Genotypic variation in water potential at different positions and water conductance in rice

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Abstract

An experiment was conducted under glasshouse conditions to determine genotypic variation in plant water potential (ψ) at different positions of the plant, namely leaf tip, leaf base, leaf sheath and stem base. The variation in ψ under stress conditions was associated with the ability of a genotype to conduct water within the plant in relation to the anatomy of vascular bundles. The leaf tip water potential (ψ_{lt}) was always lower than other positions and the gradient was consistent with the progress of water stress for the 6 genotypes. The total xylem cross section area in the stem varied from 34960 to 93760 ψ m^2. Genotypic variation in maintenance of high leaf water potential (ψ_l) was associated with large xylem size and hence high internal water conductance. Water potential was also positively associated with variation for cross section area of the stem among genotypes, which ranged from 16.0 to 34.8 mm^2. Therefore, the number of vascular bundles was positively associated with ψ at different plant positions within a genotype.

Key words

Rice, Leaf water potential, vascular bundles, xylem cells, and stem area.

Introduction

Drought is a major constraint for yield stability of rainfed rice in Asia. Water deficit during the vegetative stage has been reported to have a strong effect on the morphology of plants, for example leaf expansion, leaf rolling, leaf death, plant height and tiller number (O'Toole and Cruz, 1980). Maintenance of high ψ_l is an induced drought resistance trait and may be useful as an indirect selection criterion for improving drought resistance of rainfed rice (O'Toole and Moya, 1978). While genotypic variation in ψ_l is well documented, the ψ gradient within the conductive tissues of the rice plant has not been well characterised. Jongdee (1998) reported that difference in ψ in different plant parts such as leaf, panicle and stem at predawn and midday were significant under well water conditions. Further, he suggested that the difference in ψ_l among lines was due to differences in capacity of their conducting tissues to transport water from the stem base to leaves. Turner *et al.* (1984) demonstrated that the hydraulic conductance differed among plant species, and the large decrease in ψ_l under water deficit in some species was partly due to lower conductance. Genotypic variation in ψ at different positions and internal water conductance in rice may be related to the anatomy of vascular bundles at these positions of the plant.

The main objectives of this study were; first to determine the ψ gradient within the plant and it's consistency across genotypes, and second to investigate the variation in ψ among genotypes in relation to anatomical differences within their vascular bundles and stem area.

Materials and methods

The experiment was conducted in a glasshouse during the1999 - 2000 summer season at the University of Queensland, Brisbane. The temperature in the glass house was between 28-32?C and varied about 2-3?C from the outside temperature. There were 6 genotypes namely Lemont, L36, L77, L28, L29 and L49, with contrasting ability to maintain ψ_l under water stress conditions (Jongdee,1998). Lemont and L36 maintained higher ψ_l than that of L28 and L77.

The six genotypes were planted (2 plants per pot) in pots filled with 3.5 kg of sandy loam soil with uniform soil moisture conditions. Pots were allocated in 4 replications and were re-randomised within the replications weekly. Adequate amounts of fertiliser and water were applied to ensure that nutrient and water supply were not limiting growth until the stress treatment commenced. The water stress condition was imposed after 79 days of sowing. Before the imposition of stress, soil moisture content was adjusted to a constant level in all pots by adding water to the pots. There was a control treatment (non-stress) with the same genotypes planted in 2 replications.

Plant ψ was measured 5 times during the 10 days of the stress cycle with a pressure chamber using the technique described by Bars and Weatherly (1962). These measurements were taken from 4 positions of the plant, namely the leaf tip, leaf base, leaf sheath and stem base of the main stem. Before the imposition of stress the primary stems were collected from plants of 6 genotypes in each replication and preserved in a 50% alcohol medium for microscopic study of vascular anatomy. These samples were used to determine the number of vascular bundles, number of xylem cells within vascular bundles, size of xylem (large vascular bundle from stem) and the area of stem cross section at the different positions of each line. Cross sections of the leaf tip, leaf base, leaf sheath and the stem were taken and observed under the microscope with varying magnifications. The diameter of the inner and outer stem was measured using the microscope with a 15x magnification to determine cell area of the stem. In addition, the diameter of 5 random xylem cells of large vascular bundles of the stem was measured under the microscope using a 100x magnification. Xylem area was calculated from those diameters for each line. Samples for ψ measurements were taken from the same positions of the stress plants. Rate of development of water stress in each position was estimated by taking the difference of first and the last ψ values of the stressed plant divided by number of days of the stress cycle. Analyses of variance were conducted for each time of measurement separately for the 4 positions of the plant. The significance of variation among genotypes and plant positions and their interaction were analysed.

RESULTS AND DISCUSSION

Maintenance of water potential among genotypes

Differences in pattern of water use and the capacity to conduct water from roots to leaf tip were important in the maintenance of ψ_l within the plant. The results showed genotypic variation in plant ψ at different plant position and for the maintenance of ψ_l . The ψ of different positions of the 6 genotypes at 0 and 10 days after imposition of stress are shown in Table 1. Lemont maintained the highest plant ψ, while L77 maintained the lowest at any of the positions in the plant. Stem base water potential (ψ_{SB}) decreased the least during the stress period. L28 and L77 showed the highest rate of development of stress in the stem base, which ranged from -0.24 to -0.83 Map and -0.25 to -1.00 Map at 0 and 10 days after stress, respectively. This trend was consistent across the plant positions of the six genotypes. The rate of development of water stress was highest in the leaf tip compare to the other positions. L77 (-0.8 to -3.55) and L28 (-0.79 to -2.40) recorded the lowest leaf tip water potential (ψ_{lt})at the end of the stress cycle.

Table 1. Comparison between non-stress and stress ψ values of stem base (ψ_{SB}), leaf sheath(ψ_{LS}), leaf base(ψ_{lbw}) and leaf tip (ψ_{lt})of 6 rice genotypes in glasshouse conditions.

	ψ_{SB} (map)		ψ_{LS} (map)		ψ_{lbw} (map)		ψ_{lt} (map)	
Genotypes	0 DAIS	10 DAIS	0 DAIS	10 DAIS	0 DAIS	10 DAIS	0 DAIS	10 DAIS
Lemont	-0.09	-0.33	-0.43	-0.78	-0.51	-1.03	-0.58	-1.30
L29	-0.10	-0.48	-0.38	-1.27	-0.39	-1.48	-0.55	-1.78
L49	-0.13	-0.43	-0.35	-1.13	-0.43	-1.52	-0.58	-1.65
L36	-0.18	-0.45	-0.38	-0.75	-0.44	-1.50	-0.63	-2.03
L28	-0.24	-0.83	-0.49	-1.57	-0.64	-1.96	-0.79	-2.40
L77	-0.25	-1.00	-0.64	-2.10	-0.73	-2.98	-0.80	-3.55
Mean	**-0.16**	**-0.58**	**-0.44**	**-1.27**	**-0.52**	**-1.75**	**-0.65**	**-2.12**

lad 0.05	ns	0.34	ns	0.60	ns	0.64	0.20	0.90

The mean values of ψ_{SB} were -0.16 and -0.58 map at 0 and 10 days after stress, respectively. Before the imposition of water stress, ψ in the stem base, leaf sheath and leaf base was not different among genotypes. Similarly, Jongdee (1998) found that ψ_{SB} did not vary among genotypes at the early stage of the stress cycle, but was significant among genotypes after 7 days in the stress cycle under lowland conditions. Decline in midday plant ψ at different positions was consistent among genotypes. L77 and L28 could not maintain a high ψ_{lt} when transpiration demand increased. However, Lemont showed an ability to maintain higher ψ_{l} (-0.58 to - 1.30 Map) at the same period of the stress cycle. Jongdee (1998) reported that L28 had the lowest midday ψ_{l} compared to other rice genotypes after 14 days of a water stress period. He reported that ψ_{l} of L28 could decline as lower as -3.50 map under severe lowland stress conditions.

The differences in midday ψ_{l} could be due to the differences in internal water conductance and it could be related to differing capacity to conduct water from roots/stem base to leaves. Fukai *et al.* (1985) found differences in whole plant water conductance among rice lines. Results in this experiment showed that the gradient of plant ψ at different plant positions was consistent. The stem maintained highest ψ, followed by the leaf sheath, the leaf base and the leaf tip. Turner (1982) suggested that the capacity of roots to take up water would have a limited impact on ψ_{l}, if the stem had a high resistance to water flow. Jongdee (1998) reported that the ψ_{SB} was relatively high, even when gravimetric soil moisture content was low (13.6% to 18.3%) and leaf drying was observed. This suggests that internal conductance of water from the stem base to the leaf may be an important factor determining genotypic variation for ψ_{l} under water stress conditions.

There is limited information available on genotypic variation for maintenance of plant ψ at different positions in the rice plant. In this experiment, the 6 genotypes showed significant genotypic variation for maintenance of plant ψ at 4 plant positions at the end of the stress cycle. These results suggested that Lemont maintained the highest plant ψ and L77 the lowest. This variation could be associated with the rate of development of plant ψ at different positions in each genotype. Line77 had the highest rate of development of water stress at different plant positions where as, Lemont had the lowest.

The number of vascular bundles among lines

The experiment investigated whether the variation in plant ψ at different positions was associated with the ability to conduct water within the plant as affected by the size of the xylem cells and number of vascular bundles. The number of vascular bundles at different positions, xylem diameter, stem cross section area and total xylem area of the 6 rice genotypes are shown in Table 2. The density of vascular bundles depended upon the tissue area of the plant position. The stem base was the largest cross section area of the plant and could maintain a higher number of vascular bundles than other plant positions. The leaf tip had the smallest cross section area and had a relatively low number of vascular bundles. There was a variation among genotypes for the number of vascular bundles in each position, except for the leaf sheath (LS). However, the association between plant ψ at different plant positions and number of vascular bundles in each position across genotypes was poor (R^2=0.07).

Table 2: Number of vascular bundles at different positions namely leaf tip(lt), leaf base (lbw), leaf sheath (LS) and stem base (SB) and diameter of xylem, stem cross section area and total xylem area of six rice genotypes. (lv=Large vascular bundles and sv=small vascular bundles).

Lines	**Number of vascular bundles**				Xylem diameter (?m)	Stem area (mm^2)	Total xylem area ($?m^2$)
	lt	lbw	LS	**SB lv sv**			

Lemont	11.5	20.5	38.5	32.0	29.8	33.8	24.0	58100.0
L29	14.5	24.5	38.5	34.3	32.3	41.8	34.8	93760.0
L49	14.0	20.5	39.0	30.0	29.8	36.2	21.3	62580.0
L36	13.5	22.0	39.5	35.0	33.0	32.5	20.8	59360.0
L28	10.5	18.5	38.5	32.8	32.3	31.8	16.8	52080.0
L77	13.5	19.5	39.0	33.5	32.3	25.8	16.0	34960.0
Mean	**12.9**	**20.8**	**38.8**	**32.9**	**31.5**	**33.6**	**22.3**	**60140.0**
lad 0.05	0.86	0.71	ns	2.99	ns	4.72	8.21	19734.0

Plant ψ at different positions showed an association with the respective xylem area and stem area of each genotype. Generally, ψ_l tended to increase with the increasing size of xylem area. When xylem area was increased up to 58100 ψ m^2 from 34960 ψ m^2 in the stem, the ψ_{lt} was increased up to -1.3 map from -3.55 map (Figure 1). However, there was no significant increased in ψ in the 4 positions of the four genotypes, Lemont, L36, L49 and L29 when the xylem area of the stem base increased beyond this limit. Generally, genotypes with the stem xylem area larger than 58100?m^2, had similar hydraulic conductance through the xylem cells in all positions and expressed higher ψ than genotypes with less stem xylem area.

Similarly, genotypes with larger stem area showed an ability to maintain higher ψ at all positions than genotypes with lower stem area (Figure 2). When the stem area increased from 16 to 24 mm^2, ψ_{lt} tended to increase from -1.30 map to -3.55 map. However, any increment in stem area beyond this limit did not show a further increase in hydraulic conductance through the 4 positions of those genotypes. These results suggested that the genotypic variation in plant ψ could be associated with xylem and stem area of these rice genotypes but not with the number of vascular bundles or number of xylem cells in the stem.

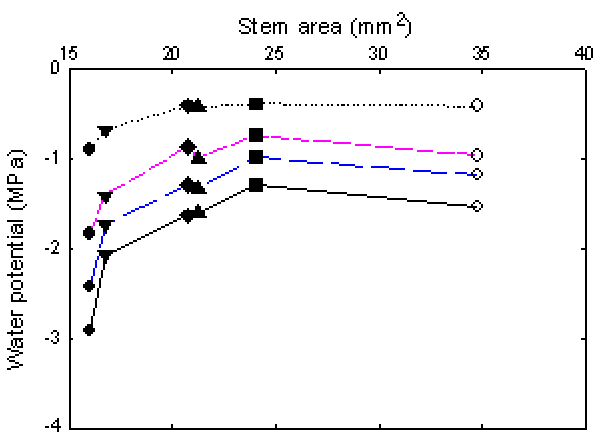

Figure 1: **Comparison between ψ (map) at different plant positions; leaf tip (solid line), leaf base (long dash line), leaf sheath (short dash line) and stem base (dotted line) of six rice genotypes; Lemont (■), L28 (▼), L29 (O), L36 (◆), L49 (▲) and L77 (●) and xylem area ψ m^2 (large vascular bundle of stem base).**

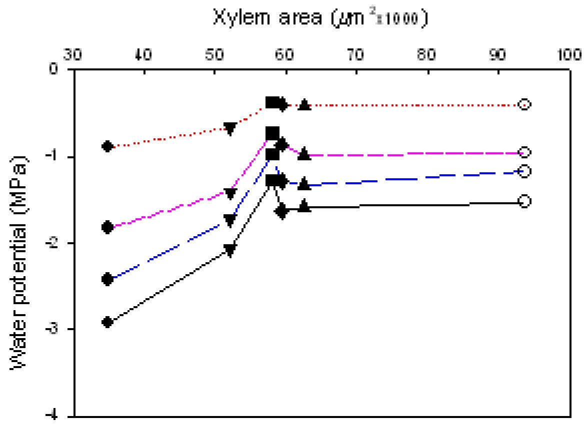

Figure 2: **Comparison between ψ (map) at different plant positions; leaf tip (solid line), leaf base (long dash line), leaf sheath (short dash line) and stem base (dotted line) and stem area mm^2 of six rice genotypes; Lemont (■), L28 (▼), L29 (○), L36 (◆), L49 (▲) and L77 (●).**

CONCLUSION

It is concluded that genotypic variation in ψ can be identified at the stem base, leaf sheath, leaf base and leaf tip of the plant. However, the magnitude of ψ was larger at the leaf tip in comparison with the other positions. The total xylem area at the stem base varied among 6 rice genotypes. Maintenance of high ψ_l was associated with large xylem size and hence internal water conductance. Plant ψ at different plant positions was also associated with the cross section area of the stem base, but was not associated with the number of vascular bundles possessed by the genotype. The ψ gradient from the stem base to leaf tip was consistent among the genotypes examined in this experiment. Differences in hydraulic conductance within vascular bundles along the plant could cause the observed genotypic variation in ψ_l in rice.

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