GENOTYPIC VARIATION FOR GRAIN YIELD OF RICE UNDER WATER DEFICIT CONDITIONS

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Abstract

Drought is a major problem for rice grown under rainfed conditions in Asia. In this study, several attributes related to drought resistance were examined for their contribution to grain yield under water limiting conditions. A population of inbred lines derived from a bi-parental cross was examined under both upland and lowland stress conditions. Flowering time in relation to the water stress development was found to be important in determining grain yield. Variation for osmotic adjustment was not related to grain yield under water limited conditions. However, variation for leaf water potential was consistent across experiments and was associated with spikelet sterility and also grain yield. Genotypes that can maintain high leaf water potential are suitable for water limiting conditions. The mechanisms for the maintenance of leaf water potential are discussed.

Key words: Rice, grain yield, and water deficit.

Rainfed lowland rice accounts for 26% and upland rice for 13% of world rice growing areas with only 17% and 4% of total rice production, respectively (1). The majority of these rainfed rice areas are found in Asian countries. Drought is a major problem which causes low productivity for rainfed rice. An effort to improve productivity by improving drought resistance in cultivars has been made in recent years but progress is slow. O'Toole (5) argued that improved drought resistance may be achieved by selecting for physio-morphological traits that contribute to drought resistance, and suggested several such traits for rice. However, limited work has been conducted to evaluate genotypic variation for putative drought resistance traits, particularly in relation to their impact on grain yield (3).

Leaf water potential has been recognised as an indicator of plant water status, while osmotic adjustment is an adaptive process which assists in the maintenance of turgor under water limiting conditions. It has been reported that there was genotypic variation in mainten-ance of leaf water potential and expression of osmotic adjustment among rice genotypes with diverse genetic backgrounds and environments of origin (6, 4). The main objectives of this work are to determine the extent of genotypic variation in a population of inbred lines and the contribution of the maintenance of leaf water potential and osmotic adjustment to grain yield.

Materials and methods

Field experiments were conducted at The University of Queensland Farm, Redland Bay from 1994 to 1997. A population of 23 randomly selected inbred lines obtained from a bi-parental cross (Lemont and BK88-BR6) was used in all experiments. The experiments were conducted under control (irrigated) and water deficit conditions at different stages of growth; vegetative, booting and flowering. Under water deficit conditions, a rainout shelter was used to prevent rain falling on to plots during the stress period. Attributes examined were leaf water potential (LWP), osmotic adjustment (OA), grain yield and spikelet sterility. The 5 experiments were:

- Water deficit at vegetative stage for 25 lines (including parents), which were grown under isolated plant conditions with wide spacing of 40 x 80 cm. The stress was imposed at 39 days after planting for 42 days.

- Water deficit at flowering stage for 24 lines as experiment 1 except that 1 line was excluded. There were different flowering dates among lines, and water deficit was imposed for 21 days when the earliest lines started to flower.

• Water deficit at booting to flowering for 21 days in one treatment and water deficit at flowering to maturity in another treatment for 14 lines with similar flowering dates.

• Effect of plant size on the maintenance of leaf water potential and biomass production during water deficit at the vegetative stage. Two lines which contrasted in maintenance of LWP, from the same population were used. Plants were grown at 3 plant densities and 2 planting dates to vary size of the crop canopy. Water deficit was imposed during the vegetative stage (43 and 29 days after planting for planting date 1 and 2, respectively).

• Water deficit at flowering stage for 4 lines under lowland and upland conditions. The lines differ-ed for maintenance of LWP.

Results and discussions

Variation for leaf water potential

LWP was measured at predawn (12.00-2.00 am) and midday (12.00-2.00 pm) on several occasions after imposing water deficit in each experiment. In general, LWP declined continuously with time after imposing water deficit for both predawn and midday. Genotypic variation among lines was observed in every experiment under water deficit conditions. Based on data from Experiment 1, variance components and their approx-imate standard errors were estimated from the combined analysis of 25 lines at 7 measurements (time) and 2 times of day (period) (Table 1). Variation between predawn and midday (period) was large (46.5%) compared to variation with time of stress period (time) (22.2%). The slow LWP development with time was a result of the wide spacing used in Experiment 1. Genotypic variation was relatively small (2.2%) compared to the experimental error (13.9%), but there was significant variation among lines.

There was consistent genotypic variation in mainten-ance of LWP across experiments. The relationship for genotype means across time of measurements in Experiment 1 and Experiment 2 was significant (r^2 = 0.42) for all 24 lines and for the 14 lines that flowered during stress period (r^2 = 0.78).

Two lines contrasting in maintenance of LWP were grown under varying plant densities and planting dates to examine whether the difference in LWP can be explained by the difference in plant size (Experiment 4). It was found that plant size had an influence on development of LWP as large plant size used more water and LWP declined more rapidly. However, plant size alone could not explain the genotypic variation as the difference between lines still existed for similar plant sizes. Water potential for stem (at ground level), leaf and panicle were determined in Experiment 5. The results revealed that stem water potential was similar in all lines at any time of measurement but the genotypic differ-ences were observed for leaf and panicle water potential. The results suggest that there were differences in internal plant water conductance, which caused the genotypic variation in LWP.

Variation for osmotic adjustment (OA)

OA was estimated as the difference in osmotic potential at 100% relative leaf water content between well watered plant and stressed plant. Development of OA was associated with development of LWP (Fig 1). In this experiment there was consistent genotypic variation in OA for 3 lines (line 62, 65 and 66) that had high OA and 3 lines (Lemont, line 49 and 50) that had low OA when stress developed slowly. However, significant genotypic variation in expression of OA was not always observed at each time of measurement. One reason for this was large errors in estimating OA. Based on combined analysis of data from Experiment 1, the genotypic variation for OA was greater than LWP but experimental error for OA was large (38.1%) relative to that for LWP (13.9%) (Table 1). On the other hand, genotypic variation in OA fluctuated from time to time of the measurements as period by time interaction was large (21.6%) relative to period and time (6.9 and 10.3%, respectively).

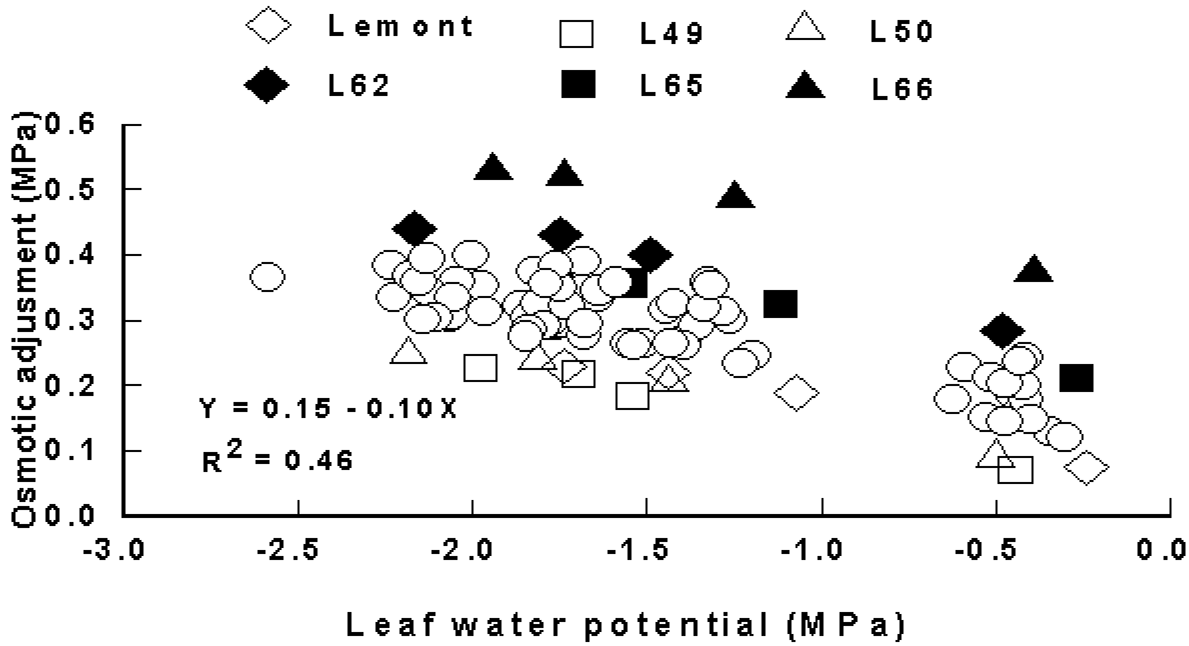

Figure 1

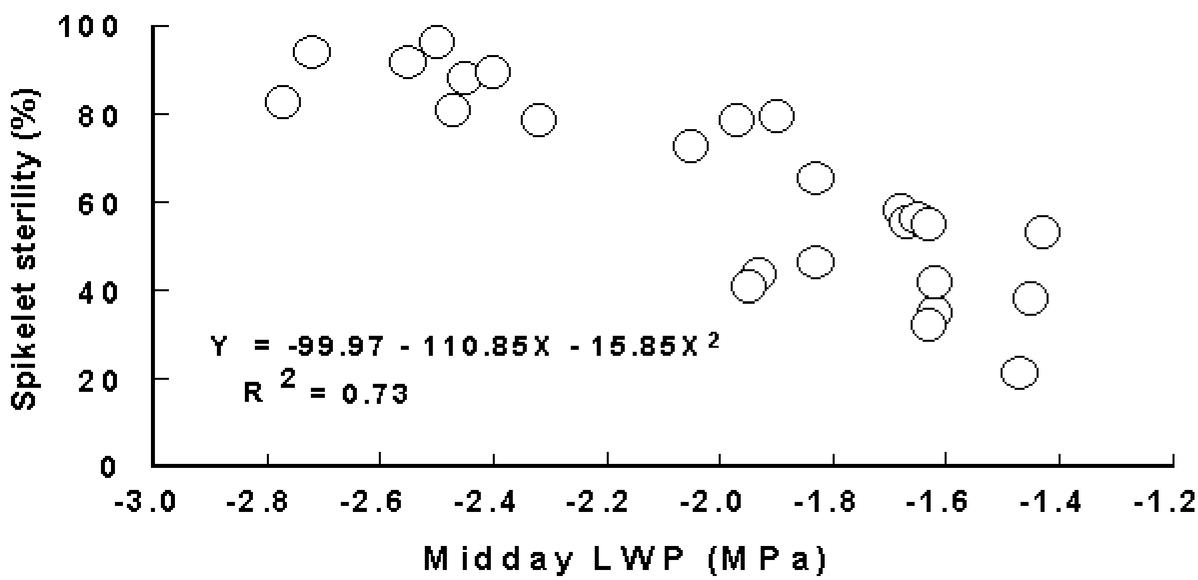

Figure 2

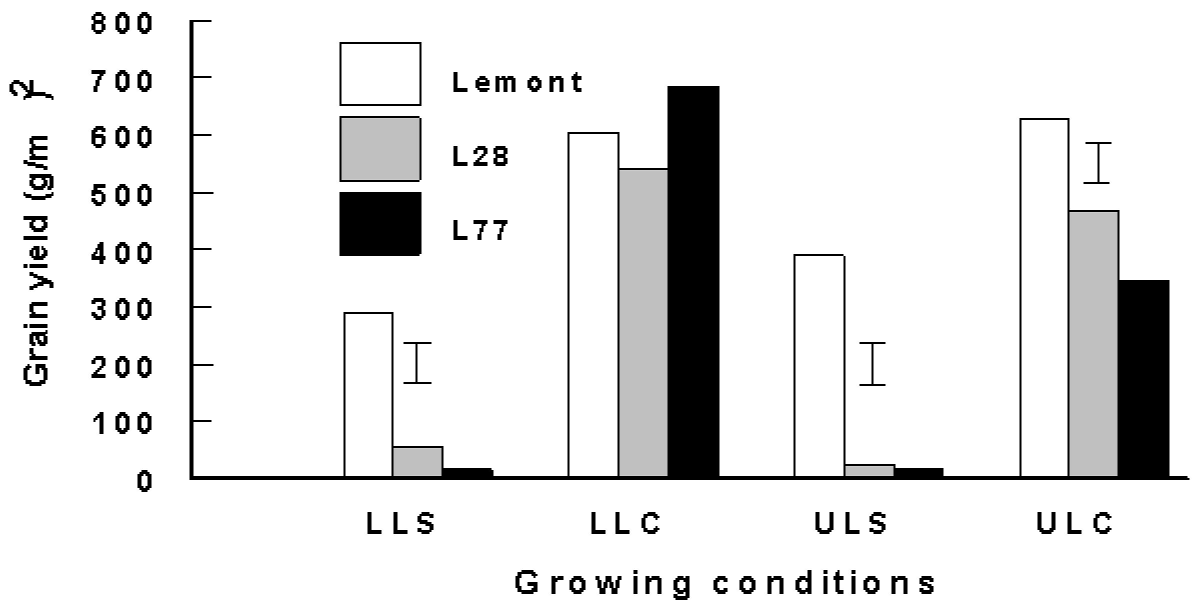

Figure 3

Across the experiments, the magnitude of OA development and genotype ranking for OA was not consistent. This is because the expression of OA depended on not only degree of stress but also rate of stress develop-ment, and genotypes responded differently to rate of stress development. Experiment 1 had slower rate of stress development than Experiment 2 in general, but some lines were able to maintain a similar rate of water deficit development in both experiments. For lines which were able to maintain a slow rate of stress development, the degree of adjustment was consistent across experiments. In contrast, degree of adjustment was less for lines in which LWP declined rapidly. Nevertheless, some lines were able to maintain similar degrees of OA at any rate of stress. Because there was a difference in rate of LWP development in each experi-ment, mean maximum OA varied from 0.7 MPa for Experiment 1 when stress developed slowly, to 0.2 MPa for stress at flowering stage in experiment 2.

Spikelet sterility

In Experiment 2 when 24 lines of different phenology development were used, percent spikelet sterility of a genotype was associated with days to 50% flowering and midday LWP at 7 days after imposing water deficit with r2 of 0.45 and 0.37, respectively. The multiple regression for combined effect of days to 50% flowering and midday LWP improved r2 to be 0.50. In order to eliminate the effect of the phenological differences, panicles emerged at the same day were tagged at 7 and 14 days after imposing water deficit for flowering stage stress (Experiment 3). During flowering stage stress, the percent spikelet sterility had strong association with midday LWP. The relationship for combined data from 7 and 14 days after imposing water deficit was strong with r2 of 0.73 (Fig. 2). Ekanayake *et al.* (2) reported that low panicle water potential (PWP) inhibited spikelet opening which caused spikelet sterility. The results from Experiment 5 showed that leaf and panicle water potential were generally similar and a difference was observed only when stress was severe, in which case PWP was higher than LWP. Therefore, lines that are able to maintain high LWP under water limitation would also be able to maintain high PWP and would have low spikelet sterility.

Grain yield

Three lines with similar time of flowering and grain yield under irrigated condition but that differed in maintenance of LWP under water deficit conditions were chosen from the population and were used to investigate the association between LWP and grain yield under lowland and upland stress conditions in experiment 5. In the control, grain yield was the same for all 3 lines under lowland conditions but there were differences under upland conditions (Fig. 3). Lemont produced the same yield in both conditions but the yield of line 77 decreased greatly under upland conditions. The reduction in grain yield under upland control was due to the reduction in grain weight with other yield components were the same. In stress, grain yield decreased more than 50% and there was significant genotypic variation under both lowland and upland conditions. Yield reduction due to stress was rather small for Lemont a line that can maintain high LWP, while large reduction was observed for lines 28 and 77, which both had low LWP. This reduction was mainly due to the large increase of spikelet sterility percentage.

Conclusion

Leaf water potential in rice has shown to be a promising trait that indicates good adaptation to water limited environments. The results showed that there was genotypic variation for the maintenance of leaf water potential and it was consistent under water deficit conditions across times and experiments. The maintenance of leaf water potential is indicative of drought resistance that minimises the impact of stress on grain yield, mainly by reducing the effect of stress on spikelet sterility. While genotypic variation in expression of OA was found in some occasions, any contribution to drought resistance could not be demonstrated. This may be due to the large errors involved in estimating OA. In addit-ion, expression of OA depends on the degree of stress and also rate of stress development, and this makes it difficult to select genotypes with high OA under field conditions.

Acknowledgments

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