee environments but a positive association in the Wimmera. Grain plumpness was strongly negatively correlated with grain yield in the Wimmera, but strongly positively associated with grain yield in drought stressed Mallee environments.

Introduction

Malting barley breeders seek to improve both grain yield and the reliability at which growers achieve malting quality premiums. Stability of grain size is a key parameter in ensuring reliability of meeting malting quality specifications. Investigations of the principal malting varieties grown in southern Australia (Boyd, 1996) have indicated that a relatively short duration of the basic vegetative phase of development is a key adaptive trait. Relative basic vegetative period (BVP) is measured as either the minimum leaf number on the main stem, or the minimum number of days to awn emergence for plants grown under long days, after any vernalisation requirement has been satisfied. In terms of plant height, historically successful varieties have been of tall (standard) stature, with a number of studies indicating semidwarf varieties have inherently smaller grain size. In recent years, a new malting variety, Gairdner, has been released principally for the medium to high rainfall regions. Gairdner possesses both a relatively long BVP and the *sdw* semi-dwarfing allele derived from the parental variety Franklin. Due to the high yield potential of this variety, the production areas for this variety are rapidly expanding in the eastern States of Australia and further into lower rainfall districts than were originally envisaged. This trend promotes a re-examination of the key adaptive traits required for southern Australia. In particular the influence of BVP and plant stature on grain yield and grain plumpness is warranted. The studies reported in this paper further the investigation of the association between BVP, grain yield and grain plumpness.

Materials and Methods

Population

A recombinant inbred population was developed from a cross between the large grained breeding line VB9104 and the European semidwarf malting variety Chariot. VB9104 was known to have a relatively short BVP, and to be relatively responsive to photoperiod. Chariot has a relatively long BVP, and is relatively non-responsive to photoperiod. The population comprised 90 randomly chosen F2 plants, from which 3 random reselections were made in the F4 generation. The reselections were propagated until the F6 generation, at which time one random selection was taken from each line. Seed of these selections was multiplied for this study. Hence the total population consisted of 270 F6 derived lines. Due to space restrictions in the birdcage environment used in this study, only two selections from each F2 family are considered ie a population of 180 randomly chosen inbred lines.

Birdcage experiment

Treatments comprised a "normal" (or short) daylength and a long daylength (16.5 hours) with two replicates in each treatment, and ten plants per replicate. The algorithm "Spades" was used to randomise treatments. The long daylength was achieved by extending normal daylength using incandescent bulbs that gave a (photo-synthetically-active radiation) light intensity of 4umol $m^{-2}s^{-1}$ at the soil surface. Seeds from each line were pre-germinated in biodegradable, perforated plastic seedling containers (40mm square by 65mm deep) containing a mixture of loam, peat moss and sand. Ten seedlings of each line were planted into a Wimmera grey cracking clay immediately after emergence in the period 7^{th} to 12^{th} July. Time to awn emergence under both long (DAE_L) and normal (DAE_N) daylength was recorded. The number of leaves (LN_L) and grain numbers per spike (GN_L) on the main culm was recorded for those plants grown under extended daylength. The length of the peduncle, from the top node to spike rachis, was measured at maturity for plants grown under both natural daylength (PED_N) and extended daylength (PED_L). All measurements were performed on the ten plants per treatment. Treatment means for each parameter were determined using the REML function of Genstat to fit an auto-regressive model to the mean values from the ten plants per treatment. Wald statistics were highly significant for all traits.

Field experiments

The same population of lines was sown in field trials at Horsham, in the Victorian Wimmera, and Birchip, in the Victorian Mallee, in both 1998 and 1999. The algorithm "Spades" was used to randomise treatments within two replicates for all trials. Soils types at Horsham and Birchip were Wimmera grey cracking clays and sodic duplex Mallee loams respectively. The Horsham trial was sown on 14th June in 1998 and 18th June in 1999, whilst the Birchip trial was sown on 1st June in 1998 and 9th June 1999. Each plot consisted of 6 rows, 4.2m in length. All trials were managed in accordance with local farm practice. Plant height from the base of the plant to the tip of the spike on the tallest tiller, for five plants in each plot, was measured at the Horsham 1998 site at maturity. Plot means were calculated and used in subsequent analysis. Unfortunately a late season frost prevented the use of grain yield and grain screenings data from this site. Grain was harvested from the Birchip site 1999 and weighed at maturity, and grain subsamples from this site were assessed for grain size fractions using a Sortimat grain screenings machine. Grain plumpness, measured as grain retained on a 2.8mm screen, was subject to natural logarithm transformation, to remove heterogeneity of error variance. Treatment means for grain yield (YLD), plant height (HGT) and transformed grain plumpness (PLU) were calculated using the REML function of Genstat to fit an auto-regressive model. Wald statistics were highly significant for all traits at these sites.

Analysis

Correlation matrices were calculated with MS Excel using adjusted treatment means for YLD, PLU, DAE_N, DAE_L, LN_L, GFD_N, GN_L, HGT, and PED. Correlations between YLD at each site and the measured physiological traits were partitioned into path-coefficients as described by Dewey and Lu (1959). A path coefficient is a standardised partial-regression coefficient that measures the direct influence of one variable upon another, permitting the separation of the correlation coefficient into components of direct and indirect effect. The method of Ortiz and Langie (1997) was used to determine the path-coefficients.

Results and Discussion

The growing season at Birchip during the 1999 season was favourable (239mm growing season rainfall), with average yields for the parental varieties VB9104 and Chariot being 2.90 and 2.75 t/ha respectively. Due to the favourable spring conditions, all genotypes produced relatively plump grain and the percentage grain retained above a 2.8mm screen, as opposed to the more conventional 2.5mm screen, was used to differentiate between VB9104 (89.0%) and Chariot (74.8%) (+/-1.2%). Growing conditions at Horsham during 1998 were also very favourable, prior to a frost on 28th October. These conditions were ideal for measurement of genotypic differences in plant height, with the average height of VB9104 and Chariot being 104.1 and 86.2

cms respectively (+/-5.5cms). In contrast, the 1998 season at Birchip was extremely dry (169mm growing season rainfall), with VB9104 and Chariot achieving yields of only 1.20 and 0.50 t/ha respectively. Site average yields were 1.90t/ha at Horsham in 1999 with dry seasonal conditions experienced (227mm growing season rainfall).

Birdcage experiments allowed the measurement DAE_N, and relative BVP, in addition to measurements of the effect of daylength on GN and peduncle length. Both leaf number (LN_L) on the main culm and days to awn emergence (DAE_L) under extended daylength were used to determine relative BVP. Significant differences in the relative duration of the BVP occurred between VB9104 (7.0 leaves, 69.3 days) and Chariot (8.7 leaves, 82.4 days). LN_L amongst progeny ranged from a minimum of 6.7 (DAE_L = 66.6 days) to a maximum of 9.3 (DAE_L = 86.0 days). Standard errors for these measurements were low (SE LN_L = +/- 0.2 leaves; SE DAE_L = +/- 1.3 days). In this paper, genotypes with less than an average of 7.6 leaves on the main culm are defined as possessing a short BVP, whilst genotypes with an average of greater than 8.5 leaves are defined as possessing a long BVP. Peduncle length was highly correlated between the normal and extended day treatments (r=0.85), indicating this is a highly heritable trait, and relative ranking of genotypes for this trait are likely to similar across environments. GN_L was strongly correlated with both LN_L (r = 0.67) and GN_N (r = 0.63). However, the correlation between GN_N and LN_L was weaker (r = 0.25).

Pathway analysis was used to investigate the relationship between grain plumpness and phenological and physiological traits. Simple correlation analysis indicated DAE_N (r = 0.30; P<0.001), HGT (r = -0.23; P<0.01), and PED (r = -0.40; P<0.001) had the greatest influence on grain plumpness. Pathway analysis indicated the influence of maturity on grain plumpness was mainly a direct effect. Of more interest, was the path coefficient for peduncle length (PED_N) which was high (0.51) whilst the direct effect of plant height on grain plumpness was very small (0.06). A strong direct influence of grain number per kernel (measured by GN_N; path coefficient =-0.38) on grain plumpness was detected, even though this trait was poorly correlated with grain plumpness. The poor correlation between grain numbers per kernel and grain plumpness can be explained by the strong positive correlation between grain numbers per kernel and peduncle length (r=0.33; P<0.001), the latter having a beneficial effect on grain plumpness.

Compared to short BVP genotypes, long BVP genotypes were approximately 2 days later in time to flowering, were 5 cms shorter, possessed peduncles 3.6 cms shorter, produced 4% less plump grain, were 5% lower yielding in a stressful Mallee environment, and were 4% higher yielding in the Wimmera. Under extended daylength, large differences in mean grain numbers per spike occurred between long and short BVP genotypes (long BVP genotypes = 29.9 grains per spike; short BVP genotypes = 24.7 grains per spike). Under natural daylength the difference in mean grain numbers per spike between long and short BVP genotypes was considerably less (long BVP genotypes = 31.3 grains per spike; short BVP genotypes = 28.6 grains per spike).

The relatively small influence of the duration of the BVP on kernel numbers per spike under natural daylength can be explained by considering the physiological basis of the BVP. The duration of the BVP is the thermal time after emergence before a response to photoperiod is detected, with the response measured by a shortening of time to anthesis. A reduction in time to anthesis can only be detected if the daylength experienced during this phase of growth is sufficient to trigger a photoperiod response reaction. Ellis et al (1988) determined this minimum photoperiod to be between 9 and10 hours per day. In southern Australia, for a late May/early June sowing date, this minimum photoperiod is not reached until approximately 90 days post sowing. Maximum potential numbers of spikelets per spike are determined within 60 - 80 days from plant emergence in southern Australia for these sowing dates (Flood et al, unpublished). Hence, for the majority of the growing period until the maximum potential number of spikelets is established, daylength is below the minimum required to induce a photoperiod response. For this reason there is only a minor association between the intrinsic duration of the BVP and grain plumpness via kernel number at sowing times generally employed by producers in southern Australia (ie before 30th June). Similarly, the relatively small difference in flowering dates, under natural growing conditions, between the long and short BVP genotypes can be explained by the short daylength during the BVP of development.

The negative association between the duration of the BVP and peduncle length can be attributable to an enhanced number of nodes on the main stem in long BVP genotypes. As extended duration of the BVP is not associated with greater height (rather a reduction in height), it follows that internode lengths must be reduced, including the length of the peduncle. Previous researchers (eg Daniels and Alcock, 1982) have indicated that the peduncle and the penultimate internode are the primary storage source of pre-anthesis assimilates for the developing grain. Pre-anthesis assimilates are particularly important in situations of post-anthesis moisture stress when the contribution of post-anthesis photosynthesis to grain filling is greatly reduced.

Conclusion

In southern Australia, for barley sown in the May/June period, the duration of the BVP has a small influence on anthesis date, peduncle length and grain numbers per kernel. Each of these parameters influence grain plumpness. The combined influence of these characteristics result in a small, negative correlation between the duration of the BVP and grain plumpness. The magnitude of this effect is not great, and plant breeders should be able to combine high levels of grain plumpness with long BVP.

Whilst peduncle length is strongly correlated with plant height, and both show strong correlations with grain plumpness, pathway analysis indicates it is peduncle length rather than height which is the primary influence on grain plumpness. In contrast, for grain yield, pathway analysis indicates plant height rather than peduncle length has a direct effect on yield. Barley breeders should be able to improve grain plumpness in semidwarf varieties through the selection for enhanced peduncle length.

In environments suffering severe drought, grain size appears to be a primary contributor to final grain yield, with grain size being enhanced by longer peduncles, less kernels per spike and earlier maturity. Genotypes with a shorter duration of BVP are favoured in these environments. In more favoured environments kernel number per spike is a more important determinant of final yield. Genotypes with an extended duration of the BVP are favoured in these environments. In the barley growing regions of Victoria, these studies suggest that the greatest genetic gains in the Mallee environment, where moisture deficiency is a common occurrence, can be achieved through the selection of varieties with a short BVP. In the Wimmera region an extended duration of the BVP may be a desirable characteristic.

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