Breeding for Improved Zinc and Manganese Efficiency in Wheat and Barley.

G.K. McDonald, R. D. Graham, J. Lloyd, J. Lewis, P. Lonergan and H. Khabas-Saberi

Department of Plant Science, Waite Institute, Glen Osmond, SA.

Abstract

Micronutrient efficiency is the ability of a crop to grow and yield well when the availability of the micronutrient is low. Field and growth room screening has shown significant genetic variation in zinc (Zn) and manganese (Mn) efficiency in winter cereals, which indicates that selection for improved micronutrient efficiency is possible. Progress has been made in identifying Mn- and Zn-efficient parents in wheat and barley and in developing more efficient genotypes. The variability inherent in field screening has produced some inconsistent results. This may be overcome by the use of molecular marker technology, so that the genes for nutrient efficiency can be selected directly. Molecular markers for Mn efficiency have been identified in barley and putative markers identified in durum wheat. Screening for Zn efficiency in wheat and barley double haploid populations is underway with the aim of developing molecular markers for Zn efficiency.

Key words

Zinc, manganese, plant breeding, wheat, barley, molecular markers.

Introduction

Micronutrient deficiencies occur in crops on a range of soils across southern Australia, and are common on the highly alkaline calcareous soils in the cereal belt of South Australia (SA) and northwestern Victoria. Zinc (Zn) and manganese (Mn) deficiencies are the most frequently diagnosed micronutrient disorders of cereals in the region. In SA, between 1995 and 1999, about 20% of the wheat crops analysed by the South Australian Soil and Plant Analysis Service (SASPAS) were marginally deficient to deficient in Zn. Manganese deficiency is the most severe micronutrient disorder for growth and development of barley in the well-watered calcareous coastal sands of SA. Less severe deficiency exists in widely distributed areas of Mallee soils, and in rendzinas and lunette soils of the lower South East of SA, through the eastern slopes of the Stirling Ranges in Western Australia (WA) and in the gravelly white gum soils in the western fringe of the WA wheat belt.

Applying fertiliser does not always correct Zn and Mn deficiency. Topsoil drying can reduce uptake of fertiliser Zn causing crops to rely on subsoil reserves of Zn. However, where subsoils are highly alkaline the availability of Zn is too low to meet the requirements of the crop. On the highly calcareous Mn-deficient soils, 90% of the fertiliser Mn is immobilised within a week of application and uptake is further decreased in the cool, wet winter months. Consequently, Mn deficiency develops even when recommended rates of Mn fertiliser are applied. In these circumstances, improving the ability of crops to utilise low supplies of micronutrients in the soil provides a cost-effective means of increasing yield under micronutrient stress (2). A ‘belt and braces’ approach of combining a nutrient-efficient genotype, using seed with high micronutrient content (5) and applying fertiliser will produce the most consistent increases in yield.

There is considerable genotypic variation both within and between cereals for micronutrient efficiency (measured as the relative yield of crops grown at low and high levels of micronutrient supply (2,3)). Genetic improvements in efficiency are possible as long as reliable methods of assessing efficiency can be developed. Screening in the field at nutrient-responsive sites and comparing yields at limiting and non-limiting rates of Zn or Mn has been used extensively to assess efficiency (2,3). However, the results can be variable because the severity of the nutrient deficiency varies between sites and seasons. Pot assays conducted under controlled conditions allow the relative efficiencies of genotypes to be assessed, but these are generally based on seedling growth rather than grain yield (1,5, 6). Developing molecular markers linked to the genes controlling efficiency has the potential to allow selection for improved efficiency independently of the environmental variability or the growth stage. This paper summarises some of the current work on screening for micronutrient efficiency in wheat and barley at the Waite Institute and describes the development of molecular markers to select for micronutrient efficiency.

Results

Zinc efficiency

Screening for Zn efficiency

Zinc efficiency is currently assessed in the field at Birchip in the Victorian mallee. Generally, yield responses to Zn are greater in durum and bread wheat than in barley (Table 1). The most inefficient lines of wheat and barley showed distinctive symptoms of Zn deficiency, such as reduced growth, pale leaves with chlorotic and necrotic lesions along the mid-vein. In 1999 a dry spring limited the yield response to Zn to about 0.5 t/ha, whereas, in 1998 yield increases up to 1 t/ha were measured. The disparity between the vegetative and the yield responses has tended to be greater in barley than in wheat. Nevertheless, consistent genotypic differences have occurred. The wheat cultivars Goldmark and Kukri have low Zn efficiency, while the widely adapted, high yielding cultivars Trident, Krichauff and Worrakatta are Zn-efficient. Within barley, a number of Japanese breeding lines (eg SBWI-1) are very inefficient, but many current cultivars from SA as well as Arapiles (Vic.) and Stirling (WA) show a high level of efficiency. Pot assays for Zn efficiency have been developed and generally show similar rankings to the field tests.

Table 1. Zinc responses and Zn efficiencies of barley and wheat genotypes at Birchip in 1999. The +Zn treatment received 7 kg Zn/ha at sowing plus 2 foliar sprays of 0.33 kg Zn/ha.

Barley				Wheat			
Genotype	Grain yield (t/ha)		Efficiency (%)	Genotype	Grain yield (t/ha)		Efficiency (%)
	Nil Zn	+Zn			Nil Zn	+Zn	
Arapiles	2.95	2.90	101	RAC893	3.27	3.42	96
Stirling	2.75	2.73	100	RAC891	3.50	3.69	95
Galleon	3.30	3.26	101	Worrakatta	3.13	3.40	92
Clipper	2.98	2.94	101	Krichauff	3.00	3.29	91
Chebec	3.34	3.31	100	Trident	3.19	3.51	91
Schooner	2.89	2.86	101	Frame	3.18	3.59	89
Keel	3.32	3.29	100	Halberd	2.85	3.22	89

Franklin	2.27	2.34	97	Janz	2.78	3.22	86
Gairdner	3.09	3.22	96	Goldmark	2.51	2.91	86
Barque	2.98	3.17	94	Cascades	2.58	3.15	82
Skiff	3.04	3.31	92	Kukri	2.51	3.19	79
Sloop	3.06	3.43	89	Yallaroi	2.22	2.86	78
Fitzgerald	2.46	2.98	83	Westonia	2.83	3.68	77
SBWI-1	2.15	2.85	75				
LSD (P=0.05)	0.33			LSD (P=0.05)	0.21		

Development of molecular markers

Wheat doubled haploid (DH) populations derived from the cross between Trident (efficient) and Songlen (inefficient) have been produced to develop molecular markers for Zn efficiency. These populations are currently being screened in the field for the first time.

Progress has been made in developing markers for seed Zn. Seed Zn content is important to the nutritional value of the grain (9) and it influences the early vigour of the crop (1,7). A Clipper x Sahara 3771 DH population was used to examine Zn loading into the grain of barley. Seed Zn concentrations ranged from 43 mg/kg to 101 mg/kg and seed Zn content from 1.6 µg/seed to 4.8 µg/seed. Three RFLP markers were significantly associated with seed Zn concentration, seed Zn content and with seed weight. The presence of all three alleles for high seed Zn increased Zn concentration by 53% and Zn content by 75%, compared to all low-Zn alleles being present.

Manganese

Screening for Mn Efficiency

Field screening for Mn efficiency is conducted at Marion Bay on the lower Yorke Peninsula, SA. The range in Mn efficiency in wheat and barley is consistently greater than the range for Zn efficiency (Table 2). In the most inefficient barley genotypes, yield responses to fertiliser Mn of 2-3 t/ha are recorded consistently and in wheat the responses for the worst lines are about 1-2 t/ha. Durum wheat is inefficient and the best durum lines are still within the lower range of efficiencies of bread wheat. Apart from grain yield, Mn concentration and Mn content of seedlings discriminate well between genotypes and provide rankings that are consistent with the yield results. A pot bioassay, based on Mn uptake of seedlings grown in a Mn-deficient soil, has been developed (4,8). The bioassay gives results consistent with the field data and has been used in marker development in durum wheat and barley.

Table 2. Manganese responses and Mn efficiencies of barley and wheat genotypes at Marion Bay in 1998

The +Mn treatment received 20 kg Mn/ha at sowing plus 2 foliar sprays of 1.12 kg Mn/ha .

Barley				Wheat			
Genotype	Grain yield (t/ha)		Efficiency (%)	Genotype	Grain yield (t/ha)		Efficiency (%)
	Nil Mn	+Mn			Nil Mn	+Mn	
WA 73S276	2.93	3.29	90	RAC 868	2.43	2.82	86
WI 2986	2.94	3.38	86	WI 94091	2.06	2.68	77
Amagi Nijo	1.58	1.96	81	Trident	1.86	2.54	73
SloopBC2-1	2.48	3.37	74	Janz	1.71	2.48	69
SloopBC2-2	2.43	3.39	72	Worrakatta	2.02	2.95	68
Vic 9307	2.34	3.31	71	Westonia	1.78	2.80	64
WA0563	2.26	3.65	62	Yitpi	2.03	3.20	63
Stirling	1.96	3.19	61	Cascades	1.34	2.19	61
Chebec	1.92	3.65	53	Frame	1.87	3.09	61
Sloop	1.77	3.41	52	Krichauff	1.73	3.03	57
Arapiles	1.59	3.29	48	Wilgoyne	1.17	2.10	56
Keel	1.64	3.56	46	Halberd	1.19	2.58	46
SBWI-1	1.26	3.03	42	Yanac	1.03	2.44	42
Schooner	1.25	3.04	41	Yallaroi	0.93	2.28	41
Galleon	1.31	3.24	40	LSD (*P*=0.05)	0.44		
Gairdner	1.24	3.13	40				

Fitzgerald	1.27	3.67	35
Barque	1.11	3.73	30
Skiff	0.67	3.56	19
WI 2585	0.53	3.14	17
LSD (*P*=0.05)	0.54		

Development of molecular markers

Development of molecular markers for Mn in barley is more advanced than marker development for Zn efficiency. Pallotta et al. (6) first mapped a Mn efficiency locus, *Mel 1*, to chromosome 4HS in an F_2 population of a cross between WI 2585 (Mn inefficient) and Amagi Nijo (Mn efficient). Recently, a DH population developed from these parents was used to further map the major *Mel 1* locus to within a short 1.4 cM interval on 4HS. *Mel 1* is associated with shoot Mn concentration.

Mel 1 explained less than half the observed genetic variation in the field and it has not been used extensively in barley breeding programs. The *Mel 1* locus appears to be associated with maturity, which may confound the Mn response in the field. Recent work, using DH lines with similar maturity, has identified another locus for Mn efficiency, which is more strongly associated with Mn efficiency in the field. Like *Mel 1*, this locus is associated with shoot Mn concentration. The second locus for Mn efficiency has been mapped to chromosome 2HL. Additional field work is being conducted this year to confirm the importance of the second locus to Mn efficiency.

Marker development in durum wheat has been based on a population derived from the cross between Stojocri 2 (moderately Mn efficient) and Hazar (Mn inefficient). Analysis of this material suggests that Mn efficiency is controlled by at least 2 genes with an additive effect. Two markers linked to Mn efficiency have been identified and these explain 40% and 45% of the genetic variation respectively.

Discussion

Zinc

There is significant genetic variability in Zn efficiency, which provides the foundation for genetic improvement in Zn efficiency in wheat and barley. Even a small increase in efficiency can increase yield substantially without additional fertiliser (Table 1). However, the severity of Zn deficiency in the field is variable. Symptoms of Zn deficiency tend to be most evident in late winter, but may decline during spring. Yield responses to Zn are sometimes less than those expected from the visual symptoms early in the growing season. This variability has hampered progress in improving Zn efficiency and delayed the development of molecular markers. Many of the SA wheat and barley varieties show reasonable levels of efficiency, whereas a number of the breeding lines from the Victorian wheat program are inefficient. Improving the Zn efficiency within the Victorian breeding program may help to improve productivity on the alkaline soils of the Victorian mallee. The results for seed Zn content are encouraging and suggest that it is feasible to select for high seed Zn content using molecular markers.

Manganese

More progress has been made in understanding the genetic control of Mn efficiency and in developing markers for Mn efficiency, compared to Zn efficiency. The reasons for this are related to the severity of the nutrient deficiency and the reliability of the growing season at Marion Bay. This has allowed better discrimination between efficient and inefficient genotypes, which has underpinned the successful development of molecular markers for Mn efficiency in barley and durum wheat. Many barley genotypes released from WA appear to have a high level of Mn efficiency, which suggests that there may have been passive selection for Mn-efficiency within the WA breeding program. It also suggests that low availability of Mn may be a chronic problem in many WA soils where barley is grown.

Soils low in available Mn occur in many of the cooler, wetter areas of SA where there is considerable potential for production of malting-quality barley. The poor Mn efficiency of barley compared to wheat may have limited barley production in these areas. A number of the SA malting barely varieties show relatively poor Mn efficiency, so improved Mn efficiency may enable increased production of malting barley in some of the higher rainfall areas of the state.

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Conclusion

The genetic variation in Zn and Mn efficiency will allow more efficient genotypes of wheat and barley to be developed. In barley and durum wheat, progress has been made in developing molecular markers to improve selection for Mn efficiency. The development of markers for Zn efficiency has been slower, but suitable populations are now being screened.

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