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Hybrid Performances and Heterosis in Sweet Corn as Grown under Organic Crop Management in Tropical Highland Climate

Chozin, M.*, Sudjatmiko, S., Fahrurrozi, F., Setyowati, N. and Muktamar, Z.

Faculty of Agriculture, University of Bengkulu, Jl. W.R. Supratman, Kandang Limun, Bengkulu 38121, Indonesia.

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Abstract Significant variation among the genotypes were observed to be the most traits, except for kernel row number and soluble solids (°brix). There were 12 out of 28 hybrids exhibited better general performances over the better parent and check variety. The estimates of MPHs, BPHs, and EH for the plant growth traits exhibited undesirable direction on all crosses, vis. positive for plant height, negative for stalk diameter, and positive for taller ear height. The desired significant negative directions in MPH and EH were recorded on most of the hybrids for tasseling and silk dates. No significant BPH was found on all crosses for tasseling date and only several crosses for silking date. Significant positive MPH and BPH, but not EH, were found on six crosses and three crosses, respectively. The majority of crosses showed significant positive MPH and BPH for unhusked ear weight, but only several numbers for unhusked ear length and diameter, and weight. None of the crosses showed significant positive EH. Similar features of MPH, BPH, and EH were found for husked ear length, ear diameter, and ear weight, except seven and two crosses, indicated significant positive Eh for ear diameter and ear weight, respectively. No significant positive MPH, BPH, and EH on all crosses for kernel row number. For kernel number row^{-1}, a large number of crosses had significant positive MPH, but the lesser number had significant positive BPH and EH. Most of the crosses exhibited non-significant MPH, BPH, and EH for soluble solid content. These finding suggested that progress of sweet corn hybrid breeding for organic production in tropical highland climate could be expected from the heterosis exploitation of the ear traits.

Keywords: organic sweet corn, F1 hybrids, mid-parent heterosis, better parent heterosis, economic heterosis

Introduction

The organic sweet corn farmers in the highlands of Indonesia have to deal with the very limited choice of varieties to grow. The available commercial varieties are mostly, if not all, intended for conventional production with the involvement of high agrochemical inputs to attain the highest possible crop yield. Moreover, the short supply of varieties adapted to highland climate

* **Corresponding Author:** Mohammad Chozin; **E-mail:** mchozin@unib.ac.id

makes the choice even narrower. It has been a common issue that the crop performances of the varieties bred for conventional production do not always perform well under organic crop management (Murphy *et al*., 2007; Burger *et al*, 2008; van Bueren *et al*., 2011). Similarly, a lower air temperature occurred in a high elevation brings a further challenge related to slower plant growth and development as compared to warmer zone in the low and medium elevations (Skarbø and Vander Molen, 2016; Moeletsi, 2017). Consequently, a breeding program aimed at producing hybrid varieties having an efficient use of nutrient derived from slow-nutrient-releasing organic fertilizer (Dawson *et al*., 2008) and broad thermal adaptation (Abakemal *et al*., 2016) would widen the range of varietal choices for organic sweet corn production in higher altitude in the tropics.

Like other crops, the development of sweet corn hybrid varieties is mainly based on taking advantage of heterosis (also known as hybrid vigor) (Dickert and Tracy, 2002; Assunção *et al*., 2010; Srdić *et al*., 2011). The term heterosis was introduced by Shull in1908 to refer the phenotypic superiority phenomenon of F_1 hybrid in adaptation, yield, quality, disease resistance, maturity and/or general vigor over its homozygous parents. Although the genetic mechanisms conferring the phenomenon remains inconclusive (Hallauer *et al*., 2010; Kaeppler, 2012; Khotyleva *et al*., 2017), the exploitation of heterosis has resulted in many sweet corn hybrid varieties differing in their superiorities.

A diallel crossing scheme is a common approach for the evaluation of heterosis in sweet corn (Assunção *et al*, 2010; Solomon *et al*., 2012; Kumar *et al*., 2013). This scheme enables heterosis prediction of F_1 hybrids derived from all possible crossing combinations of the parental array and, thus, facilitate the breeder to discern the less from the more promising crosses and to concentrate further evaluation on few, but valuable corresponding parents (Singh *et al*., 2016). The objectives of this study were to evaluate the agronomic performances and to estimate the heterosis in terms of mid-parent, better parent, and economic heterosis of various traits for identification desirable parents and development of sweet corn hybrid varieties for organic production at the tropical highland area.

Materials and methods

Characteristics of the experimental site

The study was conducted in 2016 at the highland area of Rejang Lebong Regency, Bengkulu Province (3°27’ 49” S; 102°36’ 52” E; 1039 m above sea level). The experimental site was characterized by Inceptisol and soil pH 5.6. The daily air temperature fluctuated around 18 – 30 ℃ with an average relative humidity of 85.5 % and average monthly precipitation of 213 mm.

Plant materials and experimental design

A total of 37 sweet corn genotypes consisted 28 hybrids along with their 8 parental lines (Caps 2, Caps 3, Caps 5, Caps 15, Caps 17A, Caps 17B, Caps 22, and Caps 23), and Secada (a commercial hybrid) as the check variety were used in this study. The parental lines were S_7 inbreds that previously developed from a series of selection trials for their performances under organic crop management. The hybrids were generated in the previous planting season from the all possible crosses of the parental lines in a half diallel fashion. A randomized complete block design involving three replications was employed to allocate the genotypes on the experimental plots. Each plot was represented by a single row of five meters length spaced 75 cm apart.

Planting and crop management

Seeds from each genotype were sown on the corresponding plot with 25 cm plant-to-plant spacing. Organic management was practiced during the crop production. Cow manure at 15 ton ha^{-1} was amended as the basal fertilizer during the soil preparation. A locally made liquid organic fertilizer (Fahrurrozi *et al*., 2016) was side-dressed 4 times during the plant growth period with two weeks interval. Weeds were controlled manually as necessary. Pest and disease infestations were negligible and, consequently, no control measure was taken. Harvest was carried out at about 25 days following silking when the ears had fully developed, husk turned dark green, silks turned brown, and kernels were soft and plump with milky juice when squeezed.

Data collection and analysis

Observations were made on samples of five plants randomly selected from the middle part of the row for plant height, stalk diameter, first ear height, tasseling and silking dates, unhusked and husked ear characteristics (length, diameter, and weight), kernel row number, kernel number row^{-1}, and soluble solid. The collected data were subjected to analysis of variance and performed using PROC GLM in SAS version 9.2 (SAS Institute Inc., 2008) for determining the significant variation among the genotypes for the observed traits. Scott-Knott cluster analysis was performed using DSAASTAT (Onofri,

2011) for genotypic mean grouping. Heterosis was estimated for each hybrid as mid-parent heterosis (MPH), better parent heterosis (BPH), and economic heterosis (EH) using the formulas as adopted by Meena *et al*. (2017).

$$\text{Mid-parent heterosis (MPH)} = \frac{\bar{F}_1 - \overline{MP}}{\overline{MP}} \times 100\ \%$$

$$\text{Better-parent heterosis (BPH)} = \frac{\bar{F}_1 - \overline{BP}}{\overline{BP}} \times 100\ \%$$

$$\text{Economic heterosis (EH)} = \frac{\bar{F}_1 - \overline{CV}}{\overline{CV}} \times 100\ \%$$

Where, $\bar{F}_1$ = hybrid mean Mean value of hybrid; $\overline{MP}$ = Mean of two corresponding parents; $\overline{BP}$ = Mean value of better parent; and $\overline{CV}$ = Mean value of check variety. The increased percentages (+) of heterosis were deemed as desirable for all traits except for plant height, ear diameter, tasseling date, and silking date, where the decreased percentages (-) were desirable. The significance of heterosis was tested using a t-test at error degree of freedom as suggested by Dabholkar (2006).

$$t = \frac{\bar{F}_1 - \overline{MP} \text{ or } \overline{BP} \text{ or } \overline{CV}}{SE_d} \quad \text{and} \quad SE_d = \sqrt{\frac{2\ MS_E}{r}}$$

where MS_E = error mean square and r = number of replications.

Results

Growth and developmental characteristics

Analysis of variance indicated significant variations among the genotypes for all observed growth and developmental traits, confirming that the genotypes retained distinguishable growth and developmental characteristics to the facilitate identification of desirable genotypes. Table 1 shows the mean performances genotypes for the traits. In most cases, the hybrids tended to have taller plant stature as compared to their corresponding parental inbreds. Among the genotypes, Caps 5 was identified as the shortest and other 19 genotypes were shorter than the check variety.

There were 9 genotypes possessed larger stalk diameter that the check variety with Caps 22 was distinctively the largest. With respect to ear height, the maximum value was observed on the Caps 3 x Caps 17A (P2 x P6) and the

Table 1. Mean performances for growth and developmental traits of 37 genotypes grown under organic crop management at tropical highland climate

Genotype	Plant height (cm)		Stalk diameter (mm)		Ear height (cm)		Tasseling date (dap)		Silking date (dap)	
P1 (Caps 2)	192.5	j	32.8	b	87.4	p	61	e	64	d
P2 (Caps 3)	184.7	l	25.5	i	107.7	h	67	a	69	a
P3 (Caps 5)	179.1	m	27.1	g	80.1	q	62	d	65	c
P4 (Caps 15)	186.4	l	29.2	d	97.6	n	60	f	65	c
P5 (Caps 17A)	184.0	l	28.4	e	102.8	k	65	a	68	b
P6 (Caps 17B)	206.6	h	31.2	c	104.5	j	61	e	64	d
P7 (Caps 22)	206.1	h	34.2	a	102.7	k	64	b	66	c
P8 (Caps 23)	188.9	k	27.3	g	94.7	o	63	c	68	b
P1 x P2	212.0	f	24.6	k	106.0	i	60	f	63	e
P1 x P3	205.5	h	25.1	j	99.1	m	59	g	62	f
P1 x P4	206.3	h	26.2	h	105.2	i	61	e	63	e
P1 x P5	233.3	a	29.3	d	110.2	g	59	g	64	d
P1 x P6	200.0	i	27.1	g	103.3	k	60	f	62	f
P1 x P7	206.3	h	26.2	h	105.6	i	61	e	64	d
P1 x P8	206.3	h	26.7	h	101.4	l	62	d	64	d
P2 x P3	227.7	b	24.7	k	126.7	b	61	e	62	f
P2 x P4	207.5	h	25.3	i	117.5	d	61	e	65	c
P2 x P5	210.6	g	26.4	h	115.2	e	62	d	63	e
P2 x P6	232.0	a	27.9	f	135.6	a	61	e	63	e
P2 x P7	232.7	a	27.2	g	127.2	b	60	f	62	f
P2 x P8	217.4	e	26.3	h	113.1	f	61	e	64	d
P3 x P4	207.8	h	24.7	k	106.2	i	60	f	62	f
P3 x P5	215.8	e	25.8	i	116.6	d	61	e	62	f
P3 x P6	185.1	l	28.2	e	97.5	n	62	d	64	d
P3 x P7	221.7	c	25.8	i	120.2	c	60	f	63	e
P3 x P8	212.6	f	26.3	h	106.7	i	61	e	63	e
P4 x P5	219.7	d	24.5	k	115.7	e	59	g	62	f
P4 x P6	226.4	b	25.7	i	113.0	f	61	e	65	c
P4 x P7	211.3	f	28.4	e	111.0	g	61	e	63	e
P4 x P8	219.3	d	26.9	g	108.4	h	59	g	62	f
P5 x P6	215.8	e	27.1	g	112.2	f	61	e	63	e
P5 x P7	226.5	b	26.0	i	117.5	d	60	f	62	f
P5 x P8	227.0	b	27.3	g	109.5	g	60	f	62	f
P6 x P7	225.5	b	25.0	j	118.1	d	61	e	64	d
P6 x P8	227.2	b	25.9	i	109.1	g	61	e	64	d
P7 x P8	233.1	a	25.7	i	111.9	f	60	f	63	e
Secada	217.7	e	28.7	e	117.2	d	65	a	66	c
Minimum	179.1		24.5		80.1		59.0		62.0	
Maximum	233.3		34.2		135.6		67.0		69.0	

Means in the same column followed by a common letter do not differ in the Scott-Knott test at the 0.05 level of significance, dap = day after planting

Table 2. Mid-parent heterosis, better parent heterosis, and economic heterosis for growth traits of 28 sweet corn crosses as grown under organic crop management at tropical highland climate

Cross	Plant height			Stalk diameter			Ear height		
	MPH (%)	**BPH (%)**	**EH (%)**	**MPH (%)**	**BPH (%)**	**EH (%)**	**MPH (%)**	**BPH (%)**	**EH (%)**
P1 x P2	12.4*	14.8**	-2.6	-15.6*	-24.9**	-14.4	8.7	21.3**	-9.6
P1 x P3	10.6*	14.8**	-5.6	-16.3*	-23.5**	-12.8	18.3*	23.7**	-15.5
P1 x P4	8.9	10.7*	-5.2	-15.5*	-20.1**	-8.9	13.8	20.4**	-10.2
P1 x P5	23.9**	26.8**	7.2	-4.1	-10.5	2.1	15.9*	26.1**	-6
P1 x P6	0.2	3.9	-8.1	-15.3*	-17.3**	-5.7	7.6	18.2*	-11.9
P1 x P7	3.5	7.2	-5.2	-21.9**	-23.5**	-8.9	11.1	20.9**	-9.9
P1 x P8	8.2	9.2	-5.2	-10.9	-18.4**	-7	11.4	16.1*	-13.5
P2 x P3	25.2**	27.2**	4.6	-6.2	-9	-14	34.9**	58.2*	8.1
P2 x P4	11.8*	12.3*	-4.7	-7.7	-13.5	-12.1	14.5*	20.4*	0.2
P2 x P5	14.2*	14.4**	-3.3	-2	-7	-8	9.5	12.1	-1.7
P2 x P6	18.6**	25.6**	6.6	-1.5	-10.5	-2.8	27.8**	29.7**	15.7**
P2 x P7	19.1**	26.0**	6.9	-9	-20.6**	-5.5	20.9**	23.8**	8.5
P2 x P8	16.4**	17.7**	-0.1	-0.4	-3.5	-8.5	11.8	19.5**	-3.5
P3 x P4	13.7**	16.1**	-4.5	-12.3	-15.4*	-14	19.6*	32.7**	-9.4
P3 x P5	18.9**	20.5**	-0.9	-7.3	-9.4	-10.3	27.5*	45.6**	-0.5
P3 x P6	-4	3.4	-15.0**	-3.4	-9.7	-2	5.7	21.8*	-16.8**
P3 x P7	15.1**	23.8**	1.9	-16.0*	-24.7**	-10.3	31.5**	50.1**	2.6
P3 x P8	15.6**	18.7**	-2.3	-3.4	-3.6	-8.6	22.1**	33.2**	-9
P4 x P5	18.6**	19.4**	0.9	-15.1*	-16.2**	-14.8*	15.5*	18.6**	-1.3
P4 x P6	15.2**	21.5**	4	-15.0*	-17.7**	-10.7	11.8	15.8*	-3.6
P4 x P7	7.7	13.4**	-2.9	-10.5	-17.1**	-1.3	10.8	13.8*	-5.3
P4 x P8	16.8**	17.6**	0.7	-4.7	-7.9	-6.4	12.8	14.5*	-7.5
P5 x P6	10.5*	17.3**	-0.9	-9.2	-13.2**	-5.8	8.2	9.1	-4.3
P5 x P7	16.1**	23.1**	4.1	-17.0*	-24.0**	-9.5	14.4*	14.3*	0.3
P5 x P8	21.7**	23.3**	4.3	-1.8	-3.9	-4.9	10.9	15.6*	-6.6
P6 x P7	9.3*	9.4*	3.6	-23.4**	-26.8**	-12.9	13.9*	14.9*	0.7
P6 x P8	14.9**	20.3**	4.4	-11.3	-16.9**	-9.7	9.6	15.2*	-6.9
P7 x P8	18.1**	23.4**	7.1	-16.4	-24.9**	-10.6	13.3*	18.1*	-4.6
Minimum	-4	3.4	-15	-23.4	-26.8	-14.8	5.7	9.1	-16.8
Maximum	25.2	27.2	7.2	-0.4	-3.5	2.1	34.9	58.2	15.7

* and ** denote significant at the 0.05 and 0.01 levels, respectively

minimum value was observed on the inbred parents Caps 5. There were 4 genotypes significantly possessing higher ear and 28 genotypes possessing lower ear as compared to the check variety. With respect to the plant development, the early maturing genotype is usually desirable. Caps 3 was identified as the latest genotype in bearing tassel and silk. As compared to the check variety, 34 genotypes had an earlier tasseling date and 28 genotypes had an earlier silking date. On average, the different between tasseling date and silking was 3 days, with the maximum different 5 days was found on Caps 23.

Table 3. Mid-parent heterosis, better parent heterosis, and economic heterosis for developmental traits of 28 sweet corn crosses as grown under organic crop management at tropical highland climate

Cross	Tasseling date			Silking date		
	MPH (%)	BPH (%)	EH (%)	MPH (%)	BPH (%)	EH (%)
P1 x P2	-6.2**	-1.6	-7.2**	-4.8**	-1	-4.0*
P1 x P3	-5.1**	-4.3	-9.7**	-4.4*	-3.6*	-6.6**
P1 x P4	-0.3	0.6	-6.7**	-2.1	-1.6	-4.5**
P1 x P5	-6.3**	-3.3	-8.7**	-2.8	0	-3
P1 x P6	-2.7	-2.7	-8.2**	-3.4*	-3.1	-6.1**
P1 x P7	-2.1	0	-5.6**	-2.1	-0.5	-3.5*
P1 x P8	0.5	1.6	-4.1*	-3.5*	-0.5	-3.5*
P2 x P3	-6.4**	-2.7	-6.7**	-7.0**	-4.1*	-5.6**
P2 x P4	-5.0**	0.6	-6.7**	-2.7	0.5	-1.5
P2 x P5	-6.5**	-5.1	-4.6*	-7.3**	-6.4**	-4.0*
P2 x P6	-4.7*	0	-5.6**	-5.5**	-2.1	-4.5**
P2 x P7	-8.1**	-5.7	-7.2**	-8.1**	-6.1**	-6.1**
P2 x P8	-5.6**	-2.1	-5.6**	-7.1**	-6.4**	-3.5*
P3 x P4	-1.6	0	-7.2**	-4.4*	-4.1*	-6.1**
P3 x P5	-5.0**	-2.7	-6.7**	-6.0**	-4.1*	-5.6**
P3 x P6	0.3	1.1	-4.6*	-1.5	-1	-3.5*
P3 x P7	-5.0**	-3.7	-7.7**	-4.3**	-3.6*	-5.1**
P3 x P8	-2.9	-2.7	-6.7**	-4.8**	-2.6	-4.0*
P4 x P5	-6.1**	-2.2	-9.2**	-6.3**	-4.1*	-6.1**
P4 x P6	0.8	1.7	-5.6**	0.3	0.5	-2
P4 x P7	-2.4	0.6	-6.7	-4.1*	-3.1	-5.1**
P4 x P8	-4.1*	-2.2	-9.2**	-6.0**	-3.6*	-5.6**
P5 x P6	-3.7*	-0.5	-6.2**	-4.0*	-1.6	-4.0*
P5 x P7	-6.7**	-5.7	-7.2**	-7.2**	-6.1**	-6.1**
P5 x P8	-5.7**	-3.7	-7.2**	-8.1**	-7.9**	-5.6**
P6 x P7	-3.2	-1.1	-6.7**	-1.8	-0.5	-3
P6 x P8	-2.2	-1.1	-6.7**	-3.8*	-1	-3.5*
P7 x P8	-5.8**	-4.8	-8.2**	-6.0**	-4.5**	-4.5**
Minimum	-8.1	-5.7	-9.7	-8.1	-7.9	-6.6
Maximum	0.8	1.7	-4.1	0.3	0.5	-1.5

* and ** denote significant at the 0.05 and 0.01 levels, respectively

The magnitude of mid-parent heterosis (MPH), better parent heterosis (BPH) and economic heterosis (EH) for plant growth and developmental traits were presented in Table 2 and Table 3, respectively. It was conceived that shorter plant stature is desirable for sweet corn, but BPH for plant height deducted from shorter parent showed no significant decrease (negative direction) in all crosses. Similarly, Caps 5 x Caps 17B (P3 x P6) was the only cross exhibited significant negative EH. A larger stalk diameter apparently could not be expected from all crosses, as their BPH and EH estimates showed no significant positive direction. For ear height, both BPH and EH estimates had a similar pattern as for plant height and, again, Caps 5 x Caps 17B (P3 x P6) was the only cross exhibited significant negative EH. There were a number of crossed showed significant and negative heterosis estimates on tasseling and silking dates, but their values may not large enough to expect a meaningful improvement.

Unhusked ear characteristics

Selection for the large ear is the main agenda in sweet corn hybrid breeding program. In this study, a significant variation among the genotypes was revealed for the traits measured on the unhusked ear, i.e. length, diameter, and weight. The mean performances of the genotypes for these traits were depicted in Table 4. Caps 5 x Caps 17A (P3 x P5) was exhibited the best genotype with respect to the overall performances of the measured traits on the unhusked ear. There were thirteen genotypes, three genotypes, and twelve genotypes exhibited their superiorities over the check variety for ear length, diameter, and weight, respectively.

Considering large ear is desirable, some crosses offered notable MPH and BPH for heterosis exploitation of unhusked ear size (Table 5). Significant positive MPH was found on five crosses for unhusked ear length, fourteen crosses for unhusked ear diameter, and twenty-four crosses for unhusked ear weight. Based on BPH, Caps 22 x Caps 23 (P7 x P8) was the only crossed exhibited significant positive heterosis for ear length, nine crosses for ear diameter, and seventeen crosses for ear weight. Unfortunately, no cross exhibited significant positive BPH for these three traits.

Husked ear characteristics

The difference between unhusked and husked ear mainly reflect the length, thickness, number, and weight of the husk. Significant variation among the genotypes was observed for husked ear length, diameter, and weight. The genotypic means for these traits were presented in Table 6. As for unhusked ear, Caps 5 x Caps 17A (P3 x P5) showed it superiority for ear diameter and weight, but not for ear length. Overall, there were 15 genotypes, 13 genotypes, and 18 genotypes exceeded the check variety on their performances for husked ear length, diameter, and weight, respectively.

Table 4. Mean performances for unhusked ear traits of 37 genotypes grown under organic crop management at tropical highland climate

Genotype	Unhusked ear					
	Length (cm)		Diameter (mm)		Weight (g)	
P1 (Caps 2)	25.5	i	56.3	h	273.5	n
P2 (Caps 3)	21.7	m	47.5	l	183.4	p
P3 (Caps 5)	23.5	l	58.9	g	333.3	k
P4 (Caps 15)	27.7	e	54.8	j	315.1	l
P5 (Caps 17A)	26.3	g	54.4	j	297.9	m
P6 (Caps 17B)	30.1	a	58.6	g	363.7	h
P7 (Caps 22)	25.9	h	55.1	i	313.9	l
P8 (Caps 23)	24.2	k	50.4	k	215.3	o
P1 x P2	27.1	f	58.8	g	347.3	j
P1 x P3	26.9	f	60.4	e	368.2	h
P1 x P4	26.2	g	59.4	f	367.7	h
P1 x P5	29.4	b	61.5	d	417.2	e
P1 x P6	28.5	d	60.3	e	391.3	g
P1 x P7	26.3	g	61.7	d	369.9	h
P1 x P8	27.6	e	58.3	g	356.9	i
P2 x P3	25.8	h	62.5	c	406.7	f
P2 x P4	24.9	j	55.3	i	376.6	h
P2 x P5	26.3	g	60.9	e	408.0	f
P2 x P6	27.8	e	60.3	e	386.9	g
P2 x P7	27.6	e	62.8	c	391.6	g
P2 x P8	27.2	f	59.4	f	369.1	h
P3 x P4	28.5	d	55.6	i	432.8	d
P3 x P5	29.6	a	65.7	a	468.3	a
P3 x P6	26.9	f	63.0	c	457.8	b
P3 x P7	25.8	h	62.8	c	436.7	d
P3 x P8	27.6	e	61.0	e	399.5	f
P4 x P5	28.5	d	62.3	c	460.7	b
P4 x P6	24.9	j	56.5	h	362.8	h
P4 x P7	27.3	f	62.9	c	447.1	c
P4 x P8	28.9	c	63.7	b	431.6	d
P5 x P6	28.4	d	61.4	d	406.6	f
P5 x P7	29.4	b	62.8	c	437.6	d
P5 x P8	29.9	a	62.6	c	432.5	d
P6 x P7	29.8	a	63.1	c	435.0	d
P6 x P8	29.8	a	63.4	c	398.4	f
P7 x P8	29.8	a	64.0	b	443.1	c
Secada	27.9	e	62.4	c	405.1	f
Minimum	21.7		47.5		183.4	
Maximum	30.1		65.7		468.3	

Means in the same column followed by a common letter do not differ in the Scott-Knott test at the 0.05 level of significance

Table 5. Mid-parent heterosis, better parent heterosis, and economic heterosis for unhusked ear traits of 28 sweet corn crosses as grown under organic crop management at tropical highland climate

Cross	Unhusked ear								
	Length			Diameter			Weight		
	MPH (%)	BPH (%)	EH (%)	MPH (%)	BPH (%)	EH (%)	MPH (%)	BPH (%)	EH (%)
P1 x P2	14.8	6.1	-2.9	13.2*	4.4	-5.8	52.0**	27.0*	-14.3
P1 x P3	9.6	5.4	-3.6	4.9	2.6	-3.2	21.4	10.5	-9.1
P1 x P4	-1.6	-5.4	-6.1	6.9	5.5	-4.8	25.0*	16.7	-9.2
P1 x P5	13.6	11.8	5.6	11.1	9.3	-1.3	46.0**	40.1**	3
P1 x P6	2.5	-5.3	2.3	5	2.9	-3.3	22.8	7.6	-3.4
P1 x P7	2.2	1.4	-5.7	10.7	9.6	-1.1	25.9*	17.8	-8.7
P1 x P8	11.3	8.4	-0.8	9.2	3.5	-6.6	46.0**	30.5*	-11.9
P2 x P3	14.2	9.6	-7.4	17.5**	6.2	0.3	57.4**	22.0*	0.4
P2 x P4	0.8	-10.1	-10.8	8.1	1	-11.3*	51.1**	19.5	-7
P2 x P5	9.7	0	-5.5	19.4**	11.8	-2.4	69.5**	37.0**	0.7
P2 x P6	7.5	-7.5	-0.1	13.7*	3	-3.3	41.4**	6.4	-4.5
P2 x P7	16.0*	6.6	-1	22.3**	13.9*	0.7	57.5**	24.8*	-3.3
P2 x P8	18.7*	12.6	-2.4	21.3**	17.9*	-4.8	85.1**	71.4**	-8.9
P3 x P4	11.5	3.1	2.4	-2.2	-5.6	-10.9*	33.5**	29.9**	6.8
P3 x P5	18.7*	12.4	6.2	16.0**	11.7*	5.4	48.4**	40.5**	15.6
P3 x P6	0.4	-10.5	-3.3	7.3	7	1	31.4**	25.9*	13
P3 x P7	4.2	-0.5	-7.5	10.2	6.7	0.7	35.0**	31.0**	7.8
P3 x P8	15.9*	14.3	-0.8	11.7	3.7	-2.1	45.7**	19.9	-1.4
P4 x P5	5.7	3.1	2.4	14.1*	13.7*	-0.1	50.3**	46.2**	13.7
P4 x P6	-13.8*	-17.3*	-10.6	-0.4	-3.6	-9.5	6.9	-0.2	-10.4
P4 x P7	1.8	-1.4	-2.2	14.5*	14.1*	0.9	42.2**	41.9**	10.4
P4 x P8	11.6	4.6	3.8	21.1**	16.2*	2.1	62.8**	36.9**	6.5
P5 x P6	0.5	-5.8	1.8	8.7	4.8	-1.5	22.9*	11.8	0.4
P5 x P7	12.7	11.8	5.6	14.6*	13.9*	0.7	43.1**	39.4**	8
P5 x P8	18.5	13.7	7.4	19.4**	14.9*	0.3	68.6**	45.2**	6.8
P6 x P7	6.3	-1.1	6.8	11	7.7	1.2	28.4*	19.6	7.4
P6 x P8	9.7	-1.1	6.8	16.3*	8.1	1.6	37.6**	9.6	-1.7
P7 x P8	18.9*	14.9*	6.8	21.3**	16.1*	2.6	67.5**	41.2**	9.4
Minimum	-13.8	-17.3	-10.8	-2.2	-5.6	-11.3	6.9	-0.2	-14.3
Maximum	18.9	14.9	7.4	22.3	17.9	5.4	85.1	71.4	15.6

* and ** denote significant at the 0.05 and 0.01 levels, respectively

Significant positive MPH and BPH for husked ear length were observed on 17 genotypes and 6 genotypes, respectively, but not EH (Table 7). Similar features were also observed on husked ear diameter (7 genotypes) and husked ear weight (15 genotypes), but there were 2 genotypes had significant positive EH, namely Caps 5 x Caps 17A (P3 x P5) and Caps 5 x Caps 22 (P3 x P7). Accordingly, the crop improvement through the exploitation of heterosis could be expected from the current parental inbreds for husked ear size.

Table 6. Mean performances for husked ear traits of 37 genotypes grown under organic crop management at tropical highland climate

Genotype	Husked ear					
	Length (cm)		Diameter (mm)		Weight (g)	
P1 (Caps 2)	15.6	m	48.5	i	180.6	m
P2 (Caps 3)	14.5	n	40.8	n	116.0	p
P3 (Caps 5)	15.9	l	49.3	h	238.3	i
P4 (Caps 15)	17.0	j	44.9	l	200.1	l
P5 (Caps 17A)	17.6	i	43.9	m	177.3	n
P6 (Caps 17B)	19.2	e	45.6	k	218.5	j
P7 (Caps 22)	17.0	j	47.5	j	205.9	k
P8 (Caps 23)	14.7	n	44.4	m	143.6	o
P1 x P2	16.7	k	49.3	h	223.2	j
P1 x P3	18.0	h	53.7	b	272.6	f
P1 x P4	19.0	f	50.1	g	244.2	i
P1 x P5	19.3	e	48.7	i	249.7	h
P1 x P6	19.2	e	49.8	g	239.1	i
P1 x P7	16.7	k	49.2	h	242.2	i
P1 x P8	18.1	h	49.9	g	242.3	i
P2 x P3	17.6	i	52.8	c	265.9	g
P2 x P4	18.4	g	44.1	m	262.1	g
P2 x P5	18.4	g	52.6	c	292.9	c
P2 x P6	19.4	e	50.5	f	254.7	h
P2 x P7	18.3	g	53.1	c	262.8	g
P2 x P8	18.0	h	49.8	g	244.5	i
P3 x P4	19.3	e	48.2	i	300.1	b
P3 x P5	19.9	c	54.8	a	313.8	a
P3 x P6	20.0	c	52.0	d	288.7	d
P3 x P7	19.3	e	54.0	b	310.0	a
P3 x P8	18.5	g	51.4	e	267.9	f
P4 x P5	20.9	b	52.3	c	304.6	b
P4 x P6	19.8	d	47.1	j	243.5	i
P4 x P7	19.6	d	50.4	f	297.4	c
P4 x P8	21.5	a	50.1	g	293.2	c
P5 x P6	19.3	e	50.3	f	261.0	g
P5 x P7	19.9	c	53.0	c	293.0	c
P5 x P8	18.8	f	52.6	c	281.1	e
P6 x P7	20.1	c	50.1	g	262.3	g
P6 x P8	18.7	f	53.7	b	252.9	h
P7 x P8	18.8	f	52.9	c	287.3	d
Secada	19.0	f	50.8	f	253.7	h
Minimum	14.5		40.8		116.0	
Maximum	21.5		54.8		313.8	

Means in the same column followed by a common letter do not differ in the Scott-Knott test at the 0.05 level of significance

Table 7. Mid-parent heterosis, better parent heterosis, and economic heterosis for husked ear traits of 28 sweet corn crosses as grown under organic crop management at tropical highland climate

Cross	Husked ear								
	Length			Diameter			Weight		
	MPH (%)	BPH (%)	EH (%)	MPH (%)	BPH (%)	EH (%)	MPH (%)	BPH (%)	EH (%)
P1 x P2	10.8	7.1	-12.3	10.3	1.7	-3	50.5**	23.6	-12
P1 x P3	14.2	13.2	-5.6	9.9	9	5.7	30.2*	14.4	7.4
P1 x P4	16.5*	11.8	-0.4	7.3	3.3	-1.4	28.3*	22.1	-3.8
P1 x P5	16.1*	9.5	1.4	5.5	0.6	-4.1	39.6*	38.3*	-1.6
P1 x P6	10.2	-0.2	0.7	5.8	2.7	-2	19.8	9.4	-5.8
P1 x P7	2.7	-1.6	-12.1	2.5	1.5	-3.1	25.4	17.6	-4.5
P1 x P8	19.4*	15.8*	-5.1	7.4	2.9	-1.8	49.5**	34.2*	-4.5
P2 x P3	15.8*	10.9	-7.5	17.2**	7.2	3.9	50.1**	11.6	4.8
P2 x P4	16.6*	8.3	-3.5	3	-1.6	-13.1*	65.8**	31.0*	3.3
P2 x P5	14.2	4.2	-3.5	24.2**	19.9**	3.6	99.7**	65.2**	15.4
P2 x P6	14.8*	0.9	1.8	16.9*	10.8	-0.6	52.3**	16.6	0.4
P2 x P7	16.1*	7.6	-3.9	20.2**	11.8*	4.5	63.3**	27.6*	3.6
P2 x P8	23.3**	22.7**	-5.4	16.8*	12.1	-2	88.3**	70.2**	-3.7
P3 x P4	17.6	13.8	1.4	2.3	7.4	-5.2	36.9**	25.9*	18.3
P3 x P5	19.0**	13	4.7	17.6**	11.2*	7.8	51.0**	31.7**	23.7*
P3 x P6	13.9*	4	4.9	9.7	5.5	2.4	26.4*	21.2	13.8
P3 x P7	17.2*	13.3	1.2	11.5*	9.5	6.2	39.6**	30.1**	22.2*
P3 x P8	21.4**	16.8*	-2.6	9.8	4.3	1.2	40.3**	12.4	5.6
P4 x P5	20.6**	18.3**	9.6	17.9**	16.6**	3	61.4**	52.2**	20
P4 x P6	9.3	3	3.9	4.2	5.1	-7.2	16.3	11.4	-4
P4 x P7	15.2*	15.1*	2.8	9.2	6.2	-0.7	46.5**	44.4**	17.2
P4 x P8	35.7**	26.5**	12.8	12.3*	11.7	-1.3	70.6**	46.6**	15.6
P5 x P6	5	0.7	1.6	12.5*	10.5	-0.9	31.9*	19.5	2.9
P5 x P7	14.7*	12.7	4.4	15.9*	11.5*	4.3	52.9**	42.3**	15.5
P5 x P8	16.2*	6.4	-1.4	19.1**	18.5**	3.5	75.2**	58.5**	10.8
P6 x P7	10.9	4.5	5.4	7.6	5.4	-1.4	23.6	20.1	3.4
P6 x P8	10.6	-2.4	-1.6	19.5**	17.9**	5.8	39.7**	15.7	-0.3
P7 x P8	18.7*	10.6	-1.2	15.1*	11.3	4.1	64.4**	39.5**	13.2
Minimum	2.7	-2.4	-12.3	2.3	-1.6	-13.1	16.3	9.4	-12
Maximum	35.7	26.5	12.8	24.2	19.9	7.8	99.7	70.2	23.7

* and ** denote significant at the 0.05 and 0.01 levels, respectively

Kernel arrangement and sweetness

Analysis of variance revealed significant genotypic variation for kernel number row^{-1}, but not for kernel row number and soluble solid content. The mean kernel row number ranged from 14 to 21 found in the genotypes is common for sweet corn (Table 8). The maximum kernel number row^{-1} was exhibited by Caps 15 x Caps 17A (P4 x P5) and Caps 15 x Caps 23 (P4 xP8). Beside these two crosses, there were 13 crosses produced more kernel number row^{-1} then check variety.

Table 8. Mean performances for kernel arrangement and sweetness of 37 genotypes grown under organic crop management at tropical highland climate

Genotype	Kernel row number	Kernel number row^{-1}		Soluble solid (^{o}Brix)
P1 (Caps 2)	14	28	o	14
P2 (Caps 3)	15	27	p	13
P3 (Caps 5)	14	28	o	11
P4 (Caps 15)	21	34	l	14
P5 (Caps 17A)	16	37	f	13
P6 (Caps 17B)	14	37	f	14
P7 (Caps 22)	15	33	m	13
P8 (Caps 23)	14	27	p	13
P1 x P2	14	33	m	12
P1 x P3	14	32	n	12
P1 x P4	15	39	d	14
P1 x P5	15	39	d	13
P1 x P6	14	39	d	12
P1 x P7	14	35	k	13
P1 x P8	14	36	g	13
P2 x P3	16	35	j	13
P2 x P4	16	40	c	14
P2 x P5	17	38	e	13
P2 x P6	15	38	e	12
P2 x P7	16	37	f	15
P2 x P8	15	36	h	13
P3 x P4	16	38	e	14
P3 x P5	16	39	c	12
P3 x P6	16	36	h	12
P3 x P7	14	37	f	13
P3 x P8	15	36	i	12
P4 x P5	17	42	a	13
P4 x P6	14	36	g	14
P4 x P7	16	41	b	13
P4 x P8	17	42	a	12
P5 x P6	15	38	e	13
P5 x P7	16	41	b	13
P5 x P8	16	40	c	13
P6 x P7	15	38	e	13
P6 x P8	15	34	k	11
P7 x P8	16	37	f	12
Secada	17	37	f	12
Minimum	14	27		11
Maximum	30	42		15

Means in the same column followed by a common letter do not differ in the Scott-Knott test at the 0.05 level of significance

Caps 3 x Caps 22 (P2 x P7) was the only cross showed significant positive MPH and EH, but not BPH (Table 9), indicating that little improvement could be expected from the current inbreds for heterosis exploitation of kernel sweetness.

Table 9. Mid-parent heterosis, better parent heterosis, and economic heterosis for husked ear traits of 28 sweet corn crosses as grown under organic crop management at tropical highland climate

Cross	Kernel row number			Kernel number row^{-1}			Soluble solid		
	MPH (%)	BPH (%)	EH (%)	MPH (%)	BPH (%)	EH (%)	MPH (%)	BPH (%)	EH (%)
P1 x P2	-6	-8.6	-19.2	21.4*	19.8*	-10.1	-13.6	-14.6*	-5.4
P1 x P3	-1.9	-2.8	-18.8	16.1	15.7	-12.5	-6.7	-14.6*	-5.4
P1 x P4	-16.1	-29.6**	-13.3	26.5**	15.0*	5.4	2.4	2.4	13.5
P1 x P5	-1	-5.7	-12.9	20.6**	5.7	5.4	-6.2	-7.3	2.7
P1 x P6	-4.7	-4.7	-20.4	20.6**	5.4	5.8	-13.3	-14.3*	-2.7
P1 x P7	-8.1	-11.7	-20	13.8	4.4	-6.1	-1.3	-4.9	5.4
P1 x P8	1.7	-0.5	-16.9	25.0**	23.6**	-7.2	-1.3	-4.9	5.4
P2 x P3	8.6	4.7	-7.5	27.7**	25.4**	-5.1	2.7	-5	2.7
P2 x P4	-8.4	-21.3*	-3.1	30.9**	17.6*	7.8	6.2	4.9	16.2*
P2 x P5	7.4	5.1	-2.9	20.6**	4.4	4.2	-1.5	-1.5	6.5
P2 x P6	0.8	-2	-13.3	19.6**	3.2	3.6	-14.6*	-16.7*	-5.4
P2 x P7	5.6	4.3	-5.5	21.7**	10.3	-0.9	15.4*	12.5	21.6**
P2 x P8	7.2	2	-9.8	31.9**	31.5**	-3.4	-3.3	-5.7	1.9
P3 x P4	-5.7	-21.5*	-3.3	24.0**	13.2	3.8	9.3	0	10.8
P3 x P5	8.4	2.3	-5.5	21.6**	7	6.7	-5.4	-12.5	-5.4
P3 x P6	13.3	12.2	-6.3	9.7	-3.8	-3.4	-2.6	-11.9	0
P3 x P7	-1.4	-6.1	-14.9	20.8**	11.3	0	11.1	5.3	8.1
P3 x P8	10.7	9.3	-10.4	29.4**	27.5**	-3.5	2.8	-2.6	0
P4 x P5	-6.1	-17.8	1.2	19.8**	15.0*	14.6*	-6.2	-7.3	2.7
P4 x P6	-18.4	-31.5**	-15.7	1.7	-2.7	-2.4	3.6	2.4	16.2*
P4 x P7	-12.7	-24.2**	-6.7	22.7**	21.5**	11.4	-1.3	-4.9	5.4
P4 x P8	-3	-20.1**	-1.6	37.8**	24.1**	13.7*	-8.9	-12.2	-2.7
P5 x P6	2.6	-2.3	-9.8	3.1	2.8	3.2	-7.3	-9.5	2.7
P5 x P7	2.5	1.5	-6.3	16.7*	11	10.7	2.6	0	8.1
P5 x P8	6.1	-1.1	-8.6	24.3**	7.9	7.6	-2.6	-5	2.7
P6 x P7	3.6	-0.4	-9.8	8.2	2.5	2.9	0	-4.8	8.1
P6 x P8	8.9	6.6	-11	7.2	-7.2	-6.9	-15.0*	-19.0**	-8.1
P7 x P8	7.4	9.6	-8.4	23.7**	12.4	1	-2.6	-2.6	0
Minimum	-18.4	-31.5	-20.4	1.7	-7.2	-12.5	-15	-19	-8.1
Maximum	13.3	12.2	1.2	37.8	31.5	14.6	15.4	12.5	21.6

* and ** denote significant at the 0.05 and 0.01 levels, respectively

Discussion

The overall performances of the genetic materials evaluated in the present study indicated that organically managed sweet corn can grow well in the highland tropical climate. The significant variations among the genotypes in growth, developmental, and ear characteristics implied that scopes of the selection were assured by the distinguishable genetic makeup to allow further improvement.

Plant height was reported to have no apparent advantages on the yield and ear size (Ali and Saleh, 2003; Kashiani *et al*., 2011; Brewbaker and Martin, 2015). A tall plant is regarded as less desirable in windy and high precipitation highland areas as it will be liable to excessively bend. Similarly, as the internode formation is ended at floral initiation, earlier flowering is usually associated with the shorter plant (Zsuzsanna *et al*., 2002; Saleh *et al*., 2002). Stalk diameter is a major determinant of stalk strength to bending and breaking incidences (Forell *et al*., 2015) and to hold a larger ear, implying that larger stalk diameter is the desired traits in the hybrid breeding program. Nevertheless, larger stalk diameter may have little impact on the ear yield (Oktem, 2008).

The importance of ear height in sweet corn is unclear. More ears can be expected to develop from the lower nodes when the first ear develops from the higher node, but the further ears developing from lower nodes would have inferior quality. Most of the correlation studies showed that ear height had a strong positive association with plant height (Ali and Saleh, 2003; Kashiani *et al*., 2011; Dagla *et al*., 2015). Accordingly, the high-eared plant would have the same liability to bending as the tall plant. Too low ear height, however, would make the harvesting difficult. Zsubori *et al*. (2002) suggested that the ideal ear height is somewhere in between – neither too high nor too low, implying that the selection for ear height is a subjective criterion.

Early maturing hybrid is commonly preferable as the plant growth and development of sweet corn tends to be slowed down under tropical highland climate. Saleh *et al*. (2002) and Kashiani *et al*. (2010) showed that earliness had a weak correlation to ear yield and ear characteristics. In the present study, there were a number of hybrids exhibited earlier tasseling and silking dates than the check variety.

Given the climatic conditions at the tropical highland, the overall performances of the ear characteristics indicated that the genotypes evaluated in this study were well adapted to the organic growing environment. In fact, the majority of genotypes exhibited better ear performances than those reported by Lazcano *et al.* (2011) and Kara (2011). There were also twelve crosses outperformed the check variety, namely Caps 5 x Caps 17A (P3 x P5), Caps 5 x

Caps 17B (P3 x P6), Caps 5 x Caps 22 (P3 x P7), Caps 15 x Caps17A (P4 x P5), Caps 15 x Caps 22 (P4 x P7), Caps 15 x Caps 23 (P4 x P8), Caps 17A x Caps 17B (P5 x P6), Caps 17A x Caps 22 (P5 x P7), Caps 17A x Caps 23 (P5 x P8), Caps 17B x Caps 22 (P6 x P7), Caps 17B x Caps 23 (P6 x P8), Caps 22 x Caps 23 (P7 x P8). Further evaluation of these promising hybrids, however, would be required to determine their stability.

Success in the development and improvement of sweet corn hybrid to a large extent relies on the exploration of heterosis. While MPH is genetically interesting (Springer and Stupar, 2007; Feng *et al*., 2015), it has relatively little economic importance. Therefore, many hybrid breeding programs pay more attention to BPH and/or EH than MPH (Khan, 2011; Makani *et al*., 2013; Tajwar and Chakraborty, 2013; Mahmoud and El-Eslamboly, 2015). The level of BPH observed for most of the economically important traits was comparable to a similar study performed by Yuwono *et al*. (2017) and the level of EH by Kumar *et al.* (2013).

In conclusion, this study showed that tropical highland climate provides a good environment for sweet corn managed under organic cropping system. The considerable variation among the genetic materials for most of the observed traits would warrant scope of the selection processes. The superior hybrids in terms of BPH and EH for the economically important traits can be further exploited in the organic sweet corn breeding programs.

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