Delivering Improved Varieties for Hostile Environments: an Integrated Approach to Research and Breeding.

Nigel Long, Stewart Coventry, and Jason Eglinton

SA Barley Improvement Program, Waite campus, University of Adelaide, SA 5064

Introduction

The cereal-growing environment of southern Australia is Mediterranean; low and variable winter dominant rainfall, with moisture stress a common occurrence during the growing season. In this setting of low moisture availability, other abiotic, as well as biotic, and subsoil constraints exist to present a hostile growing environment for cereal crops. Plant establishment and growth, availability and utilisation of water and nutrients, and ultimately grain yield and physical grain quality of barley are governed by prevailing constraints in the growing environment. Major subsoil constraints include soils with inherently low fertility and water holding capacity (such as sandy soils), abiotic constraints to root growth (high salt and boron, high pH induced nutrient deficiency), and biotic constraints such as CCN. Foliar disease and high temperatures particularly during grain set and development are major above ground constraints to plant growth and yield.

To improve performance across a range of moisture environments and broaden the adaptation base of Australian barley, a balanced composition of traits conferring tolerance to a range of environmental constraints is necessary to allow the water-limited yield potential of the average environment to be achieved.

The potential for achieving this objective is dependent on incorporating traits that capture and efficiently utilise the available soil water for growth and yield to avoid moisture stress, as well as the capacity to tolerate other constraints to growth. These traits are mostly constitutively expressed and involve stress avoidance to confer adaptation, and can be incorporated into a variety to improve adaptation to the mid-low rainfall environments. The new breeding line WI3804 is an example of how constitutive traits from three different germplasm sources can be integrated to improve adaptation to low rainfall environments including those with sandy soils. The adaptive characteristics of WI3804 in the low rainfall environments are discussed along with the genetics of adaptation related to the parental sources of WI3804.

Adaptive characteristics of WI3804

WI3804 is derived from the cross Mundah/Keel//Barque, and has inherited adaptive characteristics from these parents (Table 1). Barque, Keel, and Mundah are important feed barley varieties in southern Australia, and each are characterised by phenotypes suitable for marginal cropping areas in South Australia (SA).

Barque is an early-mid flowering, high yield potential variety (Tables 2 & 3) that was released in 1997. Barque is suited to all areas of SA, however recent virulence changes have rendered it susceptible to scald and net form of net blotch.

Released by the SA Barley Improvement Program (SABIP) in 1999, Keel has combined early maturity with high yield potential (Tables 2 & 3). It has higher yield than Barque in the low rainfall areas, and better grain plumpness, lower screenings, and heavier grain. Keel has a good spectrum of resistance to economically important diseases in SA including CCN, although susceptible to leaf rust. Keel is suited to most areas and soil types except sandy soils.

Mundah, developed by the Western Australian Barley Breeding program, is agronomically suited to the deep sandy soils (Table 5). Sandy soils are typically associated with dune/swale environments and characterised by poor fertility, rapid drainage of soil water, water repellency, leaching loss of nutrients, erosion, and a high incidence of root borne diseases. The superiority of Mundah is derived from a combination of traits, including vigorous early growth, which improves adaptation on this soil type (1,2). Mundah has significantly heavier and plumper grains than Barque and Keel. However, a lower yield potential in other environments and soil types compared with Barque and Keel, and significant disease deficiencies in terms of CCN, spot form of net blotch, and scald, limits the area sown to Mundah in SA the sandy soils.

Table 1: Comparison of Barque, Keel and Mundah for key adaptive traits when grown under South Australian conditions. (Disease reaction ratings provided by Hugh Wallwork, SARDI)

Trait type	Phenotype	Barque	Keel	Mundah	WI3804
Disease	Cereal Cyst Nematode (CCN)	R/T	R/T	S/T	R/T
	Leaf Rust	MS	VS	S	MS
	Leaf Scald	S/VS	MR/MS	S	MR/MS
	Powdery Mildew	MR	MR/MS	MS/S	N/A
	Spot form net blotch (SFNB)	R/MR	R/MR	S	MR
	Net form net blotch (NFNB)	MS	R/MR	MR	R/MR
	Stripe Rust	N/A	MS	N/A	MR
Plant type	Flowering	Early-Mid	Early	Early	Early-Mid
	Stature	Medium	short-medium	Medium	Medium
	Spikelet	2 row	2 row	2 row	2 row
	BVP	Mod. Short (photoperiod sensitive)	Short (photoperiod sensitive)	Long (photoperiod insensitive)	Mod. Short (photoperiod sensitive)
	Early growth habit	Intermediate	Intermediate	Erect	erect
	Early vigour	Moderate	Moderate	Very high	Moderate
	Tillering	Very high	High	Moderate	Moderate
Grain size	Average across environments	Moderate (ave 46 mg)	Moderate (ave 45 mg)	Large (ave 48 mg)	Large
Grain size	Sandy soils	Moderate (ave 43 mg)	Moderate (ave 43 mg)	Large (ave 48 mg)	Large

N/A=not available

The breeders line WI3804 is a direct result of the breeding strategy employed to combine the superior qualities of each variety, to significantly advance the adaptation of barley to marginal cropping environments. WI3804 has combined the plant architecture and phenology of Barque, the disease resistance and yield potential of Keel, and the adaptation to deep sandy soils of Mundah. WI3804 is early-mid flowering (Mundah, Barque), has moderate early vigour (Barque), erect growth habit (Mundah), is similar in height to Barque, and is moderately intolerant of boron toxic soils. Resistance to head loss is at least equal to current commercial varieties. WI3804 has a spectrum of disease resistance equivalent to Keel, with the additional benefit of a significantly lower disease reaction to leaf rust, which is comparable with Barque and Mundah (*i.e.* MS).

The outstanding grain yield potential and stability of WI3804 across a range of environments and seasonal conditions in four years of evaluation in SABIP and two years in SARDI yield trials (Tables 2 & 3) suggests that an optimal combination of the different constitutively expressed adaptive traits from Barque, Keel and Mundah have been successfully attained. WI3804 is an improved cultivar with broad adaptation and yield stability, alleviating the phenotypic limitations of each germplasm source, and will encourage growers to continue growing barley in low rainfall environments.

Table 2: Long-term grain yield data for SARDI CVT trials (1998-2004) (SAFCEP data, REML analysis)

	YP	MM	MN	SE	LEP	UEP
Barque	3.26	1.77	3.54	3.73	3.59	1.95
Capstan	3.36	1.81	3.77	3.80	3.68	1.96
Galleon	3.10	1.60	3.41	3.58	3.44	1.80
Keel	3.34	1.77	3.79	3.80	3.66	2.00
Maritime	3.31	1.76	3.64	3.83	3.70	1.92
Mundah	3.11	1.75	3.48	3.57	3.55	1.86
WI3804*	3.45	1.86	3.74	3.90	3.77	2.02

*2003-2004 only

Table 3: Seasonal grain yield data for SARDI CVT trials and SABIP yield trials(REML analysis)

	SABIP				SARDI	
	2001	2002	2003	2004	2003	2004
Barque	1.47	1.48	3.11	1.90	3.50	2.24
Keel	1.51	1.52	3.23	2.13	3.43	2.40
Mundah	1.37	1.31	3.04	1.95	-	-
Maritime	-	1.41	3.38	1.99	3.45	2.27
Capstan	-	1.49	3.17	1.80	3.45	2.23
WI3804	1.61	1.55	3.27	2.03	3.65	2.34

Potential in the low-rainfall environments

Graphic representation of the detailed GxE analysis of grain yield in low rainfall environments illustrates the different adaptation response of the parental germplasm of WI3804 (Figure 1)(3). The data in this analysis is bias toward low rainfall environments (<450mm annual rainfall), such that performance and stability is discussed in this context only. Keel (indicated by ◆ in the graph) possesses the highest yield (positive yield effect) and is better adapted to low yielding environments (negative environment effect). Barque (▲) has average yield and better adaptation to higher yielding environments and Mundah (●) above average yield in favourable environments. The performance of WI3804 (■) is intermediate to Keel and Barque, and similar to Mundah reflecting a combination of adaptation traits derived from the parents and a yield architecture that supports higher yield potential in the average environment. WI3806 is a sister line of WI3804 that has shown good performance and stability in the low rainfall environments but lacks the disease resistance profile of WI3804.

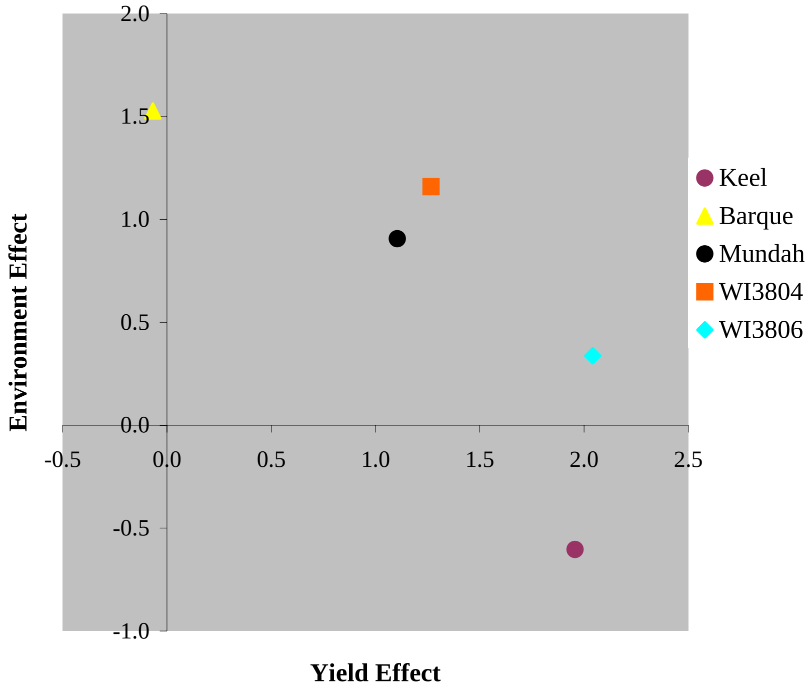

Figure 1: The yield and environmental stability of Mundah, Keel, Barque, and derived genotypes WI3804 and WI3806. Genotypes expressed as the common effect from the average of 210 barleys and 10 environments in Australia. Data analysed by MET analysis.

Grain yield data of WI3804 from SARDI variety testing trials is limited (2003 and 2004 only), although performance by rainfall category (Table 4) over two seasons can be extrapolated from the detailed yield and environmental stability analysis of the low rainfall trials (Figure 1). While WI3804 has better yield potential in low rainfall areas than Barque and Mundah, GxE influences (Figure 1) in this environment makes it unlikely that WI3804 will replace Keel. However, in higher yielding environments (Figure 1), particularly the medium to high rainfall zones where it has displayed excellent grain yield, WI3804 is likely to be a pivotal line, and replace Barque.

Table 4: Grain yield of WI3804, parental lines and two other commercial varieties in SARDI S4 trials by Rainfall (SAFCEP data, REML analysis)

	< 325mm		325-450mm		> 450mm	
	Yield (t/ha)	Observations	Yield (t/ha)	Observations	Yield (t/ha)	Observations
WI3804	1.64	12	3.22	22	3.91	8
Barque	1.59	40	3.07	69	3.67	35
Capstan	1.59	30	3.12	45	3.91	27
Keel	1.66	40	3.15	69	3.75	35
Maritime	1.56	28	3.08	29	3.90	10
Mundah	1.52	14	2.94	42	3.66	27

Tolerance to subsoil constraints is also assessed in an effort to improve adaptation through maintaining the plants ability to utilise available moisture. Boron is one constraint prevalent in the soils of southern Australia. WI3804 and WI3806 have significantly lower leaf symptom score (2.8 and 1.5 respectively) relative to their parents Barque, Keel, and Mundah (5, 4, and 7 respectively).

Adaptation potential on sandy soils

In three years of evaluation on sandy soils of low fertility, WI3804 has exhibited equal or better yield potential to Mundah and Barque (Table 5).

Table 5: Long term yield data of commercial varieties on sand (SAFCEP data, REML analysis)

	Yield (t/ha)	**Observations** (site years)
WI3804	1.474	8
Barque	1.468	18
Capstan	1.388	6
Keel	1.391	18
Maritime	1.437	11
Mundah	1.451	18

Adaptation response of barley on sandy soils of low fertility is complex and strongly influenced by GxE associations. This is clearly illustrated by the grain yield response of Mundah and Keel on sand across nine site/years between 1999 and 2001 (Figure 2). The extent of the deviation from the site means reveals the relative stability across environments of both varieties.

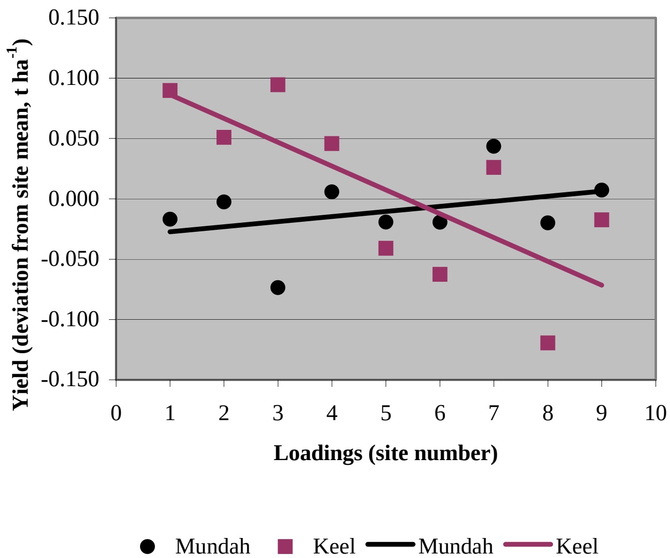

Figure 2: Deviation of grain yield from the site means for Mundah and Keel in the Mundah/Keel RIL population field trials, 1999-2001. Legend: Sites 1-4 exhibited moisture stress/terminal drought. Sites 5-9 displayed 'typical' sand response. Data analysed by MET analysis.

In environments characterised by below average seasonal rainfall and/or terminal moisture stress Keel yielded well since adaptation response was more a function of moisture stress than soil type (sites 1-4). At sites more typical of a sand response (sites 5-9), on the basis of grain yield ranking following expectation for this environment (Table 5), Keel performed poorly. Conversely, the adaptation response of Mundah was quite stable between environments. From this analysis it can be concluded that prevailing environmental conditions over-ride the soil response, since Keel with apparently better moisture stress tolerance traits out-yields Mundah where water was limiting.

QTL analysis of yield in the Mundah/Keel population confirmed this response demonstrating that alleles contributed from Keel are expressed at sites affected by moisture stress. This clearly identified drought tolerance as an intrinsic component of sand adaptation, although very site specific. In addition, Keel alleles were associated with some loci for superior agronomic traits at sites characterised by a sand response, suggesting Keel has some limited genetic potential on sand. QTL putatively associated with improved grain yield, grain weight and grain size on sand were detected on chromosome 1H and 2H. The QTL on chromosome 2H were associated with grain yield, grain weight, and lower screenings. Earlier flowering is a key component of adaptation on sand to maximise grain yield potential through effective use of the available soil water to maintain grain filling, and avoidance of late season heat and moisture stress that can significantly restrict yield in southern Australian cropping environments.

Combining Keel alleles for drought escape and Mundah alleles for sandy soil adaptation can bridge the adaptation gap commonly seen between sandy and low rainfall sites and improve yield potential and stability on sand by accommodating for the over-riding impact of moisture stress.

WI3804 has drought tolerance attributes of Keel to support yield on sandy soils in specific situations of moisture stress. In combination with a superior disease resistance and agronomic profile, WI3804 is a significant advancement for adaptation on sandy soils, and it is expected that in regions where this soil type dominates growers will quickly adopted it.

WI3804 has inherited yield potential of Barque, and performs similarly with contrasting seasons. Barque displays good grain yield potential on sandy soils (Table 5), although it is distinctly more variable between sites for grain yield than Mundah (1).

Conclusion

Studies focusing on adaptation to low rainfall environments and sandy soils have improved our knowledge of the genetic basis of adaptation to hostile environments and clarified the phenotypic qualities necessary to tolerate these abiotic stresses (1,2,3). WI3804 is prime example of how this knowledge can be successfully integrated in to a plant breeding program to development new varieties with advanced adaptation to hostile environments. The studies have also highlight how adaptation response can be profoundly influenced by environmental pressures. A solid understanding of traits associated with adaptation and there behaviour in field situations is critical to understanding how genes/genetic regions can be applied to improving adaptation to hostile environments because of GxE factors.

WI3804 has been selected for commercial release in 2006 as replacement for Barque and Mundah.

References

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