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COMBINING ABILITY ANALYSIS FOR YIELD-RELATED TRAITS IN SWEET CORN ACROSS THE DIVERSE ENVIRONMENTS

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SUMMARY

Sweet corn (*Zea mays* var. *saccharata* Sturt) is a popular horticultural crop cultivated widely in Indonesia. However, low productivity still hampers the development of its cultivation. The following study aimed to evaluate the combining ability of seven sweet corn parental genotypes (SB8.4.3, SB13.1.3B.1, SM1.1.9, SM6.3.1, SM9.3A.1, SM12.2.13, and T13.1.8.1) with their diallel hybrids and identify the optimal combinations with higher yields. The parental cultivars sustained crossing in a complete diallel fashion to generate the 42 hybrids, studied in comparison with four check cultivars (Secada, Talenta, Bonanza, and Glory) from January to November 2023 at two locations—Pasir Kuda and Leuwikopo, Indonesia. The variables observed include the cob weight with and without husks, cob length and diameter, productivity, and sweetness level. The results showed the hybrid SM6.3.2 x SB8.4.3 had the highest SCA values for all observed traits, except sweetness level, and was also the second-highest genotype for cob diameter at both locations. Moreover, the said promising hybrid had the maximum mean values for yield-related traits, except sweetness level. The hybrid SM6.3.2 x SM9.3A emerged with negative SCA effects and the lowest mean values for all traits. The study concluded that the best hybrid in this study is the combination of SM6.3.2 and SB8.4.3.

Keywords: sweet corn (*Z. mays* var. *saccharata* Sturt), mean performance, combining ability, GCA and SCA, yield-related traits, sweetness level

Key findings: The results revealed a cross combination with two parental genotypes having different GCA produced the hybrid with a higher SCA and mean performance for most sweet corn traits (*Z. mays* var. *saccharata* Sturt). However, the hybrid formed from two parent cultivars with the same GCA produced the hybrid with a low SCA and mean performance.

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INTRODUCTION

Sweet corn (*Zea mays* var. *saccharata* Sturt) is a popular horticultural crop in Indonesia, prized for fresh and industrial consumption. According to Iriany *et al.* (2011), local demand for sweet corn is around 1.5 tons/day and continues to increase in several regions. The main difference between sweet corn and other corn cultivars is that it can reduce the conversion of sugar to starch in the endosperm (Frederic, 1984). The sweet corn formation results from the spontaneous recessive mutation in ordinary corn. The highest level of sweetness in sweet corn occurs in specific sweet corn varieties (Erdal *et al.*, 2011).

Four types of genes affect corn's sweetness level, including *sh2*, *bt*, *su1*, and *se* (Lertrat and Pulam, 2007). The development in sweet corn cultivation cannot be set apart from the productivity constraints. In addition, the taste is also unsuitable because the sugar content is lower than the starch (Lertrat and Pulam, 2007). Therefore, further efforts are essential to improve the said characteristics. In commercial sweet corn breeding, ear quality is the most crucial character, and economic approaches and advanced plant breeding are necessary to improve the properties of sweet corn (Rice and Tracy, 2013).

In general, sweet corn development leads to hybrid varieties, in which the breeders face confusion in choosing the best parental genotypes to produce the high-yielding hybrid combinations. Combining ability analysis using diallel populations is the best choice to study all the possible combinations formed from parental genotypes. A diallel crossing is a crossing in a set of selected inbred lines with all possible combinations that produce different cross combinations (Hayman, 1954a, and b). These diallel hybrids, in comparison with the parental genotypes and check cultivars, can proceed to further scrutiny for improving the yield-related traits (Griffing, 1956).

The differential analysis can separate the performance of parental cultivars and their offspring, which can also be applicable to determine the general combining ability (GCA) and specific combining ability (SCA) (Murtadha *et al.,* 2018). A combining ability study of various genotypes is essential for identifying the suitable parental genotypes in a breeding program to enhance the productivity through hybrids in different crops. The GCA value indicates a parent's overall ability to combine with other parents. However, the SCA showed the response of a combination of several genes from two different parents, forming a hybrid (Baker, 1978). The presented study aimed to evaluate the combining ability of seven sweet corn parental genotypes and their full diallel hybrids and identify the promising cross combination with a better yield.

MATERIALS AND METHODS

Breeding material and procedure

The experiment began from January to November 2023 at the Leuwikopo IPB Experimental Field and Pasir Kuda, Bogor Agricultural University, Bogor, Indonesia. The study involved seven sweet corn parental pure lines (SB8.4.3, SB13.1.3B.1, SM1.1.9, SM6.3.1, SM9.3A.1, SM12.2.13, and T13.1.8.1), and their 42 F_1 hybrids obtained through full diallel crosses, and four check cultivars (Secada, Talenta, Bonanza, and Glory). The study used a single-factor randomized complete block design (RCBD) with 53 genotypes and three replications. Each genotype, planted with 20 plants, had a spacing of 75 cm × 25 cm. Sweet corn plants received watering, fungicide application for disease control, and bi-weekly fertilization with NPK (16:16:16) at 10 g/L, with each plant receiving about 250 ml of the solution.

Data recorded and statistical analysis

The data recorded on the traits included ear weight with husk (g), ear weight without husk (g), ear diameter (mm), ear length (cm), productivity (t/ha), and sweetness level which was reflected by total soluble solids (TSS, ^{0}brix) in the sweet corn. TSS value, which is dominated by total sugar content and a small portion of soluble proteins, amino acids and other organic materials (Bexiga *et al.*, 2017), indicates the level of sweetness. The higher the TSS value, the sweeter the fruit tastes. We used full diallel analysis, with the complete diallel method used if the differences in reciprocity are significant and the parents do not experience infertility or incompatibility. The advantage indicates each parent has the same opportunity to mate as a male and female with other parents, allowing for the measurement of the maternal effect (Choudhary *et al.,* 2004). Combining ability analysis and the GCA and SCA estimates succeeded using the AGDR software application, while the mean values' comparison used the PKBT STAT (http://pbstat.com/pkbt-stat/).

RESULTS AND DISCUSSION

Analysis of variance

The analysis of variance showed the genotypes, GCA, and SCA variances were significant ($P \leq 0.05$) for all traits in sweet corn (Table 1). Significant differences in GCA and SCA variances for all characters suggested that additive and non-additive genes influence these traits. Additionally, the reciprocal variances signified maternal effects on all observed attributes. The interaction of the GCA and SCA effects with the environment indicated that each test environment has varying influences on the estimated GCA and SCA effects for yield-related traits of sweetness level. Habiba *et al*. (2022) stated that genotype and environment interactions (GEI) revealed substantial variations in response to the tested genotypes at different locations. Such types of information were very much essential for the evaluation of the genotypes under multi-environmental conditions.

Mean performance

The mean performance of the hybrids for yield-related traits and sweetness level in sweet corn appears in Tables 2 and 3. The highest husked ear weight at Leuwikopo resulted in the hybrid SM9.3A.1 x SB8.4.3 (462.58 g), while the SM6.3.2 x SB8.4.3 (389.99 g) was leading at the Pasir Kuda. The maximum ear weight without husks emerged in the hybrid SM6.3.2 x SB13.13B.16 (313.20 g) at Leuwikopo and in the hybrid SM6.3.2 x SB8.4.3 (299.09 g) at Pasir Kuda. On average, the three trait values indicated that Leuwikopo proved to be superior and significantly different from Pasir Kuda. The longest ear length at both locations manifested in the hybrid SM6.3.2 x SB13.13B.16 at Leuwikopo (22.93 cm) and Pasir Kuda (21.75 cm). At Leuwikopo, the highest productivity occurred in the hybrid SM6.3.2 x SM12.2.1 (20.24 t/ha) and in the hybrid SM6.3.2 x SB8.4.3 (24.03 t/ha) at the Pasir Kuda. These hybrids seemed significantly better than the check cultivars. The supreme sweetness level surfaced in the hybrid SB8.4.3 x T13.1.8.1 (17.87 ^{o}brix) at the Pasir Kuda, which was nonsignificantly different from the hybrid SM1.1.9 x SM12.2.1 (17.76 ^{o}brix).

General combining ability

The GCA effects of the sweet corn parental genotypes at the two locations, highlighting each parent's strengths, are available in Tables 4 and 5. The parental genotype SB8.4.3 had the highest GCA for ear weight with husk at both locations, Leuwikopo (21.35) and Pasir Kuda (23.57). The said genotype was leading and had the topmost GCA for ear weight without husk at Leuwikopo (9.05) and Pasir Kuda (19.13), ear diameter at Pasir Kuda (1.01), and sweetness level at Pasir Kuda (1.08). Sweet corn cultivar SM12.13B.16 had the ultimate GCA for ear length at both locations, i.e., 0.90 cm (Leuwikopo) and 0.67 cm (Pasir Kuda). The cultivar SM6.3.2 had the maximum GCA prediction for the character as productivity at Leuwikopo (3.80), while cultivar SB13.13B.16 was best at the Pasir Kuda (1.67) for the same feature. The cultivar SM9.3A.1 had the best GCA (1.01) for ear diameter at the Leuwikopo, while in Pasir Kuda, it was the cultivar SB8.4.3 (1.08), and SM6.3.2 had the best GCA (1.08) for sweetness level.

General combining ability measures the average contribution of inbred lines to hybrid performance (Temesgen, 2021). A parent with the highest stable GCA effect at each location

Table 1. Combined analysis of variance for yield-related traits and sweetness level in sweet corn at the two locations (Leuwikopo and Pasir Kuda).

Source of variation	d.f.	Mean Squares					
		EWH	EWWH	ED	EL	Yield	SL
Environments (E)	1	340933.83**	100694.48**	314.84**	176.63**	1513.40**	28.39**
Reps (environment)	4	7052.78**	4869.33ns	9.27ns	0.60ns	38.55**	11.02**
Genotypes (G)	48	33064.72**	842422.89**	84.69**	25.87**	88.92**	7.26ns
GCA	6	18674.88**	35750.59**	28.47**	61.79**	97.83**	16.85**
SCA	21	63757.41**	726304.26**	167.59**	36.59**	139.27**	7.09**
Reciprocals	21	6483.41**	80368.04**	17.86**	4.88**	36.03**	4.68**
G x E	48	2493.15**	44245.03**	6.50ns	1.17ns	31.56**	4.9**
GCA x E	6	3166.12**	11803.34**	12.40**	3.33**	128.60**	10.66**
SCA x E	21	2489.38**	19612.09**	5.48ns	0.89ns	17.38**	3.19**
R x E	21	2304.64**	12829.60ns	5.84ns	0.82ns	18.02**	5.17**
Error	192	1200.54	97975.08	4.98	0.91	8.80	1.71

** = Significant at $P < 0.01$, ns = nonsignificant, EWH = ear weight with husks (g), EWWH = ear weight without husks (g), ED = ear diameter (mm), EL = ear length (cm), SL= sweetness level (TSS ºBrix).

Table 2. Mean performance of the 7 x 7 diallel hybrids and check cultivars for ear weight with and without husks and ear diameter in sweet corn at the two locations (Leuwikopo and Pasir Kuda).

F_1 hybrids and Check genotypes	Ear weight with husks (g)		Ear weight without husks (g)		Ear diameter (mm)	
	LP	PK	LP	PK	LP	PK
SM1.1.9 x SM6.3.2	310.68	254.97	205.18	179.01	46.03	45.10
SM1.1.9 x SM9.3A.1	365.11	277.39	243.64	192.46	50.15	46.81
SM1.1.9 x SM12.2.1	339.40	250.62	213.05	171.41	44.94	44.01
SM1.1.9 x SB13.13B.16	427.37	326.05	250.25	235.66	49.97	47.00
SM1.1.9 x T13.1.8.1	389.38	312.51	248.85	216.24	49.41	45.17
SM1.1.9 x SB8.4.3	306.41	266.13	196.77	177.74	44.88	43.19
SM6.3.2 x SM1.1.9	330.59	258.55	215.64	174.81	47.69	44.98
SM6.3.2 x SM9.3A.1	217.91	135.08	155.23	98.88	45.54	40.35
SM6.3.2 x SM12.2.1	365.07	278.69	239.24	186.95	46.59	44.73
SM6.3.2 x SB13.13B.16	421.53	368.93	313.20	278.21	50.28	50.09
SM6.3.2 x T13.1.8.1	376.79	259.22	260.72	195.33	49.79	46.94
SM6.3.2 x SB8.4.3	444.70	389.99	299.86	299.09	50.31	49.13
SM9.3A.1 x SM1.1.9	303.28	222.43	222.71	153.35	49.18	45.97
SM9.3A.1 x SM6.3.2	192.05	132.39	130.16	86.72	42.89	38.93
SM9.3A.1 x SM12.2.1	346.09	244.80	217.74	170.57	41.55	44.57
SM9.3A.1 x SB13.13B.16	383.47	316.82	259.38	231.32	49.30	50.73
SM9.3A.1 x T13.1.8.1	319.09	222.46	236.86	158.82	51.25	45.77
SM9.3A.1 x SB8.4.3	462.58	328.52	303.87	235.90	54.02	52.86
SM12.2.1 x SM1.1.9	386.09	278.35	251.46	204.42	48.65	48.53
SM12.2.1 x SM6.3.2	279.11	244.66	209.29	185.25	44.99	44.79
SM12.2.1 x SM9.3A.1	308.90	227.72	211.51	166.17	48.10	45.91
SM12.2.1 x SB13.13B.16	342.53	279.99	250.86	200.40	48.32	45.66
SM12.2.1 x T13.1.8.1	318.19	246.23	221.16	176.52	47.64	45.64
SM12.2.1 x SB8.4.3	371.35	307.49	245.58	215.07	47.34	45.60
SB13.13B.16 x SM1.1.9	299.06	346.38	201.83	252.71	44.43	48.08
SB13.13B.16 x SM6.3.2	270.59	200.62	200.55	133.61	44.95	42.54
SB13.13B.16 x SM9.3A.1	399.32	313.89	266.55	229.10	50.54	46.46
SB13.13B.16 x SM12.2.1	362.95	265.51	267.27	192.07	49.41	45.20
SB13.13B.16 x T13.1.8.1	272.85	302.28	204.82	161.67	47.34	43.28
SB13.13B.16 x SB8.4.3	382.42	256.22	196.28	190.14	46.40	46.22

Table 2. (cont'd).

F_1 hybrids and Check genotypes	Ear weight with husks (g)		Ear weight without husks (g)		Ear diameter (mm)	
	LP	PK	LP	PK	LP	PK
T13.1.8.1 x SM1.1.9	391.84	296.82	274.23	222.66	50.59	47.77
T13.1.8.1 x SM6.3.2	320.99	242.22	224.54	181.91	47.50	44.34
T13.1.8.1 x SM9.3A.1	342.12	223.86	243.59	171.20	49.51	46.07
T13.1.8.1 x SM12.2.1	360.61	277.94	257.35	205.81	49.01	46.81
T13.1.8.1 x SB13.13B.16	343.05	251.39	237.06	185.97	48.19	45.23
T13.1.8.1 x SB8.4.3	364.27	287.48	272.83	219.85	49.60	47.04
SB8.4.3 x SM1.1.9	312.40	290.50	212.55	199.57	46.30	46.06
SB8.4.3 x SM6.3.2	446.61	302.61	283.56	227.39	49.05	47.24
SB8.4.3 x SM9.3A.1	396.47	287.38	251.61	204.00	49.60	49.33
SB8.4.3 x SM12.2.1	350.22	327.83	225.38	233.27	46.90	49.21
SB8.4.3 x SB13.13B.16	339.33	279.04	235.06	190.24	47.81	44.45
SB8.4.3 x T13.1.8.1	345.43	276.58	240.80	215.18	47.97	47.52
Secada	423.07	365.61	269.79	264.73	50.12	47.53
Talenta	347.11	263.14	256.92	202.58	49.05	46.11
Bonanza	327.24	291.80	232.52	220.21	47.43	47.14
Glori	382.32	332.12	277.59	258.58	51.61	49.79
$HSD_{0.05}$	125.66	125.66	82.52	82.52	-	-
Location means	349.748	276.33	237.71	198.97	48.09	46.21

Note: Numbers followed by the same letter in the same column are not significantly different based on the $HSD_{0.05}$ test; LP = Leuwikopo, PK = Pasir Kuda.

Table 3. Mean performance of the 7 x 7 diallel hybrids and check genotypes for ear length, productivity, and sweetness level in sweet corn at the two locations (Leuwikopo and Pasir Kuda).

F_1 hybrids and Check genotypes	Ear length (cm)		Yield (t ha^{-1})		Sweetness level (TSS °brix)	
	LP	PK	LP	PK	LP	PK
SM1.1.9 x SM6.3.2	19.65	18.78	11.44	12.96	15.77	14.91
SM1.1.9 x SM9.3A.1	19.62	18.37	10.00	15.84	14.52	15.54
SM1.1.9 x SM12.2.1	21.07	19.46	13.47	13.25	16.00	17.76
SM1.1.9 x SB13.13B.16	22.15	21.32	14.04	18.61	15.07	15.09
SM1.1.9 x T13.1.8.1	20.96	19.89	4.50	13.64	15.97	14.09
SM1.1.9 x SB8.4.3	20.99	19.79	3.31	14.90	14.78	15.86
SM6.3.2 x SM1.1.9	20.16	18.47	14.18	13.29	17.19	16.38
SM6.3.2 x SM9.3A.1	15.38	14.22	8.65	7.85	15.57	15.33
SM6.3.2 x SM12.2.1	20.98	18.63	20.23	16.77	17.17	14.54
SM6.3.2 x SB13.13B.16	22.93	21.75	15.77	20.20	15.17	14.63
SM6.3.2 x T13.1.8.1	20.78	18.15	11.83	14.43	15.73	15.49
SM6.3.2 x SB8.4.3	22.32	21.11	22.01	24.03	14.82	12.40
SM9.3A.1 x SM1.1.9	19.49	16.55	5.35	10.91	17.13	15.10
SM9.3A.1 x SM6.3.2	15.58	13.58	4.47	4.87	14.52	14.50
SM9.3A.1 x SM12.2.1	20.25	17.41	10.29	14.29	13.75	14.22
SM9.3A.1 x SB13.13B.16	19.73	19.16	7.49	18.03	13.56	14.40
SM9.3A.1 x T13.1.8.1	17.84	16.37	5.87	8.40	15.21	15.23
SM9.3A.1 x SB8.4.3	21.11	18.75	13.59	19.28	14.23	15.22
SM12.2.1 x SM1.1.9	21.33	18.12	10.21	16.75	15.29	14.48
SM12.2.1 x SM6.3.2	19.81	18.12	12.66	13.86	15.70	15.42
SM12.2.1 x SM9.3A.1	19.27	17.07	11.38	12.82	14.78	14.39
SM12.2.1 x SB13.13B.16	21.71	20.27	10.41	14.11	15.59	15.17

Table 3. (cont'd).

F_1 hybrids and Check genotypes	Ear length (cm)		Yield (t ha^{-1})		Sweetness level (TSS °brix)	
	LP	PK	LP	PK	LP	PK
SM12.2.1 x T13.1.8.1	20.04	17.26	4.15	14.41	13.26	14.98
SM12.2.1 x SB8.4.3	21.84	20.32	9.48	18.93	15.80	16.27
SB13.13B.16 x SM1.1.9	20.51	21.04	5.23	20.22	14.20	14.34
SB13.13B.16 x SM6.3.2	18.69	17.07	13.48	12.00	17.38	15.93
SB13.13B.16 x SM9.3A.1	19.94	19.62	13.84	18.17	14.68	10.59
SB13.13B.16 x SM12.2.1	21.87	20.86	16.82	14.39	15.22	13.79
SB13.13B.16 x T13.1.8.1	19.52	17.82	5.53	16.85	15.12	14.05
SB13.13B.16 x SB8.4.3	19.00	18.84	3.79	15.71	15.70	14.73
T13.1.8.1 x SM1.1.9	21.14	20.83	10.13	14.36	16.13	16.71
T13.1.8.1 x SM6.3.2	19.91	17.69	15.62	13.06	15.83	12.59
T13.1.8.1 x SM9.3A.1	19.53	16.56	10.12	11.80	15.22	12.33
T13.1.8.1 x SM12.2.1	21.68	19.97	6.74	10.95	14.74	15.96
T13.1.8.1 x SB13.13B.16	19.93	18.46	8.75	13.51	16.30	9.05
T13.1.8.1 x SB8.4.3	21.04	19.20	7.68	15.31	17.08	17.11
SB8.4.3 x SM1.1.9	20.06	19.53	3.07	14.10	16.13	16.88
SB8.4.3 x SM6.3.2	22.69	19.22	14.50	16.06	14.52	16.76
SB8.4.3 x SM9.3A.1	19.70	17.94	4.91	17.37	15.28	15.40
SB8.4.3 x SM12.2.1	19.97	19.49	5.00	12.67	15.02	14.43
SB8.4.3 x SB13.13B.16	19.61	18.70	4.26	13.52	15.57	15.09
SB8.4.3 x T13.1.8.1	20.27	19.28	5.57	13.23	15.58	17.87
Secada	21.61	21.57	11.29	17.69	14.38	14.05
Talenta	20.25	18.92	15.51	13.59	16.38	15.87
Bonanza	20.33	19.77	2.24	17.10	16.52	15.97
Glori	19.62	19.26	6.17	12.83	15.38	11.93
$HSD_{0.05}$	3.19	3.19	11.11	11.11	4.83	4.83
Location means	20.26	18.79	9.67	14.72[a]	15.41	14.84

Note: Numbers followed by the same letter in the same column are not significantly different based on the $HSD_{0.05}$ test; LP = Leuwikopo, PK = Pasir Kuda.

Table 4. General combining ability (GCA) effects for the ear weight with and without husks and ear diameter in sweet corn at the two locations (Leuwikopo and Pasir Kuda).

Parental genotypes	Ear weight with husks (g)			Ear weight without husks (g)			Ear diameter (mm)		
	LP	PK	Means	LP	PK	Means	LP	PK	Means
SM1.1.9	9.91^{ns}	12.83**	11.37**	-6.56^{ns}	4.90^{ns}	-0.84^{ns}	-0.18^{ns}	0.36^{ns}	0.09^{ns}
SM6.3.2	-13.68**	-14.92**	-14.3**	-5.80^{ns}	-8.90**	-7.35**	-0.90**	-1.08**	-0.99**
SM9.3A.1	-5.18^{ns}	-29.34**	-17.26**	-3.57^{ns}	-18.94**	-11.25**	1.01**	0.40^{ns}	0.71**
SM12.2.1	-3.39^{ns}	-2.30^{ns}	-2.85^{ns}	-0.61^{ns}	-1.24^{ns}	-0.92^{ns}	-0.85**	0.04^{ns}	-0.41^{ns}
SB13.13B.16	1.34^{ns}	18.71**	10.03**	4.17^{ns}	9.21**	6.69**	0.12^{ns}	-0.15^{ns}	-0.01^{ns}
T13.1.8.1	-10.35^{ns}	-8.55^{ns}	-9.45**	3.34^{ns}	-4.17^{ns}	-0.41^{ns}	0.58^{ns}	-0.58^{ns}	-0.00^{ns}
SB8.4.3	21.35**	23.57**	22.46**	9.05**	19.13**	14.09**	0.22^{ns}	1.01**	0.61**

** = Significant at $P < 0.01$, ns = Nonsignificant, LP = Leuwikopo, PK = Pasir Kuda.

showed strong potential for developing high-yielding and adaptable hybrids. The GCA reflects additive gene action, meaning the offspring consistently inherits its effects (Cheng *et al*., 2010). This is evident from the SCA data (Tables 6 and 7) and average values (Tables 2 and 3), which showed high-yielding hybrids surpassing the best cultivars have at least one parent with the highest GCA effect.

Table 5. General combining ability (GCA) effects for ear length, productivity, and sweetness level in sweet corn at the two locations (Leuwikopo and Pasir Kuda).

Parental genotypes	Ear length (cm)			Yield (ton ha^{-1})			Sweetness level (TSS °Brix)		
	LP	PK	Means	LP	PK	Means	LP	PK	Means
SM1.1.9	0.36**	0.64**	0.50**	-0.58^{ns}	0.340^{ns}	-0.09^{ns}	-0.09^{ns}	0.64**	0.28^{ns}
SM6.3.2	-0.22^{ns}	-0.66**	-0.44**	3.80**	-0.42^{ns}	1.69**	0.48**	-0.35^{ns}	0.41**
SM9.3A.1	-1.45**	-1.76**	-1.61**	-0.31^{ns}	-1.37**	-0.84**	-0.42^{ns}	-0.57**	-0.05**
SM12.2.1	0.90**	0.67**	0.78**	1.20**	-0.19^{ns}	0.50^{ns}	-0.16^{ns}	0.16^{ns}	0.00^{ns}
SB13.13B.16	0.22^{ns}	0.94**	0.58**	-0.18^{ns}	1.67**	0.74**	0.13^{ns}	-0.90**	-0.39**
T13.1.8.1	-0.32**	-0.41**	-0.37**	-1.78**	-1.31**	-1.55**	-0.09^{ns}	-0.76**	-0.42**
SB8.4.3	0.51**	0.58**	0.55**	-2.14**	1.21**	-0.46^{ns}	0.15^{ns}	1.08**	0.62**

** = Significant at $P < 0.01$, ns = Nonsignificant, LP = Leuwikopo, PK = Pasir Kuda.

Table 6. Specific combining ability (SCA) effects for the ear weight with and without husks and ear diameter in sweet corn at the two locations (Leuwikopo and Pasir Kuda).

F$_1$ hybrids	Ear weight with husks (g)		Ear weight without husks (g)		Ear diameter (mm)	
	LP	PK	LP	PK	LP	PK
SM1.1.9 x SM6.3.2	2.42^{ns}	6.03^{ns}	5.57^{ns}	1.25^{ns}	1.07^{ns}	1.04^{ns}
SM1.1.9 x SM9.3A.1	8.97^{ns}	13.6^{ns}	26.87**	7.28^{ns}	2.09**	0.90^{ns}
SM1.1.9 x SM12.2.1	35.72**	1.14^{ns}	22.99**	4.59^{ns}	1.07^{ns}	1.15^{ns}
SM1.1.9 x SB13.13B.16	31.46**	51.86**	12.01^{ns}	50.41**	0.49^{ns}	2.60**
SM1.1.9 x T13.1.8.1	70.55**	47.57**	48.33**	39.06**	2.85**	1.97**
SM1.1.9 x SB8.4.3	-43.83**	-10.90^{ns}	-15.02^{ns}	-15.04^{ns}	-1.32^{ns}	-1.47^{ns}
SM6.3.2 x SM1.1.9	-9.96^{ns}	-1.79^{ns}	-5.23^{ns}	2.10^{ns}	-0.83**	0.06^{ns}
SM6.3.2 x SM9.3A.1	-98.14**	-74.83**	-65.16**	-59.02**	-2.77**	-4.40**
SM6.3.2 x SM12.2.1	17.17^{ns}	26.08**	13.44^{ns}	16.57^{ns}	0.66^{ns}	1.08^{ns}
SM6.3.2 x SB13.13B.16	36.41**	28.17**	41.29**	25.94**	1.50^{ns}	2.83**
SM6.3.2 x T13.1.8.1	50.94**	21.37^{ns}	27.86**	22.03**	2.10**	2.58**
SM6.3.2 x SB8.4.3	114.52**	84.83**	70.48**	73.35**	3.37**	3.54**
SM9.3A.1 x SM1.1.9	30.91**	27.48**	10.46**	19.56**	0.48^{ns}	0.42^{ns}
SM9.3A.1 x SM6.3.2	12.93**	1.35^{ns}	12.54**	-8.52**	1.32**	-0.54^{ns}
SM9.3A.1 x SM12.2.1	15.57^{ns}	15.08^{ns}	2.34^{ns}	8.89^{ns}	-2.09**	0.07^{ns}
SM9.3A.1 x SB13.13B.16	74.73**	73.16**	45.91**	60.29**	2.01**	3.62**
SM9.3A.1 x T13.1.8.1	25.64^{ns}	8.22^{ns}	23.99**	8.45^{ns}	2.04**	1.37^{ns}
SM9.3A.1 x SB8.4.3	91.38**	60.90**	55.04**	40.09**	3.71**	4.96**
SM12.2.1 x SM1.1.9	-23.34**	-13.86**	-19.21**	6.08^{ns}	-1.86**	0.71^{ns}
SM12.2.1 x SM6.3.2	42.98**	17.02**	14.98**	72.3**	0.80^{ns}	3.77**
SM12.2.1 x SM9.3A.1	18.60**	8.54^{ns}	3.12^{ns}	6.71^{ns}	-3.28**	1.30**
SM12.2.1 x SB13.13B.16	34.28**	3.52^{ns}	39.05**	8.60^{ns}	2.82**	0.82^{ns}
SM12.2.1 x T13.1.8.1	32.64**	20.11^{ns}	20.06**	16.91**	1.84**	2.05**
SM12.2.1 x SB8.4.3	20.84^{ns}	43.57**	9.82^{ns}	26.61**	0.88^{ns}	1.63**
SB13.13B.16 x SM1.1.9	64.15**	-10.17^{ns}	24.21**	-16.51**	2.77**	-2.26**
SB13.13B.16 x SM6.3.2	75.47^{ns}	84.16**	56.32**	1.11^{ns}	2.67**	2.14**
SB13.13B.16 x SM9.3A.1	-7.93^{ns}	1.46^{ns}	-3.58^{ns}	-6.19^{ns}	-0.62^{ns}	-0.15^{ns}
SB13.13B.16 x SM12.2.1	-10.21^{ns}	7.24^{ns}	-8.21**	-10.91**	-0.55^{ns}	-1.43**
SB13.13B.16 x T13.1.8.1	-3.55^{ns}	13.85^{ns}	-3.03^{ns}	-10.89^{ns}	0.29^{ns}	0.26^{ns}
SB13.13B.16 x SB8.4.3	16.20^{ns}	-27.47**	-14.76^{ns}	-17.81**	-0.12^{ns}	-0.25^{ns}
T13.1.8.1 x SM1.1.9	-1.23**	7.84^{ns}	-12.69**	0.85^{ns}	-0.59^{ns}	-0.03^{ns}
T13.1.8.1 x SM6.3.2	27.90^{ns}	8.50^{ns}	18.09**	4.16^{ns}	1.15**	0.23^{ns}
T13.1.8.1 x SM9.3A.1	-11.52**	-0.70^{ns}	-3.36^{ns}	-14.65**	0.87**	-0.59^{ns}
T13.1.8.1 x SM12.2.1	-21.21^{ns}	-15.86**	-18.09**	35.85**	-0.69^{ns}	0.95**
T13.1.8.1 x SB13.13B.16	-35.1^{ns}	25.44**	-16.12**	-9.10**	-0.43^{ns}	-1.80**
T13.1.8.1 x SB8.4.3	21.87^{ns}	14.19^{ns}	27.21**	22.89**	1.12^{ns}	2.13**

Table 6. (cont'd).

F_1 hybrids	Ear weight with husks (g)		Ear weight without husks (g)		Ear diameter (mm)	
	LP	PK	LP	PK	LP	PK
SB8.4.3 x SM1.1.9	-3.00^{**}	-12.19^{**}	-7.89^{**}	2.20^{ns}	-0.71^{ns}	-0.67^{ns}
SB8.4.3 x SM6.3.2	-0.96^{ns}	43.69^{**}	8.15^{**}	-3.21^{ns}	0.63^{ns}	-1.30^{**}
SB8.4.3 x SM9.3A.1	33.06^{**}	20.57^{**}	26.13^{**}	-12.15^{**}	2.21^{**}	-0.97^{**}
SB8.4.3 x SM12.2.1	10.56^{**}	-10.17^{ns}	10.10^{**}	15.95^{**}	0.22^{ns}	1.76^{**}
SB8.4.3 x SB13.13B.16	21.54^{**}	-11.40^{ns}	-19.39^{**}	-0.05^{ns}	-0.71^{ns}	0.89^{**}
SB8.4.3 x T13.1.8.1	9.42^{ns}	5.45^{ns}	16.02^{**}	2.33^{ns}	0.81^{**}	-0.24^{ns}

** = Significant at $P < 0.01$, ns = Nonsignifcant, LP = Leuwikopo, PK = Pasir Kuda.

Table 7. Specific combining ability (SCA) effects for ear length, productivity, and sweetness level in sweet corn at the two locations (Leuwikopo and Pasir Kuda).

F_1 hybrids	Ear length (cm)		Yield (ton ha^{-1})		Sweetness level (TSS °Brix)	
	LP	PK	LP	PK	LP	PK
SM1.1.9 x SM6.3.2	0.05^{ns}	0.49^{ns}	0.42^{ns}	-0.38^{ns}	0.67^{ns}	-0.18^{ns}
SM1.1.9 x SM9.3A.1	0.94^{**}	0.43^{ns}	-0.35^{ns}	0.82^{ns}	0.87^{ns}	0.43^{ns}
SM1.1.9 x SM12.2.1	0.24^{ns}	-0.67^{ns}	2.31^{**}	1.26^{ns}	0.43^{ns}	0.49^{ns}
SM1.1.9 x SB13.13B.16	1.04^{**}	1.45^{**}	1.48^{ns}	3.82^{**}	-0.87^{ns}	0.15^{ns}
SM1.1.9 x T13.1.8.1	1.31^{**}	1.97^{**}	0.77^{ns}	1.38^{ns}	0.77^{ns}	0.69^{ns}
SM1.1.9 x SB8.4.3	-0.06^{ns}	0.28^{ns}	-3.26^{**}	-0.64^{ns}	-0.03^{ns}	-0.18^{ns}
SM6.3.2 x SM1.1.9	-0.26^{ns}	0.15^{ns}	-1.37^{**}	-0.16^{ns}	-0.71^{**}	-0.73^{**}
SM6.3.2 x SM9.3A.1	-2.56^{**}	-1.83^{**}	-6.10^{**}	-5.38^{**}	-0.43^{ns}	0.31^{ns}
SM6.3.2 x SM12.2.1	0.00^{ns}	0.22^{ns}	2.28^{ns}	2.40^{**}	0.69^{ns}	-0.36^{ns}
SM6.3.2 x SB13.13B.16	1.10^{**}	0.98^{**}	1.84^{ns}	1.32^{ns}	0.25^{ns}	1.00^{ns}
SM6.3.2 x T13.1.8.1	1.18^{**}	0.84^{**}	2.54^{**}	1.95^{ns}	-0.03^{ns}	-0.38^{ns}
SM6.3.2 x SB8.4.3	2.50^{**}	2.08^{**}	7.17^{**}	5.72^{**}	-1.34^{**}	-1.69^{**}
SM9.3A.1 x SM1.1.9	0.06^{ns}	0.91^{**}	2.33^{**}	2.46^{**}	-1.31^{**}	0.22^{ns}
SM9.3A.1 x SM6.3.2	-0.10^{ns}	0.14^{ns}	2.09^{**}	-0.80^{ns}	0.52^{**}	0.37^{ns}
SM9.3A.1 x SM12.2.1	0.61^{ns}	0.18^{ns}	1.03^{ns}	1.59^{ns}	-0.62^{ns}	-0.11^{ns}
SM9.3A.1 x SB13.13B.16	1.36^{**}	2.06^{**}	2.24^{ns}	4.27^{**}	-1.05^{**}	-0.86^{ns}
SM9.3A.1 x T13.1.8.1	0.76^{**}	0.49^{ns}	1.17^{ns}	-0.74^{ns}	0.26^{ns}	0.29^{ns}
SM9.3A.1 x SB8.4.3	1.64^{**}	1.37^{**}	2.53^{**}	4.96^{**}	-0.40^{ns}	-0.03^{ns}
SM12.2.1 x SM1.1.9	-0.13^{ns}	0.32^{ns}	1.63^{**}	1.49^{**}	0.36^{ns}	0.42^{ns}
SM12.2.1 x SM6.3.2	0.58^{**}	2.34^{**}	3.79^{**}	4.10^{**}	0.73^{**}	-0.65^{**}
SM12.2.1 x SM9.3A.1	0.49^{**}	0.23^{ns}	-0.55^{ns}	0.69^{ns}	-0.51^{**}	1.45^{**}
SM12.2.1 x SB13.13B.16	0.97^{**}	0.81^{**}	3.68^{**}	-0.76^{ns}	-0.03^{ns}	0.39^{ns}
SM12.2.1 x T13.1.8.1	0.58^{ns}	0.20^{ns}	-2.88^{**}	0.66^{ns}	-1.21^{**}	1.25^{**}
SM12.2.1 x SB8.4.3	-0.22^{ns}	0.50^{ns}	-0.98^{ns}	1.25^{ns}	0.00^{ns}	-0.72^{ns}
SB13.13B.16 x SM1.1.9	0.82^{**}	0.67^{**}	4.41^{**}	-1.75^{**}	0.43^{**}	1.64^{**}
SB13.13B.16 x SM6.3.2	2.12^{**}	-0.23^{ns}	1.14^{**}	-0.07^{ns}	-1.11^{**}	1.91^{**}
SB13.13B.16 x SM9.3A.1	-0.11^{ns}	-0.10^{ns}	-3.18^{**}	-1.70^{**}	-0.56^{**}	1.45^{**}
SB13.13B.16 x SM12.2.1	-0.08^{ns}	0.13^{ns}	-3.20^{**}	0.40^{ns}	0.18^{ns}	-0.51^{**}
SB13.13B.16 x T13.1.8.1	0.13^{ns}	-0.54^{ns}	0.19^{ns}	1.29^{ns}	0.21^{ns}	-1.62^{**}
SB13.13B.16 x SB8.4.3	-1.14^{**}	-0.90^{**}	-2.82^{**}	-1.79^{ns}	-0.07^{ns}	-0.10^{ns}
T13.1.8.1 x SM1.1.9	-0.09^{ns}	0.26^{ns}	-2.81^{**}	1.46^{**}	-0.08^{ns}	-0.44^{ns}
T13.1.8.1 x SM6.3.2	0.44^{**}	-0.29^{ns}	-1.89^{**}	-0.14^{ns}	-0.05^{ns}	0.69^{**}
T13.1.8.1 x SM9.3A.1	-0.85^{**}	-1.35^{**}	-2.12^{**}	1.73^{**}	-0.01^{ns}	-0.49^{**}
T13.1.8.1 x SM12.2.1	-0.82^{**}	0.94^{**}	-1.30^{**}	3.99^{**}	-0.74^{**}	-2.18^{**}
T13.1.8.1 x SB13.13B.16	-0.20^{ns}	0.42^{**}	-1.61^{**}	3.13^{**}	-0.59^{**}	0.92^{**}
T13.1.8.1 x SB8.4.3	0.76^{**}	0.91^{**}	1.38^{ns}	0.84^{ns}	0.85^{ns}	2.34^{**}

Table 7. (cont'd).

F_1 hybrids	Ear length (cm)		Yield (ton ha^{-1})		Sweetness level (TSS °Brix)	
	LP	PK	LP	PK	LP	PK
SB8.4.3 x SM1.1.9	0.47^{**}	0.17^{ns}	0.12^{ns}	0.74^{ns}	-0.68^{**}	-0.08^{ns}
SB8.4.3 x SM6.3.2	-0.19^{ns}	-0.47^{**}	3.76^{**}	-0.36^{ns}	0.15^{ns}	-1.31^{**}
SB8.4.3 x SM9.3A.1	0.71^{**}	-0.32^{ns}	4.34^{**}	1.67^{**}	-0.52^{**}	2.51^{**}
SB8.4.3 x SM12.2.1	0.94^{**}	0.41^{**}	2.24^{**}	0.96^{**}	0.39^{ns}	-0.09^{ns}
SB8.4.3 x SB13.13B.16	-0.30^{ns}	0.07^{ns}	-0.23^{ns}	1.09^{**}	0.07^{ns}	-0.18^{ns}
SB8.4.3 x T13.1.8.1	0.38^{**}	-0.04^{ns}	1.06^{ns}	1.04^{**}	0.75^{**}	-0.38^{ns}

** = Significant at $P < 0.01$, ns = Nonsignificant, LP = Leuwikopo, PK = Pasir Kuda.

High GCA was a good indicator of producing better fruit yield (Bahari *et al.*, 2012). Based on the estimated GCA values, cultivar SB8.4.3 was the most promising genotype, with leading GCA values for three traits. The parental genotype has the greater potential for producing sweet corn hybrids with large ears and can be directly applicable as a composite variety. High GCA values specify the parents' contribution in transferring the characters with better values to their hybrids (Yerva *et al*., 2016). Based on the SCA effect data, parents with high GCA were prone to be more effective as donor parents.

Specific combining ability

The sweet corn F_1 populations with estimated specific combining ability values presented in Tables 6 and 7. The F_1 hybrid SM6.3.2 x SB8.4.3 had the highest positive SCA effects for ear weight without husk at both locations, i.e., Leuwikopo (114.52) and Pasir Kuda (84.83). This promising cross combination also had the best SCA values for most traits and locations, including ear weight without husk, ear diameter, length, and productivity. Conversely, the highest positive SCA effect for ear diameter at Pasir Kuda was notable in the hybrid SM9.3A.A x SB8.4.3 (4.96). For sweetness level, the highest SCA value at Leuwikopo resulted in the hybrid of SB8.4.3 x T13.1.8.1 (0.75), while at Pasir Kuda, the leading sweet corn hybrid was SB8.4.3 x SM9.3A.1 (2.51). Specific combining ability is an essential criterion for hybrid evaluation (Machikowa *et al*., 2011).

The cross combinations SM6.3.2 x SB8.4.3 and SM9.3A x SB8.4.3 consistently showed significant positive SCA values at both test sites for all traits, except sweetness level This consistency was likely due to both sites' uniform ear size and weight. Both cross combinations were outcomes from the parental genotypes with the highest GCA for specific traits, i.e., cultivar SM9.3A.1 had the maximum GCA for ear traits, while in contrast, the parental cultivar SM6.3.2 excelled in productivity, and genotype SB8.4.3 was leading in ear weight. Promising hybrids always involve the parental inbred lines with the superior GCA (Patel *et al*., 2017).

The F_1 hybrid SM6.3.2 x SB8.4.3 constantly had the highest SCA value for most traits at both locations, except ear diameter at the Pasir Kuda, indicating its considerable genetic potential for yield components and grain yield in sweet corn. These results also received confirmation from the mean performance analysis, showing the said hybrid SM6.3.2 x SB8.4.3 with the highest productivity at both locations, i.e., Leuwikopo (22.01 t/ha) and Pasir Kuda (24.03 t/ha), surpassing the best check cultivars (Talenta and Secada) in both sites. Unfortunately, both promising cross combinations had negative SCA values for sweetness level. Most cross combinations with the highest SCA for productivity also had negative SCA effects for sweetness level, likely due to a suspected negative correlation between sucrose concentration and starch synthesis. Therefore, grain sweetness can gain an increase by reducing starch synthesis activity and increasing sucrose accumulation in sweet corn (Szymanek *et al*., 2015).

Based on the mean performance of sweet corn F_1 populations, the hybrid SM6.3.2 x SB8.4.3 has sweetness levels of 12.40 at Pasir Kuda and 14.82 at Leuwikopo. The cross combination SM6.3.2 x SB8.4.3 steadily showed the best SCA effect, resulting from the high x low GCA genotypes, i.e., the female parent with significant positive GCA effects and the male parent with significant negative GCA values for yield components, except ear diameter. Crosses between parental cultivars with significant positive and negative GCA values (high x low GCA parents) revealed the hybrids with maximum positive SCA effects, indicating a significant dominant gene effect in maize (Engida *et al*., 2024). This phenomenon occurs because the two genotypes combine well, with a beneficial gene in one genotype dominating the detrimental gene in the other genotype (Amzeri *et al.*, 2024). The hybridization program enunciated that combining two parental genotypes with different GCA effects can produce a superior hybrid with the best SCA and high vigor.

The cross combination SM6.3.2 x SM9.3A consistently provided a significant negative SCA effect, indicating low genetic potential, as evidenced by its low mean values across all traits compared to other hybrids in sweet corn. The GCA results manifested that this cross combination involves two parental cultivars with negative GCA values, except for productivity. Another F_1 hybrid with constantly low SCA values was SB13.13B.16 x SB8.4.3. Both parental cultivars have positive GCA values for all traits, except cob diameter and sweetness level at Pasir Kuda and productivity at Leuwikopo. These two cross combinations were unworthy of developing into hybrid varieties because of the low genetic potential compared with their parental genotypes at both locations. The result confirmed the cross combination formed from the two parental cultivars will produce a hybrid with low SCA and hybrid vigor.

CONCLUSIONS

The F_1 hybrid SM6.3.2 x SB8.4.3 became identified and selected as the best cross combination based on the mean performance and SCA effects for yield-related traits and sweetness level in sweet corn. The results also confirmed cross-combination can be achievable from parental cultivars with different GCA (high x low and low x high GCA parents), while the poor F_1 hybrid comes from two parents with the same GCA. Parental genotypes with high GCA will produce offspring with high SCA as donor parents.

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