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Genetic analysis for yield and quality traits in forage sorghum [*Sorghum bicolor* (L.) Moench]

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Abstract

Genetic and joint regression analysis was carried out in 28 F_1 hybrids and their 8 diverse parents for fodder yield, its quality and other yield related traits. Predominant non-additive type gene effects for yield, whereas additive type for quality traits were observed. The parents SRF286, SRF305 and RSSV104 had good gca effects for yield and component characters. High sca effect for yield was recorded for hybrid GFS3×GFS4 involving parents with poor gca effects. Amongst the parents, SRF 286, SRF305 and SRF311 and hybrids SRF286×SRF305, RSSV104×AKFSV2 were stable across the environments with high mean values for yield, quality and other yield contributing traits. The linear and non-linear components were significant for all the characters studied which indicated significant differences among the genotypes for their regression on environmental indices. GxE interaction played a significant role in determining linear and non-linear regression for the traits viz., plant height, number of leaves per plant, leaf: stem ratio, stem juiciness, green fodder yield and dry matter yield revealing differences in stability across the environments.

Key words: Genetic analysis, regression, combining ability, gene action, stability, sorghum

Introduction

Like Green Revolution, India is contemplating for white revolution which is possible only with adequate supply of nutritious feeds and fodder. There is a deficit of fodder in the country amounting to over 16% of the stover and 64% of the green fodder requirement [1]. Moreover, livestock population survives to a large extent on crop residues, which are nutritionally poor. Therefore, target can be achieved by developing varieties/hybrids of forage crops giving high yield per unit area and time combined with superior quality. The cultivated area under different forage crops is 4.4% of the total area under cultivation of which about 2.3 mha is under fodder sorghum [2]. Sorghum ranks first among the cereal fodder crops because of its faster growing habit, high yield potential, suitability to cultivate throughout the year, palatable and nutritious fodder quality, higher digestibility and various forms of its utilization. It is relatively drought tolerant that makes it suitable for cultivation in moisture stress conditions [3]. In order to make forage sorghum as more enterprising and remunerative crop, there is an urgent need to develop varieties and hybrids having faster growth, early to medium maturity and higher fodder yield with good fodder quality. To develop such fodder varieties/hybrids, knowledge and information of the genetic architecture are necessary. In addition, information on genotype ×environment interaction will help in deciding the role of environment in expression of different characters and stability of genotypes. The information on these aspects is scanty; hence the present study was conducted to identify parents and hybrids which may be suitable across the environments.

Materials and methods

The testing materials (Table 1) consisted of 28 F_1 hybrids and their eight diverse parents viz., SRF 286, SRF 305, SRF 311, GFS 3, RSSV 104, AKFSV 2, SSG 59-3 and GFS 4.The F_1 hybrids were generated through half diallel and were planted during *kharif*-2007 season at Navsari and Surat; and summer-2008 at Surat. The trials were conducted in RBD with three replications. Each entry was planted in two rows of

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Table 1. Pedigree, source and salient features of parents

S.No.	Name parent	Pedigree	Source	Salient features
1	SRF 286	GSSV 148 × SR 897	Surat (Gujarat)	Single cut type, high biomass, juicy and sweet stem, leafy with low HCN content
2	SRF 305	(GJ 37 × Malvan) × CF 4	Surat (Gujarat)	Tan type with higher yield, juicy stem and low HCN content
3	SRF 311	GJ 39 × SRF 284	Surat (Gujarat)	Medium tall, loose panicle with low protein and yield
4	GFS 3	Selection from IS 5026	Anand (Gujarat)	Single cut type, tall, late type, high biomass, with sweet and juicy stem
5	RSSV 104	AKFSV 16 × RSSV 10-10-8-1-1	Rahuri (M.S)	High Brix (%), tall and thick stem with sweetness and juiciness in stem
6	AKFSV 2	Not available	Akola (M.S)	Tall, loose panicle, long and narrow leaves with medium TSS and high HCN content
7	SSG 59-3	Sudan grass × IS 263	Hisar (Haryana)	Multicut type with quick regenerating habit with low TSS and high protein content
8	GFS 4	GJ 37 × Sudan type	Surat (Gujarat)	Earliest type with very thin stem, less number leaves, small loose panicle

2.0 m length by keeping row to row distance 30 cm and within the row 7.5 to 10.0 cm. All the recommended agronomical practices and plant protection measure were followed as and when required to ensure good crop. Data were recorded on ten competitive plants selected randomly for days to 50 percent flowering, plant height (cm), number of leaves per plant, stem girth (cm), leaf :stem ratio, brix (%), stem juiciness (score 1-5), HCN content (ppm), protein content (%), green fodder yield per plant (g) and dry matter yield per plant (g). The combining ability analysis was carried following method 2, model-1 of Griffing [4] and pooled analysis over environments was done as per the method suggested by Singh [5, 6]. The stability of 37 genotypes including one standard national check HC 308 was worked out following Eberhart and Russel model [7]. The data were analyzed statistically using the software WINDOSTAT version 8.1 developed by Indostat Services Ltd., Hyderabad, India.

Results and discussion

The analysis of variance revealed significant differences among genotypes, lines and crosses for all the characters in individual as well as pooled over environments. The variances due to gca and sca were also found significant for all the traits in pooled over environments (Table 2) as well as in individual environments. That indicated that both additive and non-additive gene action were important in the inheritance of these characters. However, the gca variances were higher in magnitude than the corresponding sca variances for days to 50 percent flowering, stem girth, HCN content and protein content in pooled over environments, that indicated preponderance of additive gene action for controlling these traits. While sca variances were higher in magnitude for plant height, leaf:stem ratio, brix percent, stem juiciness, green fodder yield and dry matter yield over the environment, that indicated that non-additive gene action played important role in the inheritance of these traits [8]. The magnitude of gca × environment interaction was higher than corresponding sca × environment interaction for stem girth, leaf:stem ratio, HCN content, green fodder yield and dry matter yield suggesting more influences of environment on gca variances than the sca variance for these traits.

Since for yield and other yield contributing characters non-additive gene action was predominant, population improvement methods like bi-parental mating or reciprocal recurrent selection or cyclic selection method for improvement of yield is suggested[1, 9]. Since the male sterility system is available in the sorghum, heterosis breeding is also suggested [10]. For improvement crop duration, HCN content and protein content hybridization followed by selection would be most appropriate [11].

The estimates of gca effects (Table 3) indicated that SRF 305, RSSV 104 and SRF 286 had positive and highly significant gca effects in pooled as well as

Table 2. Mean square for combining ability and their ratio for various characters pooled over environments in forage sorghum.

Source	d.f.	Days to to 50% flowering	Plant height (cm)	No. of leaves/ plant	Stem girth (cm)	Leaf : stem	Brix (%)	Stem juiciness (score 1-5)	HCN content (ppm)	Protein content (%)	Green fodder yield/plant (g)	Dry matter yield/plant (g)
gca	7	382.82**	595.10**	2.77**	0.18**	0.004**	4.31**	0.10**	5458.27**	2.36**	4098.20**	418.56**
sca	28	81.56**	1329.90**	2.77**	0.05**	0.005**	6.17**	0.13**	3697.28**	1.94**	4332.12**	461.49**
gca/sca		4.69	0.45	1.00	3.78	0.90	0.70	0.78	1.48	1.22	0.95	0.91
Environments	2	344.41**	52890.26**	13.14**	0.73**	0.009**	30.99**	0.05**	2223.06**	7.95**	41386.23**	3684.62**
gca × environments	14	14.38**	471.44**	1.46**	0.03**	0.004**	1.36**	0.04**	1900.79**	0.62**	974.49**	142.75**
sca × environments	56	28.22**	536.36**	2.01**	0.02**	0.003**	3.75**	0.06**	1819.21**	1.67**	600.20**	92.82**
Error	210	2.56	67.11	0.29	0.00	0.000	0.27	0.00	16.07	0.05	72.28	6.74

*, ** significant at 1% and 5% level of probability, respectively

in individual environments for both the yield traits. The SRF 286 and RSSV 104 were also good combiners for quality parameters like brix percent, stem juiciness, HCN content and protein content. The GFS 4, SSG 59-3 and AKFSV 2 were good combiners for earliness, stem thinness and tallness; however they were poor combiners for yield. The SRF 311 and GFS 3 were good general combiners for leaf:stem ratio. The good combining lines for yield were generally late in flowering and early flowering lines GFS 4, SSG 59-3 and AKFSV 2 were poor combiners for green fodder yield. The good general combining ability of SRF 305, RSSV 104 and SRF 286 for one or more yield attributes might have resulted into good general combining ability of these genotypes for yield. These parents could therefore, be utilized in breeding programme for developing high yielding varieties/hybrids. Moreover, the parents GFS 4, SSG 59-3 and AKFSV 2 could be utilized for developing early maturing varieties/hybrids.

The estimates of sca effects revealed that none of the hybrids were consistently superior for all the characters. Considering the overall performance of hybrids over environments in respect of green fodder yield, total twelve hybrids manifested significant positive sca effects. These cross combinations had also manifested significant and desired sca effects for some of the important yield contributing characters. The significant and positive sca effects appeared in hybrid SRF 286 × SRF 305 for green fodder yield and dry matter yield as well as other fodder quality and yield contributing characters having both good × good combining lines might have resulted from interaction of dominant gene contributed by both lines. Out of 12 crosses with significant sca effects, eight crosses had atleast one of the parents as good general combiner for yield per plant. The high sca effects in these crosses might be due to additive × additive or additive × dominant type gene interaction. The hybrids RSSV 104 × AKFSV 2, SRF 286 × SRF 311, SRF 286 × GFS 4, SRF 305 × GFS 4, RSSV 104 × AKFSV 2, RSSV 104 × SSG 59-3 and RSSV 104 × GFS 4 which involved good × poor combining parents for yield have significant and positive sca effects. The high sca effects in above crosses might be the result of dominant × additive gene interaction.

The information regarding best three *per se* performing lines, good general combiners with high yielding hybrids coupled with crosses possessing high sca effects (Table 3) revealed that good general combiners might not necessarily produce good specific

Table 3. Best parents and hybrids with their sca effects for various traits in forage sorghum.

Characters	Best performing Parents	per se	Best general	Best performing Hybrids	per se	Best specific hybrids with their sca	
Days to 50% flowering	GFS 4	51.33	GFS 4	SSG 59-3 × GFS 4	69.56	GFS 3 × GFS 4	–7.66**
	SSG 59-3	68.22	SSG 59-3	AKFSV 2 × SSG 59-3	74.67	SRF 311 × AKFSV 2	–6.16**
	AKFSV 2	76.56	AKFSV 2	SRF 305 × SSG 59-3	74.89	SRF 305 × RSSV 104	–5.41**
Plant height (cm)	AKFSV 2	230.67	RSSV 104	GFS 3 × GFS 4	260.56	GFS 3 × GFS 4	41.23**
	SRF 286	214.22	AKFSV 2	AKFSV 2 × SSG 59-3	256.56	AKFSV 2 × SSG 59-3	33.13**
	RSSV 104	210.56	SRF 286	RSSV 104 × GFS 4	251.44	SRF 286 × SRF 305	29.17**
No. of leaves/ plant	GFS 3	11.13	SRF 286	SRF 286 × SRF 305	12.33	GFS 3 × GFS 4	1.52**
	RSSV 104	10.11	RSSV 104	RSSV 104 × GFS 4	11.82	RSSV 104 × GFS 4	1.46**
	SRF 286	10.09	GFS 3	SRF 311 × RSSV 104	11.80	SRF 286 × SRF 305	1.31**
Stem girth	GFS 4	0.38	GFS 4	SSG 59-3 × GFS 4	0.64	SRF 286 × SRF 305	–0.21**
	SSG 59-3	0.72	SSG 59-3	SRF 311 × SSG 59-3	0.75	SRF 286 × GFS 3	–0.16**
	AKFSV 2	0.86	AKFSV 2	RSSV 104 × GFS 4	0.81	GFS 3 × AKFSV 2	–0.13**
Leaf : stem	GFS 4	0.25	SRF 311	SRF 286 × SRF 311	0.33	SRF 286 × SRF 311	0.07**
	AKFSV 2	0.24	GFS 3	SRF 311 × AKFSV 2	0.33	GFS 3 × SSG 59-3	0.05**
	GFS 3	0.24	GFS 4	GFS 3 × GFS 4	0.33	SRF 311 × AKFSV 2	0.05**
Brix (%)	RSSV 104	10.66	SRF 286	SRF 286 × SSG 59-3	12.31	GFS 3 × GFS 4	2.75**
	SSG 59-3	9.97	RSSV 104	SRF 286 × SRF 305	12.08	SRF 286 × SSG 59-3	2.34**
	SRF 305	9.07	SRF 305	GFS 3 × GFS 4	11.80	RSSV 104 × AKFSV 2	1.77**
Stem juiciness (score 1-5)	SRF 305	2.33	GFS 3	SRF 311 × SSG 59-3	1.78	SRF 311 × SSG 59-3	–0.46**
	SRF 286	2.56	SRF 305	SRF 286 × SRF 305	2.11	GFS 3 × GFS 4	–0.32**
	RSSV 104	2.67	RSSV 104	SRF 286 × GFS 4	2.22	RSSV 104 × GFS 4	–0.29**
HCN content (ppm)	SRF 286	83.67	GFS 3	GFS 3 × RSSV 104	40.00	SRF 311 × SSG 59-3	–54.54**
	GFS 3	102.44	SRF 286	GFS 3 × SSG 59-3	52.22	GFS 3 × GFS 4	–39.81**
	SRF 311	115.22	RSSV 104	SRF 286 × SRF 305	63.00	RSSV 104 × GFS 4	–31.12**
Protein content (%)	GFS 3	6.29	GFS 3	RSSV 104 × GFS 4	7.97	SRF 286 × SRF 305	1.51**
	RSSV 104	6.14	GFS 4	SRF 305 × GFS 3	7.96	RSSV 104 × GFS 4	1.30**
	SRF 286	6.11	RSSV 104	SRF 286 × SRF 305	7.73	SRF 305 × GFS 3	1.23**
Green fodder yield /plant (g)	SRF 286	135.00	SRF 305	SRF 286 × SRF 305	216.56	GFS 3 × GFS 4	75.67**
	SRF 305	133.67	RSSV 104	GFS 3 × GFS 4	204.00	RSSV 104 × AKFSV 2	61.73**
	RSSV 104	125.89	SRF 286	RSSV 104 × AKFSV 2	194.67	AKFSV 2 × SSG 59-3	56.54**
Dry matter yield /plant (g)	GFS 3	38.22	RSSV 104	SRF 286 × SRF 305	70.25	GFS 3 × GFS 4	25.97**
	SRF 286	37.25	SRF 305	GFS 3 × GFS 4	64.68	SRF 286 × SRF 305	24.20**
	SRF 305	34.20	SRF 286	RSSV 104 × AKFSV 2	57.23	AKFSV 2 × SSG 59-3	21.55**

*,**Significant at 1% and 5% level of probability, respectively.

combinations for various characters. The crosses had either both or one good general combiner in which better segregants could be identified by adopting selection breeding methodology [12]. Such crosses were observed for the characters days to flowering, stem girth and protein content. The GFS 3 × GFS 4 cross was most superior having high sca effects coupled with high *per se* performance for yield but having both the lines as poor × poor or poor × average combiners for number of leaves per plant and brix percent. For getting better segregants, intermating system in F_2 and advanced generation is more suitable. The cross GFS 3 × GFS 4 for early flowering, plant height, number of leaves per plant and brix content; SRF 286 × SRF 311 for leaf:stem ratio and RSSV 104 × AKFSV 2 for HCN content possessed highest sca effects with poor x poor combiner. Such combinations might through desirable transgressive segregants and these could be exploited for recombination breeding [8, 13].

Pooled analysis of variance (Table 4) revealed significant differences among the genotypes and environments for all the traits studied suggesting the presence of variability both among genotypes and environments. The mean squares due to genotype × environment interaction were significant for all the traits,

Table 4. ANOVA for various stability parameters with regard to various characters in forage sorghum

Source	d.f.	Days to to 50% flowering	Plant height (cm)	No. of leaves/ plant	Stem girth (cm)	Leaf : stem	Brix (%)	Stem juiciness (score 1-5)	HCN content (ppm)	Protein content (%)	Green fodder yield/plant (g)	Dry matter yield/plant (g)
Genotypes	36	140.395••**	1153.623••**	2.710??	0.075••**	0.005•**	5.665•	0.118••**	3939.802••**	1.978	4171.415••**	440.353••**
Environments	2	378.597••**	54084.536••**	14.728••**	0.798••**	0.009**	29.463••**	0.069	2230.483	8.303••**	42909.335••**	3705.680••**
G × E	72	25.178	509.179	1.890	0.023	0.003	3.229	0.053	1785.027	1.425	657.131	101.059
Env. (linear)	1	757.193**	108169**	29.456**	1.597**	0.018**	58.925**	0.137*	4460.966	16.606**	85818.671**	7411.359**
G × E (linear)	36	22.428	571.125	2.120	0.016	0.004	3.072	0.072*	1747.963	0.813	808.628	104.399
Pooled deviation	37	27.173	435.146	1.617	0.028	0.002	3.293	0.033	1772.845	1.982	491.967	95.080
Pooled error	216	2.502	65.439	0.292	0.002	0.001	0.272	0.003	16.0755	0.047	71.453	6.690

•,•• = Significant when tested against G × E interaction at 5 % and 1 % level of probability, respectively.
*,** = Significant when tested against Pooled deviation interaction at 5 % and 1 % level of probability, respectively.
?,?? = Significant when tested against Pooled error interaction at 5 % and 1 % level of probability, respectively.

indicating differential response of genotypes to different environments [14]. Significant mean squares due to environments (linear) indicated considerable differences among environments and their predominant effects on all the traits. Pooled deviations were significant for all the traits when tested against pooled error indicated the importance of non-linear component in the manifestation of genotype × environment interaction for all the traits [14]. This poled deviation was utilized for testing the other variances.

The linear and non-linear components were significant for all the characters which indicated significant differences among the genotypes for their regression on environmental indices and genotypes differed considerably with respect to their stability [14]. The large portion of G × E interaction was due to the linear component as the magnitude of G × E (linear) was higher than corresponding non-linear parts for the traits plant height, number of leaves per plant, leaf:stem ratio, stem juiciness, green fodder yield and dry matter yield revealed that linear regression was the major component responsible for differences in stability where by the performance can be predicted for these traits with some reliance under different environments. However, for the unpredictable traits prediction can be made by considering the stability parameters of individual genotype.

Twelve hybrids were stable across the environment for high green fodder yield with non significant and near unity regression value with non significant deviation from regression value. The ten stable hybrids having high mean green fodder yield value than the check as well as hybrids mean with other related traits stability under overall and specific environment presented in Table 5 and graphically in Fig. 1. Hybrid SRF 286 × SRF 305 was identified as the best performer with average stability for green fodder yield, dry matter yield, days to flowering, plant height, number of leaves per plant, stem girth, leaf: stem ratio and stem juiciness. The other high per se performing stable hybrids for green fodder across the environment were RSSV 104 × AKFSV 2, RSSV 104 × GFS 4, SRF 286 × SRF 311 and AKFSV 2 × SSG 59-3. The stability of these hybrids might be due to stability in other yield contributing traits [15]. The hybrids SRF 286 × SSG 59-3 and RSSV 104 × SSG 59-3 were more suitable for green fodder yield and dry matter yield, respectively specifically under good farming conditions. The b_i values were significant and more than unity with less deviation from regression with respect to green fodder and dry matter yield. On the

Table 5. Average stable hybrids for green fodder yield with their related traits stability under overall and specific environment.

SNo.	Hybrid	Green fodder yield/plant (g)	bi	S^2di	Traits stability			
					Average stable	Under unfavou-rable environ-ment	Under favour rable environ-ment	Unstable
1	SRF 286 × SRF 305	216.56	1.02	202.12	DF, PH, NLP, SG, PRT	-	-	BR, HCN and L:S,SJ and DMY
2	RSSV 104 × AKFSV 2	194.67	0.82	200.59	PH, SG and SJ	DF	-	NLP, L:S, BR, HCN, PRT and DMY
3	RSSV 104 × GFS 4	182.89	1.57	–13.74	PH, L:S, HCN and DMY	-	SJ	DF, NLP, SG, BR and PRT
4	SRF 286 × SRF 311	176.89	1.46	33.17	NLP, SG and PRT	-	PH	DF, L:S, BR, SJ, HCN and DMY
5	AKFSV 2 × SSG 59-3	172.00	0.98	73.58	DF, PH and SJ	-	-	NLP, SG, L:S, BR, HCN, PRTand DMY
6	SRF 305 X RSSV 104	170.22	1.42	–34.02	DF,PH, NLP and DMY	SJ	SJ	SG, L:S, BR, HCNand PRT
7	SRF 311 X GFS 4	167.89	0.96	–46.54	NLP, L:S, SJ and DMY	-	-	DF, PH, SG, BR, HCN and PRT
8	SRF 286 X GFS 4	164.22	2.21	13.80	DF, NLP and PRT	-	SJ,	PH, SG, L:S, BR, HCN and DMY
9	SRF 305 X GFS 4	162.45	0.87	–7.26	DF,PH and DMY	SJ	-	NLP,SG, L:S, BR, HCN and PRT
10	RSSV 104 X SSG 59-3	162.11	1.27	–66.16	DF, PH, NLP, L:S and BR	-	SJ	SG, HCN, PRT and DMY

DF=days to 50% flowering, PH=plant height, NLP=number of leaves/ plant, SG=stem girth, L:S= leaf : stem ratio, BR=brix, SJ=stem juiciness, PRT=protein and DMY= dry matter yield/ plant

contrary SRF 305 × SRF 311 was more suitable for green fodder yield especially under poor farming situation as its b_i value was significant and less than unity with less deviation from regression. It can be concluded from the study that for high brix content, parents GFS3 and GFS4 can be exploited through intermating in F_2 and advanced generations, whereas hybrids having high sca effects *viz*., SRF286 x SRF211 for leaf: stem ratio and RSSV104 x AKFSV2 for HCN contents could be utilized. For developing inbred line(s) with increased brix percentage, high stem: leaf ratio along with high protein content, bi-parental crossing between selected parents would be more effective and less time-consuming than direct pedigree selection and/or back-cross methods as it would help in accumulating favorable genes distributed across segregants and, thus provides an opportunity to obtain more desirable hybrids.

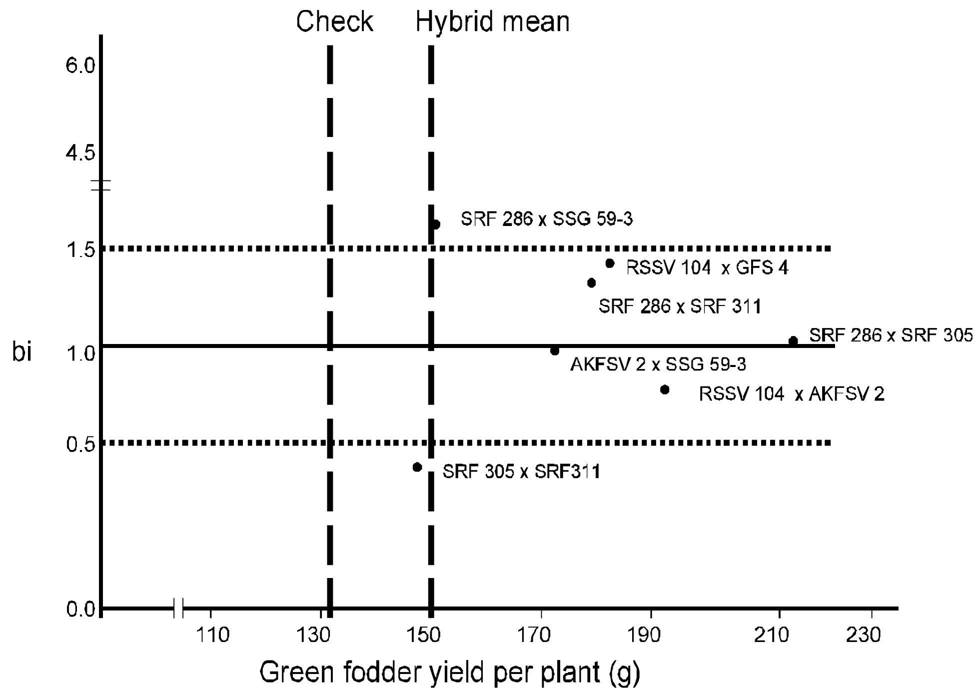

Fig. 1. Comparison of top five high green fodder yielding average stable hybrids with other specifically adapted hybrids.

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