Understanding the contribution of root traits for phosphorus responsiveness of wheat

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List of abbreviations

Al	Aluminum
AMF	Arbuscular Mycorrhizal Fungi
ANOVA	Analysis of Variance
ATP	Adenosine tri-phosphate
BLUEs	Best Linear Unbiased Estimates
BLUPs	Best Linear Unbiased Predictions
C	Carbon
Ca	Calcium
Cu	Copper
DAP	Di Ammonium Phosphate
DCP	Di Calcium Phosphate
D-LDH	D-Lactate Dehydrogenase
DH	Double Haploid
DM	Dry Matter
Fe	Iron
HAP	Hydroxyapatite
L-MDH	L-Malate Dehydrogenase
LOD	Logarithm of Odds
LR	Lateral Root
LRS	Likelihood Ratio Statistic
LSD	Least Significant Difference
MAP	Mono Ammonium Phosphate
MDH	Malate Dehydrogenase
Mg	Magnesium
N	Nitrogen
NADH	Nicotinamide Adenine Dinucleotide
NPK	Nitrogen Phosphorus Potassium
P	Phosphorus
PAE	Phosphorus Acquisition Efficiency
PUE	Phosphorus Uptake Efficiency
PR	Primary Root
QTL	Quantitative Trait Loci
RDW	Root Dry Weight
RO	Reverse Osmosis
RHL	Root Hair Length
S	Sulphur
SDW	Shoot Dry Weight
SNP	Single Nucleotide Polymorphism
SRA	Specific Root Area
SRL	Specific Root Length
SSP	Single Super Phosphate
TRL	Total Root Length
TSP	Triple Super Phosphate
Zn	Zinc

Abstract

Wheat is a major and widely-grown cereal crop around the world. Phosphorus (P) is a crucial element for plant growth and development, but the availability of soil P is very low. The low availability of soil P poses a serious nutritional constraint for plant growth. To combat the large difference between the P requirement for plant growth and the available soil P, plants have developed a number of root-based adaptive strategies to cope in low P environments. Crop improvement to increase P uptake efficiency will depend on exploiting one or more of these adaptive strategies.

To understand the contribution of a number of adaptive mechanisms of wheat varieties under P deficiency, a series of controlled environment experiments and some field studies were conducted. Ten bread wheat varieties were selected which have shown differential responses to applied P in a previous series of field trials over different sites and seasons. According to their response to P, varieties were categorised as non-responsive or responsive varieties. Non-responsiveness to applied P is indicative of high phosphorus use efficiency (PUE) which was considered to be the preferred trait. The study compared several root traits, which have been demonstrated to contribute to plant growth under P deficient conditions: seminal and crown root angle, root hair length, rhizosheath size, arbuscular mycorrhizal fungi (AMF) colonization and organic acid releasing capacity. Based on the results of these experiments, a further study was done to identify quantitative trait loci (QTL) for rhizosheath size and root hair length.

The findings of these experiments suggests that wide crown root angle, rather than seminal root angle, was associated with the non-P responsive varieties. These varieties benefit from shallow crown roots at later stages of their growth cycle when the demand for P increases. The non-responsive varieties also had longer root hairs regardless of

soil type or P treatments, and this was associated with a greater rhizosheath size. From these experiments, it was concluded that longer root hair length, greater rhizosheath size and shallow crown root are traits that contributed to the better performance in the field of the non-responsive varieties. Multivariate analysis for the all the traits also support this as most of the non-responsive varieties clustered together. Cluster analysis for shoot dry weight at nil P treatment and from two different soils in these experiments demonstrated that the ranking of varieties were similar to the ranking of varieties from the field based on the yield response.

QTL analysis was performed using a double haploid wheat population to understand the relation between root hair length and rhizosheath size. Despite the weak phenotypic correlation between root hair length and rhizosheath characteristics, co-located QTL were detected on chromosome 7A, a result consistent with reports from the literature supported. Four novel QTLs were detected for rhizosheath size from this study. Co-localization of other QTLs on chromosome 2A, 4B and 5A was also observed and information from available literature suggests that those chromosomal regions are important for yield and yield related components.

A significant difference among varieties was observed for AMF colonization, but it was not possible to relate this variation with the varietal P responsiveness. Varietal difference was also observed for the citric and malic acid concentration in the rhizosheath soil, but it was also not possible to relate that difference with the observed difference in varietal P responsiveness from field.

This study suggested that selection of varieties with more than one adaptive mechanisms to grow well under P deficient conditions is possible. Selection based on greater root hair length, greater rhizosheath size and wide crown root angle appears to be most crucial adaptive mechanisms for growth and yield under P deficiency. Selection of varieties with more than one mechanisms will allow the variety to grow well under wide range of environmental conditions without compromising yield. The chromosomal region identified from this study can be selected for gaining further understanding on the genetic control of those traits and could be targeted for marker aided selection to improve wheat varieties. Future work should consider the genetic control and inheritance of these root traits to develop new varieties with less P dependency and greater capacity to acquire of soil P.

Declaration

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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