Problems in Forage Sorghum Breeding in Japan

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Recently, forage sorghum has come to be grown widely in Japan, mostly in warm southwestern prefectures. In 1974 a total of 1,133,000 tons was harvested from 18,000 ha of cultivated area, as an important forage crop during the summer season next to corn. Because of a limited acreage available for forage crops, the cultivation has to aim at high yield. Use of high-yielding varieties, and practices of early sowing, dense sowing and heavy application of fertilizers are recommended. Forage sorghum is harvested by 2–3 times of cutting at around heading stage and utilized as green chops or silage. Based on such a situation, demand for varietal improvement is focused on high-yielding capacity, vigorous growth under low temperature, vigorous regrowth, resistance to lodging and to diseases and insect pests.

Breeding program of forage sorghum in Japan was initiated in 1963 at the Hiroshima Agricultural Experiment Station. To meet the demand stated above, efforts have been made to develop hybrid cultivars using cytoplasmic male sterile lines (hereafter referred to MS lines). Utility of MS lines different in plant type, characteristics and productivity of hybrids classified by groups of pollen parents, and heterotic effects in hybrids will be reported briefly in this paper, among the results obtained in the Station.

Utility of MS lines and related problems

Many studies have been made since Craigmiles et al.[3] on the use of MS lines to forage sorghum breeding, and this method has been proved to be an effective measures. However, all the attempts were made by the use of MS lines of grain type. The author pointed out that all these lines are characterized by early maturing, short plant height, few tillers, and a small range of morphological and ecological variations among lines. Due to the limited range of variation of heading time of MS lines, the range of the selection of pollen parents is also very much limited, because pollen parents having the heading time close to that of MS lines have to be selected. Therefore, the author proposed the need to enlarge variation in heading time among MS lines[8].

Thus, MS lines of sorgo type and grass type, different from existing grain type in plant type and heading time, were examined.

Sorgo type MS lines were developed by backcrossing African millet, a variety of sorgo, to grain type MS lines for 4 times. The lines were tall with thick stems and medium maturing, and showed complete sterility. Hybrids produced from these lines, as seed parents, were, however, poor in an initial growth and regrowth habit, giving yields lower than that of commercial hybrid cultivars. They can hardly be used as practical cultivars[9].

Grass type MS lines, introduced from Nebraska, were called as Tall Rhodesian. The lines were characterized by tall and very thin stems, profused tillering, medium maturing and complete sterility. Hybrids produced by using this line were poor in an initial growth

Table 1. General properties of F_1 hybrids classified by groups of pollen parents

Group of pollen parents		Plant height	Stem diameter	Number of tillers	Initial vigor	Lodging	Leaf blights	Heading	Regrowth
Hegari	(G)*	high	very thick	few	somewhat poor	none	resistant	late	somewhat vigorous
Kaoliang	(G)	high	somewhat thick	few	very vigorous	none	resistant	very early	poor
IARI	(G)	somewhat high	thick	few	poor	none	resistant	early	somewhat poor
Sorgo	(S)	high	thick	few	poor	slight	resistant	medium	somewhat vigorous
Japanese native	(S)	very high	somewhat thick	abundant	vigorous	slight	somewhat susceptible	medium	vigorous
Sudangrass	(Gr)	somewhat high	somewhat thin	very abundant	very vigorous	none	somewhat susceptible	early	very vigorous

*G, S and Gr signify grain sorghum, sweet sorghum and grass sorghum, respectively.

and yield, and not recognized better than commercial cultivars. Tall and very thin stems and profused tillering habit of the lines caused several disadvantages: too tall for seed production practice, lodging during ripening period, and lack of uniformity in seed ripening among tillers of individual plant. Further improvement is needed.

Because of such difficulties in using sorgo type and grass type MS lines, grain type lines have to be used at present, although they have some problems as stated. The above sorgo and grass type lines are considered to be used as an intermediate material in enlarging the variation of MS lines.

Major characteristics and productivity of hybrids as classified by groups of pollen parent

Hybrids of 354 combinations were examined in 1966–1973, and classified by groups of pollen parent. Major characteristics are shown in Table 1, and productivity is given in Tables 2 and 3. Variation among hybrids by seed parent lines (grain type MS lines) was small. Pollen parent groups are Hegari and its relatives, Kaoliang, lines introduced from IARI, sorgo, Japanese native sorghum varieties, and Sudangrass. The hybrids are referred to Hegari group hybrids, Kaoliang group hybrids, IARI group hybrids and so on, respectively[8].

It was found that characteristics of hybrids were apparently different by groups of pollen parent, showing diverse variations in plant type, initial vigor, heading, regrowth, etc., among hybrid groups. As to the plant type, Hegari group and IARI group hybrids showed tall and very thick stems and few tillers, but Sudangrass group hybrids showed thin stems and profused tillering, while Japanese native group and Kaoliang group hybrids being intermediate. Heading time was earliest in Kaoliang group, followed by IARI group and Sudangrass group, while Japanese native group and Sorgo group was

Table 2. Frequency distribution of yield level of hybrids classified by groups of pollen parents

Groups of pollen Parents	Number of hybrids at indicated yield levels*					Frequency showing yield level I (%)
	I	II	III	IV	Total	
Hegari	5	23	14	1	43	11.6
kaoliang	—	3	20	7	30	0.0
IARI	1	—	1	49	51	2.0
Sorgo	—	7	23	34	64	0.0
Japanese Native	20	21	16	10	67	29.9
Sudangrass	10	18	39	32	99	10.1
Total	36	72	113	133	354	—

* Rating of yield level is given in the text.

medium, and Hegari group was late.

Initial growth, an indicative of vigorous growth under low temperature, was better in Kaoliang and Sudangrass groups, and good in Japanese native group. Some of the Japanese native group hybrids showed lodging[1,6]. The occurrence of lodging was related to pollen parents. Furudoi et al.[7] confirmed that lodging was related to morphological characteristics of pollen parents. Good regrowth was recognized with Sudangrass and Japanese native groups, followed by Hegari group. Kaoliang group showed better growth of regenerated stems, but number of them was few, and almost no regenerated stem was recognized at the third cutting. IARI group and Sorgo group showed few number of regenerated stems and their poor growth[2,4,5,9].

As to the productivity, frequency distribution of yield levels is shown in Table 2, and actual yields of selected varieties representing each group are shown in Table 3. Yield levels were based on a scale of I to IV, with I indicating higher yield, with II indicating yield of commercial hybrid cultivars, and IV indicating lowest yield. Frequency of showing higher yield was high with Japanese native group, Hegari group and Sudangrass group, indicating 30, 12, and 10% respectively[9].

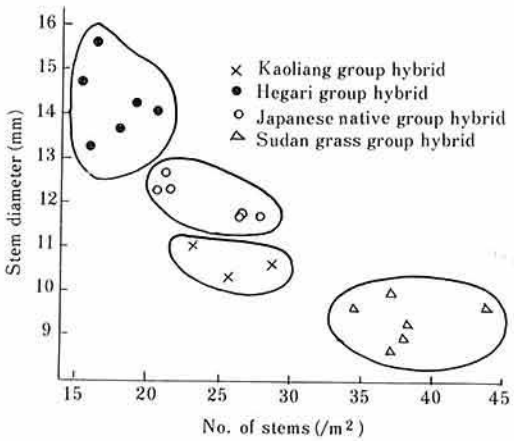

Fig. 1. Distribution of number of stems per m² and stem diameter of hybrids derived by crossing with 4 different groups of pollen parents.

These results show that breeding of hybrids with diverse plant types and ecological characteristics is made possible by selecting pollen parents, and that the selection of pollen parents is important in forage sorghum breeding using grain type MS lines. In response to the demand for characters of cultivars, it can be regarded that Hegari group having tall, thick stems, late maturity and good regrowth, Japanese native group with very tall, relatively thick stems, relatively many tillers, medium maturity and good initial growth and regrowth, and

Table 3. Forage yields of selected hybrids representing each hybrid group classified by groups of pollen parents

Groups of pollen parents	Variety	G. F. Y. (kg/a)*			D. M. P. (%)*		D. F. Y. (kg/a)*		
		1st	2nd	Total	1st	2nd	1st	2nd	Total
Hegari	Hiro-Ko No. 3	595	526	1121	9.9	16.2	58.4	85.5	143.9
	Hybrid Sorgo	503	472	975	10.8	16.4	54.4	77.4	131.8
Kaoliang	Hiro-Ko No. 12	462	313	775	15.1	21.6	70.0	67.7	137.7
	Hiro-Ko No. 14	463	293	756	15.8	21.5	73.4	62.6	136.0
Japanese native	Chugoku-Ko No. 4	492	523	1015	9.8	20.1	48.3	104.8	153.1
	Hiro-Ko No. 10	492	554	1046	10.4	19.0	50.9	105.6	156.1
Sudangrass	Sendachi	439	430	969	12.0	18.0	52.5	77.4	129.9
	Sweet Sorgo	460	398	858	12.7	17.9	58.6	71.1	129.7

* G. F. Y., D. M. P. and D. F. Y. indicate green forage yield, dry matter percentage and dry forage yield, respectively.

Sudangrass group with relatively tall, thin stems, many tillers, early maturity and good initial growth and regrowth are promising ones at present.

Mode of expression of heterotic effects

To examine heterotic effects in comparison with parent varieties, heterosis ratio $= 2F_1/(P_1 + P_2) \times 100$ (%) was calculated. Examples of Japanese native group hybrids are shown in Figs. 2 and 3. Heterotic effect was apparent with plant height and yield, but hardly recognized with stem diameter. Number of stems showed an extremely large variation among hybrids, suggesting that it is specific to a given combination, although the

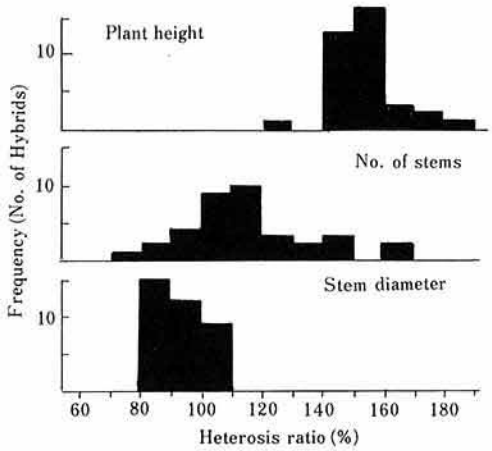

Fig. 2. Frequency distribution of heterosis ratio of hybrids derived by pollination with Japanese native sorghum varieties in plant height, number of stems and stem diameter at the 2nd cutting period.

Table 4. Factorial analysis of several characteristics of hybrids classified by groups of pollen parents

Groups of pollen parents	Sources of variance	Plant height		No. of stems		Stem diameter		G. F. Y.			D. F. Y.		
		1st	2nd	1st	2nd	1st	2nd	1st	2nd	Total	1st	2nd	Total
Hegari	G. C. A. of ♀	**	**	N. S.	N. S.	—	—	**	**	N. S.	—	—	—
	G. C. A. of ♂	**	**	N. S.	N. S.	—	—	N. S.	**	**	—	—	—
	S. C. A	**	N. S.	**	N. S.	—	—	N. S.	N. S.	N. S.	—	—	—
Kaoliang	G. C. A. of ♀	N. S.	**	**	**	**	N. S.	N. S.	**	N. S.	N. S.	**	**
	G. C. A. of ♂	**	**	N. S.	**	N. S.	N. S.	**	**	**	**	**	**
	S. C. A.	N. S.	N. S.	*	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.
IARI	G. C. A. of ♀	*	*	**	N. S.	N. S.	*	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.
	G. C. A. of ♂	**	**	N. S.	N. S.	**	**	**	**	**	**	*	**
	S. C. A	N. S.	**	*	**	N. S.	N. S.	N. S.	*	*	**	*	**
Sorgo	G. C. A. of ♀	**	N. S.	**	**	**	*	N. S.	*	N. S.	*	**	N. S.
	G. C. A. of ♂	**	N. S.	N. S.	**	N. S.	N, S.	**	**	**	**	**	**
	S. C. A.	N. S.	**	**	N. S.	N. S.	*	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.
Japanese native	G. C. A. of ♀	**	N. S.	**	**	**	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.
	G. C. A. of ♂	**	**	**	**	**	**	**	**	*	**	**	**
	S. C. A.	N. S.	*	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.	N. S.
Sudangrass	G. C. A. of ♀	*	**	N. S.	N. S.	*	*	N. S.	N. S.	N. S.	—	—	—
	G. C. A. of ♂	**	**	*	*	**	**	N. S.	N. S.	N. S.	—	—	—
	S. C. A.	**	N. S.	**	**	**	N. S.	**	N. S.	*	—	—	—

Notes 1) G. C. A. of ♀ and ♂ and S. C. A. indicate general combining ability of seed parents, that of pollen parents and specific combining ability, respectively.
2) **, * and N. S. show significant at 1% level, at 5% level and not significant, resyectively.
3) F-tests of G. C. A. were perfomed by use of S. C. A. and S. C. A. by error mean squares.

average of all hybrids was close to midparent. Other groups also showed the similar pattern of heterotic effects. However, Hegari group showed particularly high heterotic effect on plant height combined with the delay of heading time, while Sudangrass group gave slightly higher effect on number of stems. Thus, it can be considered that high heterotic effect on plant height and that on number of stems occurring with particular combination bring about the high heterotic effect on yield.

Characteristics of each group of hybrids were analyzed according to Beil and Atkins[2] and shown in Table 4. Effects of parent characteristics on hybrid characteristics differed with different hybrid groups and characters. Namely, with hybrid groups, it is observed that in Hegari group, Kaoliang group[5], Sorgo group and Japanese native group[4] variations among hybrids are mostly contributed by general combining ability of parents, while effect of specific combining ability is not recognized. In these groups, it was revealed by the comparison of components of variances that the pollen parent exhibited more effect than another parent[9]. In Sudangrass and IARI groups, effect of specific combining ability was observed in addition to the effect of general combining ability. Particularly in the former group yield was determined only by specific combining ability; a remarkable difference from other groups.

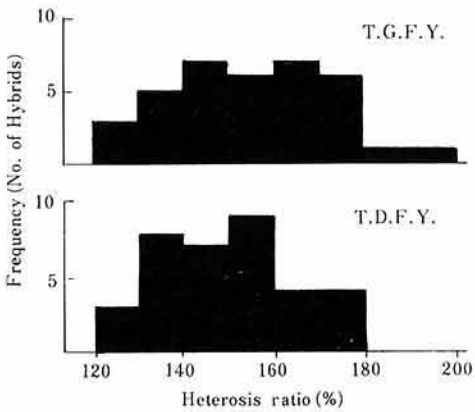

Fig. 3. Frequency distribution of heterosis ratio of hybrids derived by pollination with Japanese native sorghum varieties in total green forage yield (T. G. F. Y.) and dry forage yield (T. D. F. Y.).

On the other hand, as to different characters, plant height is effected by general combining ability of parents, but pollen parent seems to be contributing more, due to small variation in plant height of MS lines. Although there are some differences by groups, number of stems seems to be generally contributed by general combining ability of seed parent as well as specific combining ability. Stem diameter seems to be contributed mostly by general combining ability of pollen parent when stems are thick, but for thin stems general combining ability of seed parent as well as specific combining ability seem to have been involved. As to yield, general combining ability of pollen parent contributes greatly in general, although some differences exist by groups.

These results indicate that characteristics of hybrid are determined by effect and interaction of parents, particularly by large effect of pollen parent. As the pattern of heterosis is different with groups of pollen parents and individual characters, it is suggested that the schemes of selecting combinations and practical procedures of selecting hybrids should be modified according to the type of hybrid to be developed.

Finally, with the increase of forage sorghum cultivation, many demands for varietal improvement have been coming up from the standpoint of better utilization of this crop, such as palatability for livestocks, adaptability for silage, content and composition of nutrients, etc. many of which are still unsolved.

The author developed new varieties, Sendachi in 1971[11] and Hiromidori in 1975[10]. Further works will be continued to meet the above demands.

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