Breeding wheat lines for southern Australia according to three climatic mega-environments

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Abstract

One hundred and sixty-one wheat variety evaluation trials from southern Australian for the years 1994, 1995 and 1996 were analysed. Using this and long-term climate data, we show that, on the basis of differences in genotype by environment interaction, the South Australian and Victorian wheat belt may be separated into 3 mega-environments. These are: a Wimmera type environment with 200 to 300mm rainfall between sowing and anthesis and an average maximum temperature of less than 26?C between anthesis and harvest; and for the same respective crop developmental phases a Mallee type environment with less than 200mm rainfall, and an average maximum temperature of greater than 26?C; and a high rainfall environment with more than 300mm rainfall, and less than 26?C. These 3 mega-environments elicit different response patterns of genotypic performance.

Key Words

Genotype x environment interaction

Introduction

Wheat production in southern Australia covers a large area (approximately 3 million ha), encompassing a range of soil types, rainfall patterns, and temperature extremes. Apart from the regional differences in soil and landscape characteristics, the season-to-season weather variation can cause highly variable grain yields and low selection efficiencies in plant breeding programs.

This complex genotype x environment interaction system can result in extreme rank change of cultivars across regions, making selection decisions difficult for breeders (1). Genotype x environment interaction variance components can be separated into two types of interaction, that due to heterogeneity of genotypic variance among environments, and the other due to the lack of correlation among environments (3). It is the second, which causes selection problems for plant breeders as it results in cross-over interactions where cultivars differ in rank change across environments. It has also previously been found (2) that sources linked to seasonal variations, or transient factor, seem to have a greater influence on relative genotypic performance compared to sources which remain relatively constant from year-to-year. Environmental attributes linked to transient factors, such as periods of moisture stress, particularly prior to anthesis, and high daily temperatures, are important determinants of site x year and genotype x site x year interaction components (2).

Historically, breeders have designed their breeding programs to account for genotype x site interactions, rather than genotype x site x year interactions (40). Through a process of experience and opinion, the breeders have aggregated sites into 5 major agro-ecological regions for cultivar development in South Australia and Victoria. These are the Wimmera, the Mallee, a duplex soil zone, a high rainfall zone and an irrigated zone.

However, the use of agro-ecological regions does not take full advantage of breeding for adaptation to environmental attributes such as soil type, rainfall and temperature. i.e. in consecutive years, sites may not always behave the same way and may require a ‘flexible’ classification depending on the actual weather experienced during each year. Determination of the most important attributes and their association with different crop developmental stages is required. The objective of our study was to identify these attributes, and use them to better explain genotype x environment interactions in southern Australia compared to the current agro-ecological zones. This will allow breeders to be more able to predict the performance of cultivars across a wide range of environment types and have a better understanding of their adaptation to these environments.

Methods

One hundred and sixty one environments throughout South Australia and Victoria were evaluated for wheat yield from the 1994, 1995 and 1996 advanced evaluation trials (Stage 4 trials). A balanced cultivar data set, where all 7 cultivars appeared in every site in each year, was selected by the breeders, and consisted of Dollarbird, Goroke, Janz, Machete, Meering, Rosella and Trident. VF519, a breeders line, also appeared in all sites in every year and was included in the analysis. The balanced cultivar data set, together with site characterisation data on soil type, temperature, rainfall, sowing and estimated anthesis dates for each trial, as well as disease incidence were used to determine mega-environments in southern Australia.

Three representative trial sites from each of South Australia and Victoria where chosen to investigate the probability of a climate event occurring. The 6 sites were: Horsham, a Victorian Wimmera site; Walpeup, a Victorian Mallee site; Rutherglen, a Victorian high rainfall site; Loxton, a South Australian Mallee site; Roseworthy, a South Australian duplex site; and Minnipa, a South Australian North-west Eyre Peninsula site. In a previous analysis (2), post-anthesis maximum daily temperature, anthesis to harvest, and pre-anthesis rainfall, sowing to anthesis, were found to be significant determinants of plant adaptation in terms of yield. Long-term pre-anthesis rainfall and long-term post-anthesis maximum daily temperature were obtained from the Bureau of Meteorology. Rainfall and temperature real data were collected back since the weather station, closest to the trial site, commenced recording.

Pre-anthesis rainfall and post-anthesis maximum daily temperature were analysed against the yield obtained for each site to determine the probability of receiving the optimum rainfall and daily temperature for each of the 6 sites. Anthesis dates were estimated from Zadoks scores (5) or heading dates for each site.

The 161 environments, across both South Australia and Victoria, were then re-classified according to the mega-environments determined. Hence, in contrast to the strict site aggregation into agro-ecological zones, the mega-environment classification allowed a site to be classified into a different mega-environment depending on the weather experienced during a particular year of testing. Analysis was conducted for the 8 check cultivars, using the ANOVA procedure in Genstat. Analysis was conducted to determine if the mega-environments increased genetic variance at the expense of environmental variance components and genotype x environment interaction variance components, and was compared to the current agro-ecological classification.

Results

Analysis in my thesis showed that only little improvement in genetic variance was achieved from sub-zoning the region into smaller homogenous zones, according to the agro-ecological zones proposed by wheat breeders (2). This suggests that sources linked to seasonal variations seemed to have a great influence on relative genotypic performance.

Most notably it was found that seasonal differences influencing cultivar performance across trials were associated with pre-anthesis rainfall and post-anthesis maximum daily temperature. The results show that average yield increased linearly up to approximately 300mm pre-anthesis. If more than 300mm were received, yields tended to decrease. The results also indicated that temperatures between 22.5?C and 26?C were optimum post-anthesis temperatures required to obtain maximum yields. Yields tended to decrease significantly when average daily yields were above this optimum, and yields decreased when average daily temperatures were below this optimum range.

From the probability calculations, based on long-term rainfall and long-term temperature data, it was determined that the South Australian and Victorian wheat belt can be separated into three mega-environments, based on the response patterns of genotypic performance. These 3 mega-environments were:

1. All environments experiencing climatic conditions between 200-300mm rainfall between sowing and anthesis and a maximum daily average of <26?C between anthesis and harvest. This is a Wimmera type environment and closest to ideal conditions.

2. Environments experiencing <200mm rainfall between sowing and anthesis and an average daily maximum temperature of >26?C maximum between anthesis and harvest, classified as a Mallee type environment.

3. All environments experiencing >300mm rainfall between sowing and anthesis and <26?C between anthesis and harvest. This is a high rainfall environment with above ideal rainfall conditions.

All 161 trial sites across Victorian and South Australia were re-classified according to one of these three mega-environments based on pre-anthesis rainfall and post-anthesis maximum daily temperatures experienced at each of these sites. An ANOVA was conducted on the agro-ecological zones and the mega-environments (Table 1) to determine the genetic variance accounted for in both methods of zoning.

There is a significant contrast between the Mean Squares of the Mega-environments and Mean Squares of the Zones previously defined by the breeders (Table 1), suggesting that much of the genotype x environment interaction can be explained by two attributes, rainfall before anthesis and temperature after anthesis.

Table 1: Mean squares from analyses of variance allowing a direct comparison between 5 agro-ecological zones and the 3 mega-environments

Agro-ecological zone			Mega-environments		
Source	Degrees of freedom	Mean squares	Source	Degrees of freedom	Mean squares
Environments	160	3.037	Environments	160	3.037
Zones	4	18.946	Mega-environment	2	93.634
Residual	156	2.629	Residual	158	1.890
Environment/Rep	394	0.019	Environment/Rep	394	0.019
Cultivar	7	0.735	Cultivar	7	0.735
Cult x Zones	28	0.043	Cult x Mega	14	0.057

Residual	3850	0.007	Residual	3864	0.007
Total	4439		Total	4439	

Conclusion

From the analyses conducted from the subset of environments, there is evidence that the southern wheat growing region can be separated into three mega-environments. This is based on the findings that rainfall between 200-300mm from sowing to anthesis, and temperatures, between 22.5?C and 26?C from anthesis to harvest, provide the best growing conditions for the region. The 3 mega-environments elicit different response patterns of genotypic performance for the 8 cultivars grown in them over a 3- year period (1994, 1995 and 1996) across 161 environments.

It should be possible for breeders to better predict the yield performance of breeding lines, by characterising their testing environments into these 3 mega-environments. This would require that flowering dates for each testing environment, plus temperature and rainfall information be collected. For many testing environments, temperature and rainfall data are available from the Australian Bureau of Meteorology. These results are also based on known adapted cultivars, however, this knowledge could be used to classify new selection lines coming through a breeding programs. Farmers will then know exactly how each line will perform according to predicted seasons.

References

(1) Basford, K.E., and Cooper, M. (1998). Aust. J. Ag. Sci., 49:153-174.

(2) Bell, C.C., and Eagles, H.A. (2001). Proceedings 10th Australian Wheat Breeding Assembly pp 32-35.

(3) Cockerham, C.C. (1963). Statistical Genetics and Plant Breeding. Publication 982. National Academy of Sciences Washington DC.

(4) Cullis, B., Smith, A., Hunt, C., and Gilmour, A. (2000). J. Ag. Sci. Cambridge, 135 (3):213-222.

(5) Zadoks, J.C., Chang, T.T., and Konzak, C.F. (1974). Weeds Research, 14:415-421.