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Genetics of Leaf Water Potential and its Relationship with Drought Avoidance Components in Rice (*Oryza sativa* L.)

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Abstract: Leaf water potential (Ψ leaf) was measured in culture solution in hydroponic system under controlled condition of the two crosses involving diverse rice genotypes to investigate the inheritance pattern and heritability. Polygenes were involved in this trait and the Ψ leaf was governed either by no-dominant or partial dominant alleles and that was controlled by genes with additive effects in upland and hill rice. The heritability estimates were low (25-28%). Leaf water potential was significantly and positively correlated with root thickness, root volume, root length, plant height and leaf area in one of the two crosses. Negative relationship was found with shoot dry weight.

Key words: Leaf water potential, genotypes, heritability

Introduction

Leaf water potential (Ψ leaf) estimation is considering one of the important quantitative measurements of drought resistance of crop (Ekanayake ***et al.***, 1985; O'Toole and Moya, 1978 and Bashar ***et al.***, 1990). Drought resistance of plant includes any or all of the mechanisms such as escape, avoidance and tolerance mechanism (Sullivan, 1971 and Levitt, 1972). Drought avoidance depends upon maintaining an adequate cell water content and/or water potential despite a low external environmental water potential (soil and/or atmosphere) whereas drought tolerance refers to the ability of plant's cell to survive and metabolically function although the tissues are markedly desiccated at reduced water potentials (Sullivan, 1971 and Levitt, 1972). Various morphological and physiological traits are reported as the components of the drought resistance mechanisms by many researchers (Chang ***et al.***, 1972; Loresto ***et al.***, 1976; O'Toole and Chang, 1978; Blum, 1982 and Bashar ***et al.*** (1990) and also the drought resistance score was found highly correlated with leaf water potential (O'Toole and Moya, 1978). The significant varietal differences of mid-day leaf water potential was observed in rice under field condition (O'Toole and Moya, 1978; Ekanayake ***et al.***, 1985) as well as in green house condition (Begum, 1985) under differential water stresses. On the other hand, a varietal difference of pre-dawn leaf water potential of rice at different level of moisture stresses was observed under green house condition (Ahmed ***et al.***, 1978). Without any stresses, the mid-day leaf water potential was reported to differ significantly among the upland cultivars grown under flooded field condition (Bashar ***et al.***, 1990). Though the variabilities of leaf water potential of rice were found in different conditions, the literature on genetic studies of leaf water potential is rather scarce. This study was conducted in hydroponics system analogous to lowland condition under controlled condition to I) investigate the pattern of inheritance, ii) to estimate heritability and iii) to know the relationship between the components of avoidance mechanism.

Materials and Methods

Test materials

The cultivars used to establish the test populations were Moroberekan, an African upland rice variety and Mijingem, a hill rice from Bangladesh; both were drought resistant, tall, broad leaved and possessed deep and thick root system. Both cultivars were crossed with a common parent, IR20, a semi-dwarf modern variety developed by IRRI, which had narrow leaf, shallow and thin root systems.

The parents, F_1 and F_2 populations of each of the cross Moroberekan/IR20 and Mijingem/IR20 were grown in a hydroponics culture solution in the IRRI phytotron glass house under controlled conditions of 29°C/21°C day and night temperature, 70% minimum relative humidity and natural light intensity to maintain other factors remaining constant.

Hydroponics technique

Hydroponics equipment consisted of Polyvinyl chloride (PVC) cylinders, 0.10 m diameter and 0.50 m height, with sealed bottoms. A Styrofoam plant holder was prepared with a piece of nylon mesh which can hold the plant and allow the roots to emerge in the culture solution based on the formula of Yoshida ***et. al.*** (1976).

Seeds were germinated on wet filter paper. Two days after germination, the seeds were placed on nylon net stretched over Styrofoam frames and floated in culture solution in plastic trays. When the seedlings were 11-days old, they were transferred to the PVC tubes and grown until 45-days old. The data were collected at that stage.

The leaf water potential (Ψ leaf) was measured by using pressure bomb techniques as described by Scholander ***et al.*** (1965) and Warning ***et al.*** (1967). Measurements of Ψ leaf were made at solar noon (1200-1300 hrs) at 45 days after sowing (DAS). Second to the youngest fully expanded leaves were cut at about 2.0 cm below the leaf collar. These were then covered with polyethylene bags, clipped at the collar to unify the pressure on leaf and to protect the vapor pressure loss and placed in a pressure chamber in such a way that the cut portion of the surface was just protruding into the atmosphere through the seal on the top of the chamber. The amount of pressure was applied slowly to the leaf blade until the meniscus just returned to the cut surface. This equivalent pressure was recorded from the gauge and this gave the approximate Ψ leaf. Root thickness (mm), root volume (ml), root length (cm), shoot dry weight (g), plant height (cm) and leaf area (cm^2) were also measured by standard methods with recognized apparatus at 45 DAS.

Five plants of each parent, 5 F_1 and 25 F_2 plants were grown in each replication following a randomized complete block (RCB) design with three replications. A three parameter mean analysis was carried out by using Gamble's (1962) genetic model; potence ratio (hp) for estimating the magnitude of dominance in the F_1 generation was computed following the formula of

Griffing's (1950). The number of effective factor pairs was computed by Burton's (1951) formula. The broad sense heritability in the F_2 generation was computed as described by Allard (1969). The simple phenotypic correlation coefficient (r) was computed for each pair among the traits for F_2 data by the formula of Weber and Moorthy (1952).

Results and Discussions

Two F_2 populations representing upland × lowland and the hill rice × low land crosses were included in the study. The genetic analysis and correlation studies of Ψ leaf were performed from the above cross combinations. The additive and dominance gene effects, potence ratio and heritability for Ψ leaf in two crosses are present in the Table 1.

Genetic analysis

Moroberekan/IR20

The leaf water potential (-6.90 bars) of Moroberekan was higher than that of IR20 (-11.61 bars). The F_1 mean for Ψ leaf was -10.30 bars.

The F_2 distribution was continuous, unimodal and positively skewed. The F_2 range was -2.20 to -26.20 bars with a population mean -9.20 bars. Only 2 F_2 plants had lower leaf water potential than the lower parents (Fig.1). The additive effect (2.36) was higher than dominance effect (-1.72) and potence ratio was 0.44 indicating partial dominance of genes governing high leaf water potential.

The estimated number of effective factor pairs was 3.04. The heritability estimate was low (28%).

Mijingem/IR20

Mijingem had higher (-9.43 bars) mean leaf water potential (Ψ leaf) than that of IR20 (-11.61 bars). The F_1 mean was -10.29 bars. The range of Ψ leaf of IR20 was higher than that of Mijingem (Fig.1).

The F_2 distribution was continuous with two peaks. The F_2 plants were distributed within the range of -4.0 to -16.4 bars. The F_2 mean was -10.07 bars. The distribution was skewed towards the Mijingem. Only three plants exceeded the upper limit of high parents (Fig. 1).

The additive effect (1.09) was also higher than the dominance effect (-0.44) and the potence ratio was 0.21 indicating no dominance of the genes of high leaf water potential. The effective factor pairs estimate was 2.60 and heritability estimate was also low (25%).

The F_1 data suggested that both additive and dominance effects contributed to the inheritance of high leaf water potential. The F_2 distribution was continuous and the effective factor pairs estimations (2.60 to 3.04) indicated that Ψ leaf was controlled by more than two genes. Some F_2 plants exceeded the higher parental limits indicated the possibility of selecting plants with high leaf water potential. The relatively low frequency of such segregants suggests the need for growing large segregating populations. Additive effects were significantly higher in both the crosses. However, Moroberekan/IR20 showed some degree of dominance. This result

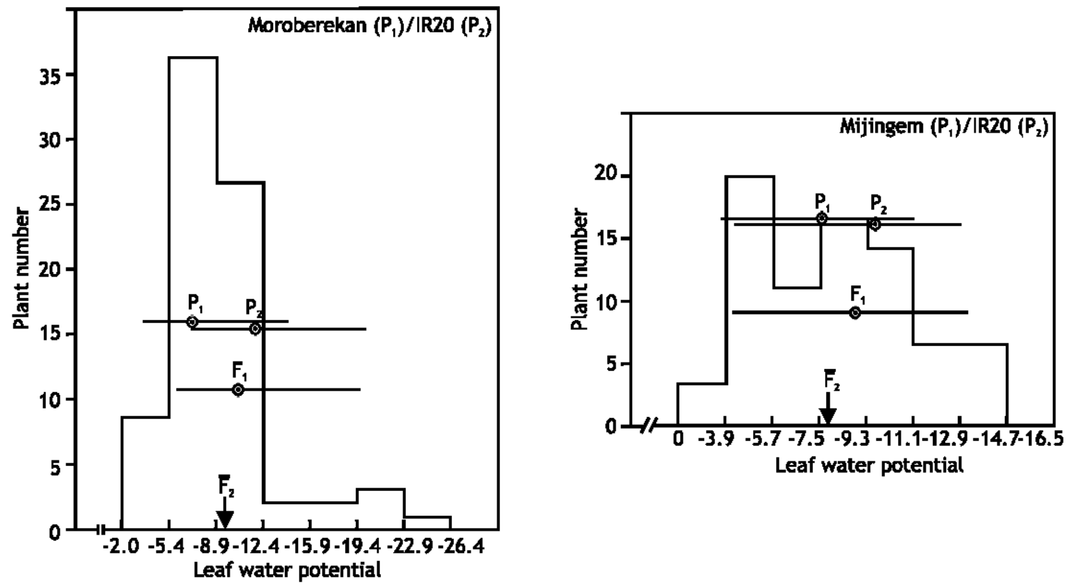

Fig. 1: Distribution and means of parents, F_1 and F_2 plants for leaf water potential in the two crosses. Horizontal lines show the range of parents and F_1 plant about the means (dotted circles) and the arrows indicate the means of F_2 populations

indicates that the additive and dominance effects were both important in the expression of Ψ leaf.

The heritability estimates were low for both the crosses. The result showed that although the additive effects were markedly higher in both the crosses, the heritability value is low. It indicates that the environmental effects were high which suppress the estimation of heritability. The bulk breeding method in early segregating population followed by pedigree selection in advanced generations could be practiced to get the improved plants with high leaf water potential.

Although the plants were grown under controlled conditions without stress, the drought resistant varieties had markedly higher leaf water potential than lowland varieties. The similar results were also reported when tested diversified varieties in the controlled condition (Begum, 1985) as well as without stress in the field condition (Bashar ***et al.***, 1990). These findings suggest that when both the situations gave similar expression a number of germplasms can be screened in the hydroponics to avoid the risk in the field condition.

Correlation analysis

Correlation analysis studied among the six traits of the two F_2 populations indicated that the positive and significant associations existed between leaf water potential and root thickness (0.36**), Ψ leaf and root volume (0.29*); and a negative correlation was observed between Ψ leaf

Table 1: Mid-parent value (m), additive (a) and dominance (d) gene effects, potence ratio (hp) and heritability (h^2) for the leaf water potential (Ψ leaf) in the two crosses

Cross	m	a	d	hp [a/]	code	h^2 (%)	n
Moroberekan/IR20	-9.44	2.36	-1.72	0.44	PD	28	3.04
Mijingem/IR20	-10.07	1.09	-0.44	-0.21	ND	25	2.60

[a/] = Any value between -0.25 to 0.25 indicates no dominance or small degree of partial dominance (ND); 0.26 to 0.75 indicates partial dominance (PD); 0.76 to 1.25 indicates complete dominance (CD) and grater than 1.25 indicates over dominance

m = Mid parent value h^2 = Heritability

a = Additive gene effect n = No. of effective factor pairs (genes)

d = Dominance gene effect hp = potence ratio in the F_1

and shoot dry weight (-0.30*) in the cross of Mijingem/IR20. Whereas no significant correlations were observed among the six traits with Ψ leaf in the cross of Moroberekan/IR20.

Simple correlation between three root and three shoot characters with leaf water potential were estimated and showed significant correlation at least in one cross. The above mentioned correlations indicate the contribution of three root and three shoot characters to maintain a high Ψ leaf. Blum (1982) reported that the root size, morphology, depth and density are important in maintaining high leaf water potential against evapotranspirational demand under water stress. O'Toole and Moya (1978) reported that visual drought scores were strongly related to the maintenance of high Ψ leaf which considered as an indicator of drought avoidance component. Ekanayake ***et al.*** (1985) also found significant correlation between drought score and Ψ leaf.

Although the test populations used were relatively small due to limited phytotron space and equipment, the information provided, regarding the inheritance pattern, heritability of Ψ leaf and association of root and shoot characters in rice, should be helpful in formulating efficient selection for drought resistant genotypes in breeding program. Further study is needed.

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