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【Short Report】

Heritability and Genetic Correlation of Al-Tolerance with Several Agronomic Characters in Sorghum Assessed by Hematoxylin Staining

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Aluminum (Al^{+3}) is a major constraint for production of sorghum in acid soil. Genetic variability for Al tolerance in sorghum (Anas et al., 2000; Flores et al., 1988) and different mechanisms of Al-tolerance among crop species have been reported. Boye-Goni et al. (1985) estimated the high heritabilities of sorghum genotypes using diallel analysis in a nutrient solution screening method. Gourley et al. (1990) also reported different heritabilities of sorghum genotypes by ANOVA on acid soil in a greenhouse study and in solution culture.

In the present study, sorghum genotypes from various origins were used as parents. Crossing was conducted between Al-tolerant and Al-susceptible genotypes and selections of Al-tolerant genotypes were screened using hematoxylin staining method. The objectives of this study are to estimate the heritability of Al-tolerance using the response to selection value and to estimate the genetic correlation between Al-tolerance and several agronomic characters (easily visible characters) in sorghum. The method using the response to selection and hematoxylin staining may be most reliable for estimation of heritability and genetic correlation.

Materials and Methods

1. Plant materials, hematoxylin screening and field experiment

Two crossings, C9/H11//ICR3 and C9/H13//ICR3, were used. C9/H11 is an early maturity genotype with a medium plant height. C9/H13 is a late maturity with a higher plant height than C9/H11. Generally C9/H13 is more tolerant to Al-toxicity than C9/H11 genotype. ICR3 was originally from ICRISAT and was used as the Al-tolerance parent in this experiment. Table 1 shows the general characters of parents.

The screening using hematoxylin staining as described by Anas et al. (2000) was used for Al-tolerance evaluation. Seedlings with well-developed roots, 1.5 cm or more in length, were chosen for scoring. Two Al concentrations at 148 μM Al and 222 μM were used for screening Al-tolerant genotypes. Six seedlings were treated with Al at each concentration with three replications and their roots were stained with hematoxylin to score the response to Al tolerance. When the roots of 0, 1 or 2, 3, 4 and 5 or 6 seedlings were stained, the score was 1 (very tolerant), 2 (tolerant), 3 (intermediate), 4 (susceptible) and 5 (very susceptible). Average score from two Al concentrations was used for final scoring of genotypes.

The same sorghum genotypes were also grown on normal soil (not acid soil) in a field of Utsunomiya University for study of phenotypic performance. Two hundred F_2 plants and 60 F_3 plants were planted in the summer in 2001 and 2002, respectively. Spacing between plants and between rows was 25 cm and 75 cm, respectively. Five phenotypic characters that involved grain weight, plant height (from the ground to the tip of panicle of the main stalk), days to flowering (panicle just appear from flag leaf), harvest index (ratio of grain weight to total above-ground weight), and length of head (from the base of head to tip) were examined and data were collected from single plant basis.

2. Calculation

The realized heritability was calculated as follows (Fehr, 1987);

Realized heritability

$$=(M_{high\ F3}-M_{low\ F3})/(M_{high\ F2}-M_{low\ F2})$$

where, $M_{high\ F3}$ is a mean performance of F_3 progeny of F_2 plants selected from the high group; $M_{low\ F3}$ is a mean performance of F_3 progeny of F_2 plants selected from the low group; $M_{high\ F2}$ is a mean performance

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Table 1. General character of the parents.

	C9/H11	C9/H13	ICR3
Plant height	medium (±104 cm)	tall (±241 cm)	short (±66 cm)
Al tolerance	susceptible	susceptible	tolerance
Day to flowering	early (± 47 d)	late (± 68 d)	medium (± 54 d)
Yield	high	high	medium

Table 2. The phenotypic correlation of Al-tolerance with six characters of sorghum.

	Dry weight	Length of head	Grain weight per plant	Days to flowering	Plant height	Harvest index	Al-tol. in F_2
Al-tolerance in F_2	−0.119	−0.174	−0.201	−0.232	0.053	−0.201	
	−0.265**	−0.258	−0.209	−0.382**	−0.376**	−0.183	
Al-tolerance in F_3	−0.505**	−0.267*	−0.488**	−0.207	0.115	−0.350**	0.268*
	−0.387**	−0.408**	−0.370**	−0.385**	−0.661**	−0.254**	0.597**

Upper value is C9/H11//ICR3 crossing and lower value is C9/H13//ICR3 crossing.
* and ** denote significant at 5% and 1% level, respectively.

of F_2 plants in the high group; and $M_{low\ F2}$ is a mean performance of F_2 plant in the low group.

Genetic correlation (r_A) was calculated as follows (Fehr, 1987);

$$r_A = CR_x i_x h_x / R_x i_y h_y$$

where, CR_x is amount of improvement of primary characters obtained by indirect selection for secondary character; R_x is amount of improvement obtained by direct selection for primary characters; i_x and i_y are selection intensity for primary and secondary character, respectively; h_x and h_y are square root of realized heritability, instead of narrow sense heritability, of primary and secondary characters, respectively.

Results and Discussion

The phenotypic correlations among characters in the data from the two series of crosses showed that dry weight, length of head, grain weight per plant, plant height, and harvest index were significantly and positively correlated to each other (data were not shown). There was no significant phenotypic correlation of these characters with F_2 Al-tolerance in the C9/H11//ICR3 cross, but except for plant height, significant negative correlations of these characters with F_3 Al-tolerance were observed in both series of crosses (Table 2).

Genotypic correlations of length of head and early flowering with Al-tolerance were similar in both C9/H11//ICR3 and C9/H13//ICR3 crosses (Table 3). The relatively high genotypic correlations with Al tolerance were observed for high performance of dry weight and grain weight per plant in the C9/H11//ICR3 cross.

Some characters showed a small genotypic correlation with Al-tolerance. A small genotypic correlation and inconsistent relationship with the phenotypic correlation suggested that environmental factors affected performance of Al tolerance. Using the same sorghum genotypes, Gourley et al. (1990) reported that the gene action observed on acid soil in a greenhouse was different from that observed in solution culture.

Genotypic correlations of days to flowering with Al tolerance were negative as in the phenotypic correlations in both series of crossing (Tables 2 and 3). This not only showed negative phenotypic correlations between early flowering and Al-tolerance but also suggested that early maturity and low Al-tolerance are linked genetically or they might be pleiotropically controlled.

The genotypic correlation of harvest index with Al tolerance was different between C9/H11//ICR3 and C9/H13//ICR3 crosses. This result is somewhat disturbing, but perhaps these might result from the use of different parents for the cross. There are some reports showing that different genes control Al-tolerance in the same plant species. In some wheat cultivars, Al tolerance is controlled by several genes, but in other wheat cultivars it is controlled by simple dominant genes (Martinez et al., 1999).

The realized heritability of Al tolerance was

Table 3. Heritability of Al tolerance and genetic correlation of Al-tolerance with six characters of sorghum.

	Dry weight	Length of head	Grain weight per plant	Days to flowering	Plant height	Harvest index	H[1)]
Al-tolerance (C9/H11//ICR3)	0.497	0.249	0.706	−0.391	0.060	−0.485	0.35
Al-tolerance (C9/H13//ICR3)	0.119	0.344	0.025	−0.468	−0.158	0.728	0.43

[1)] H=heritability; High performances of dry weight, grain weight per plant and harvest index, short plant height and early flowering were used in genetic correlation analysis.

moderately low (0.35 and 0.43) in C9/H11//ICR3 and C9/H13//ICR3 crossing (Table 3) confirming that several genes controlled Al-tolerance. Al tolerance in wheat cv. Atlas 66 was controlled by two or more major genes (Berzonsky, 1992); dominant or semidominant genes in *Arabidopsis thaliana* (Larsen et al., 1996).

Boye-Goni et al. (1985) reported that narrow-sense and broad-sense heritabilities were 0.78 and 0.99, respectively. Gourley et al. (1990) reported that the narrow-sense heritability assessed on acid soil in a greenhouse was different from that assessed using solution culture; 0.05~0.31 and 0.65~0.72, respectively.

Al tolerance in sorghum has been reported to be inherited as a dominant character and predominantly additive genetic effect with some degree of dominance controlled it (Boye-Goni et al., 1985). Gourley et al. (1990) reported that the additive variance of Al-tolerance in sorghum was much greater than the variance in the degree of dominance. However direct selection of Al-tolerance might be difficult for improving Al-tolerance character judging from the data obtained in this study. Consequently, selections with a more accurate evaluation method for Al-tolerance, and use of wider germplasm with high Al-tolerance, and a larger number of progeny plants are necessary for increasing Al-tolerance.

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