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Performances of sweet corn hybrids under organic crop management across three agro-climatic zones of the tropics

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Abstract Sweet corn is best adapted to warm climate and it can be grown year-round in the tropics. However, the crop performances may vary substantially along the elevation gradients. This study was conducted to compare the relative performances of sweet corn hybrids as grown organically in three tropical agro-climatic zones of the tropics, to determine the pattern of variation among the hybrids, and to group the hybrids based on their similarity in performances. Twenty-eight hybrids generated from a half diallel crossing scheme involving eight inbred lines (Caps 2, Cap 3, Caps 5, Caps 15, Caps 17A, Caps 17B, Caps 22, and Caps 23) and a commercial hybrid (as a check variety) were evaluated for their growth, development, and ear performances under organic crop management at three locations differed in the elevations (10, 618, and 976 m above sea level). The observations were made on plant height, stalk diameter, biomass, tasseling and silking dates, and ear length, ear diameter, ear weight, kernel-row number, and kernel number row^{-1}. The higher elevation tended to produce higher growth and ear performances, but slower in both tasseling and silking dates. The principal component analysis generated three principal axes accounted for 74% of the total variation among the hybrids. The first axis (39%) mainly related to the ear yield characteristics, the second axis (23%) related to tasseling and silking dates, and the third axis (12%) was related to plant stature. Cluster analysis has grouped the hybrids into three distinct clusters. Five hybrids (Caps 5 x Caps 17A, Caps 5 x Caps 17B, Caps 15 x Caps 17A, Caps 15 x Caps 23, and Caps 17A x Caps 22) are considered to have potential for organic production across the agro-climatic zones of the tropics.

Keywords: cluster analysis, combined analysis of variance, elevation, organic crop management, principal component analysis

Introduction

Tropical regions are well known for the climatic conditions favored the plant growth the year-round. Although sweet corn is a temperate crop by origin (Tracy, 1997), its production has spread over to tropical areas. With the fairly constant high temperature, high level of incoming radiant energy, invariable day length, and high annual rainfall, the sweet corn growers in the tropics can

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produce crops without seasonal constraints as occurred in the temperate and subtropical climates (William, 2008; George *et al*., 2003; Franco *et al*., 2016).

The term agro-climatic zones refer to the regionalization of areas based on the homogeneity in weather variables having the greatest effect on crop growth and yield (Van Wart *et al*., 2013). Under the tropical condition, air temperature is the most pronounced meteorological component in characterizing the agro-climatic zones along the elevational gradients. The average annual temperature decreases by about 0.6 ℃ with every 100 m increase in elevation (Juo and Franzluebbers, 2003). As a warm season crop, sweet corn has been reported to be sensitive to temperature variation (Ben-Asher *et al*., 2008; Khan *et al*., 2009; Cicchino *et al*., 2010). Accordingly, crop growth, phonological development, and yield can vary with differing elevations (Brewbaker, 2003).

To organic sweet corn growers in the tropics, the phenomenon of differential plant performances across agro-climatic zones will influence the choice of right varieties to be grown. The decision would not only be based on the suitability of the variety for a particular agro-climatic zone but also based on the suitability for organic production. To meet such requirements, therefore, sweet corn breeders are challenged to develop varieties having capability to perform well in the tropic with varying elevations (Abadassi, 2015) and to produce a good ear yield and ear quality under organic crop production system (Lazcano *et al*., 2011) in order to be widely accepted by organic sweet corn growers throughout a tropical region.

New crop varieties are generally developed under environmental conditions existing in the breeding station. Consequently, they always require evaluation under broader environmental conditions prior to release and make available to the growers. Such evaluation is particularly relevant if the targeted areas of production cover a wide range of climatic conditions. To this end, several sweet corn hybrids aimed for organic production have been developed in the Closed Agriculture Production System (CAPS) breeding station, Faculty of Agriculture, University of Bengkulu, Indonesia. This study was undertaken to compare their growth and yield performances as grown organically in three tropical agro-climatic zones of the tropics, to determine the pattern of variation among the hybrids, and to group the hybrids based on their similarity in performances.

Materials and methods

Plant materials and experimental sites

Sweet corn inbred lines Caps 2 (P1), Cap 3 (P2), Caps 5 (P3), Caps 15 (P4), Caps 17A (P5), Caps 17B (P6), Caps 22 (P7), and Caps 23 (P8) were crossed in 2016 according to a half diallel mating design to produce 28 F_1 hybrids. These inbred lines were selected and developed under organic environment throughout seven generation of selfings (S_7). The resulting 28 hybrids along with a commercial hybrid cv Lorenza (as the check variety) were evaluated in 2017 for this study. Lorenza is a commercial variety commonly grown under intensive cropping management. The experiment was set up at three locations in Bengkulu Province, Indonesia, to represent the difference in agro-climatic zones, namely: 1) Bengkulu City (10 m asl) to represent a lowland environment; 2) South Rejang Lebong Sub-district (618 m asl) to represent a midland environment; and 3) Selupu Rejang Sub-district (1054 m asl) to represent a highland environment.

Experimental set-up

In each location, the hybrids were randomly assigned in the experimental plots according to a randomized complete block design with three replications. The plot was a single row of five meters long and 0.75 cm spacing between rows. Blocks were one meter spaced apart. Plant density was maintained at 20 plant row^{-1} by sowing the seeds from each hybrid at 25 cm planting space in each row. Prior to planting, the soil was prepared and amended with cow manure at 15 ton ha^{-1}. All recommended organic crop management was adopted in the cultural practice, including fertilization using locally made organic fertilizer for side-dressings, manual weeding tools for weed management, and bio-pesticides for controlling pests and diseases. Hand-picked was conducted 25 days after the silking date as the silk turned brown, ear fully developed, and husk turned to dark green.

Data collection and analysis

The data were collected from 15 plants randomly selected from the middle part of the row for plant height, stalk diameter, tasseling and silking dates, unhusked ear length, ear diameter, and ear weight, kernel row number, and kernel number row^{-1}. All statistical analyses were carried out using SAS 9.4 (SAS Institute Inc., Cary, NC). A pooled analysis of variance over three environments was performed using Proc GLM to determine the significant effects of the environment, hybrid, and environment x genotype interaction. In this case, the significance of the hybrid was tested against environment x genotype interaction, while the remaining were tested against the pooled error term. A least significant difference test was performed to compare the environmental means. The pattern of variations among the hybrids was studied using principal component analysis (PCA). Proc PRINCOMP on the correlation matrix was employed to perform PCA with equal footing for all traits (Jolliffe, 2002; Peres-Neto *et al*., 2003). To reduce the dimensionality of the variation among the hybrids, only the eigenvector (PC axes) having eigenvalue larger than unity (Iezzoni and Pritts, 1991; Maji and Shaibu, 2012) were selected and used for the hybrids discrimination. The scores derived from the principal axes having a cumulative proportion of variance of more than 75% were then used to perform a cluster analysis. For this, Proc CLUSTER with Ward's minimum variance clustering method was selected to joint of each level of the hierarchy. The dendrogram showing the hierarchy of the hybrids was drawn using Proc TREE.

Results

Analysis of variance

Results of the combined analysis of variance across agro-climatic zones (Table 1) indicated that no significant hybrid x environment interaction effect on all observed traits, indicating that the hybrids rank were consistent across altitudes. The environment had a significant effect on all traits except the kernel-row number. Similarly, the hybrids varied significantly for all traits. The maximum contribution of the environment to the total variation in the total sum of square was detected on tasseling date (82.1%) and silking date (81.1%), while the maximum contribution hybrid was detected on kernel-row number (54.4%) as followed by kernel number row^{-1}.

Table 1. Combined analysis of variance for nine characters observed on 29 sweet corn hybrids grown organically at three agro-climatic zones in the tropics

Source	Environment	Blok (Environment)	Hybrid	Hybrid x Envrironment	Pooled Error
Plant height	20825.35**	822.68**	538.01**	99.79ns	126.31
Stalk diameter	423.48**	22.39**	6.25*	3.51ns	3.05
Tasseling date	2398.59**	7.90*	8.92**	3.79ns	3.20
Silking date	2492.35**	8.52*	10.46**	4.46ns	3.38
Ear length	82.95**	20.49*	21.12**	8.22ns	7.52
Ear diameter	283.06**	14.93*	28.24**	8.54ns	6.43
Ear weight	78649.21**	2295.93ns	8682.08**	2169.48ns	1830.58
Kernel-row number	1.02ns	0.97ns	7.79**	0.97ns	0.72
Kernel number row^{-1}	148.23**	10.90ns	74.63**	10.23ns	8.89

* and ** statistically significant at 5% and 1 %, respectively, ns = non-significant

Average plant performances

The growth performances of the hybrids as represented by their plant height and stalk diameter across environments were presented in Figure 1. On average, the highland had produced significant taller plants (217.0 cm) than the midland (191.6 cm) or lowland (189.0 cm) which showed no significant difference. Similar features were found for stalk diameter, where the significant differences were found among the environments. The largest stalk diameter was observed on highland (26.4 mm) as followed by midland (25.1 mm) and lowland (22.1 mm).

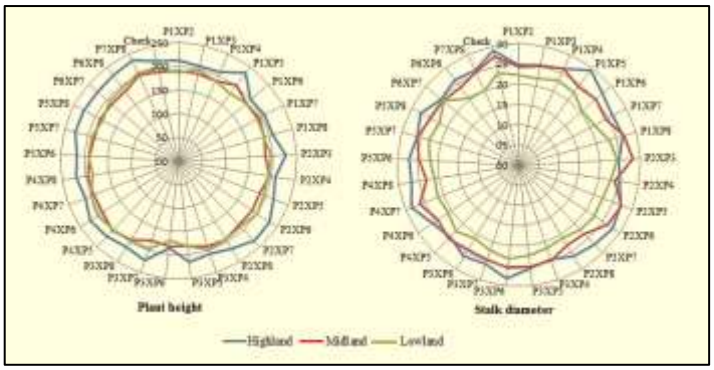

Figure 1. Plant height and stalk diameter of sweet corn hybrids grown organically at three agro-climatic zones in the tropics (P1 = Caps 2, P2 = Caps 3, P3 = Caps 5, P4 = Caps 15, P5 = Caps 17A, P6 = Caps 17B, P7 = Caps 22, P8 = Caps 23, and Check = Lorenza)

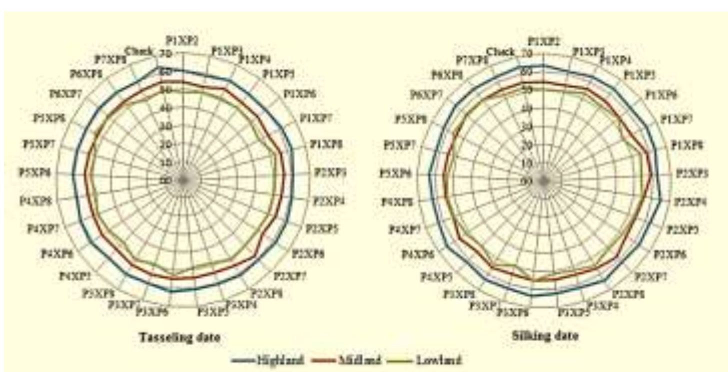

Figure 2. Tasseling and silking dates of 29 sweet corn genotypes grown organically at three agro-climatic zones in the tropics (P1 = Caps 2, P2 = Caps 3, P3 = Caps 5, P4 = Caps 15, P5 = Caps 17A, P6 = Caps 17B, P7 = Caps 22, P8 = Caps 23, and Check = Lorenza)

Figure 2 displays the phonological development of the plants, in terms of tasseling and silking dates, across agro-climatic zones. On average, the earliest appearance of tassel (50.2 dap) and silk (53.7 dap) were detected in the lowland. Both traits were delayed significantly in the midland (54.3 dap and 55.3 dap, respectively) and further delayed significantly in highland (60.6 dap and 63.0 dap, respectively).

Figure 3 depicts the performances of ear length, ear diameter, and ear weight. Midland environment had significantly produced the longest ear and no significant difference was detected between highland and lowland. On average, the ear length in the highland, midland, and lowland were 27.8 cm, 29.0 cm, and 27.1 cm, respectively. For ear diameter, a distinctive was observed among the environments. Midland produced the largest ear diameter (62.6 mm) followed by highland (61.5 mm) and lowland (59.1 mm). For ear weight, highland (407.5 g) and midland (401.8 g) showed no significant difference, but both were significantly higher than lowland (352.8 g).

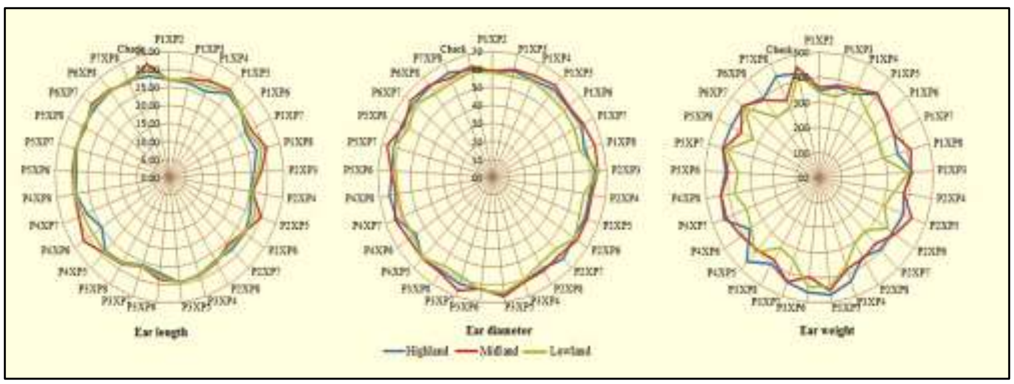

Figure 3. Ear length, diameter, and weight of 29 sweet corn genotypes grown organically at three agro-climatic zones in the tropics (P1 = Caps 2, P2 = Caps 3, P3 = Caps 5, P4 = Caps 15, P5 = Caps 17A, P6 = Caps 17B, P7 = Caps 22, P8 = Caps 23, and Check = Lorenza)

In this study, the ear components were represented by kernel-row number and number of kernel row^{-1} with their performances across environments as displayed in Figure 4. Kernel-row number was only ranged from 15.1 (at lowland) to 15.4 (at highland) and statistically was not significant. On the other hand, kernel number row^{-1} was varied significantly among the environments. The highest number of kernel row^{-1} was exhibited in highland (37.7), followed by midland (36.4) and lowland (35.1).

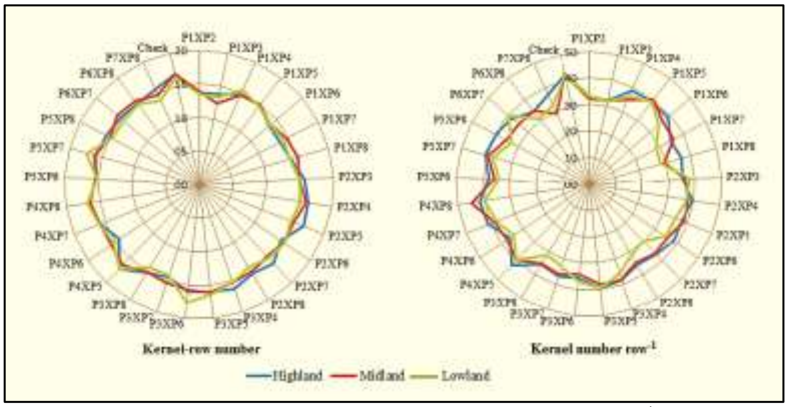

Figure 4. Kernel-row number and kernel number row^{-1} of 29 sweet corn genotypes grown organically at three agro-climatic zoness in the tropics (P1 = Caps 2, P2 = Caps 3, P3 = Caps 5, P4 = Caps 15, P5 = Caps 17A, P6 = Caps 17B, P7 = Caps 22, P8 = Caps 23, and Check = Lorenza)

Pattern of variation among hybrids

The non-significant effect of hybrid x environment interaction for all observed traits indicated that the ranks of hybrids for each trait were consistent in each location. Consequently, the PCA was performed on the pooled data from the three locations. In reference to the criterion of eigenvalue larger than unity, the PCA generated three major PC axes accounted for 74% of the total variation among the hybrids as indicated by the scree plot as presented in Figure 5.

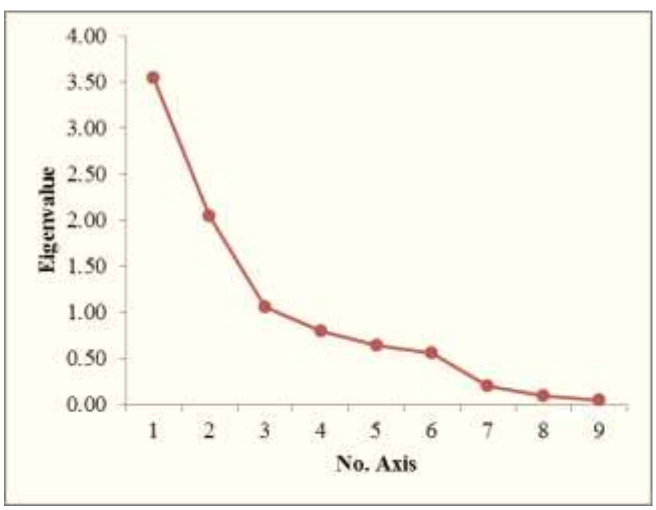

Figure 5. Scree plot showing eigenvalues and number of PC axes derived from nine sweet corn traits

The component loading of a trait measures the correlation of the trait to its corresponding PC axis and a loading larger 0.3 is commonly deemed as meaningful (Table 2). PC-1 accounted for 39.45 % of the total variance reflects ear yield characteristics as it mainly related to ear length, ear diameter, ear weight, kernel-row number, and kernel number row^{-1}. Having the highest eigenvalue and contribution to the total variance, the generated scores from PC-1 would provide a maximum discrimination among the hybrids. Thus, hybrids having higher scores on PC-1 would have higher ear performances. Furthermore, with the decreasing eigenvalues and the contributions to the total variance observed in PC-2 and PC-3, the PC scores generated from these axes would also deliver the decreasing power in discriminating the hybrids, respectively. PC-2 accounted for 22.78% of the total variance was related to heading and silking dates, implying that hybrids having higher scores on PC-2 would have prolonged phonological development. PC-3 accounted for 11.81% of the total variance represents plant height and ear length, suggesting that hybrids with hybrids having high scores on this axis to some extent would have taller stature and longer ear. Figure 6 illustrates the pattern of the hybrid variation as plotted along the three PC axes.

Table 2. The eigenvector, loading, eigenvalue, and proportion of contribution to the total variation accounted for by the first three principal components axes contributed by nine traits

Trait	Eigenvector		
	PC-1	PC-2	PC-3
Plant height	0.12	-0.01	**0.86**
Stalk diameter	**0.30**	0.29	-0.26
Tasseling date	0.11	**0.65**	-0.05
Silking date	0.05	**0.63**	0.05
Ear length	**0.32**	0.13	**0.38**
Ear diameter	**0.40**	-0.12	0.02
Ear weight	**0.50**	-0.14	-0.10
Kernel-row number	**0.44**	-0.04	-0.15
Kernel number row^{-1}	**0.42**	-0.22	-0.10
Eigenvalue	3.55	2.05	1.06
% Variance	39.45	22.78	11.81
Cumulative % variance	39.45	62.23	74.04

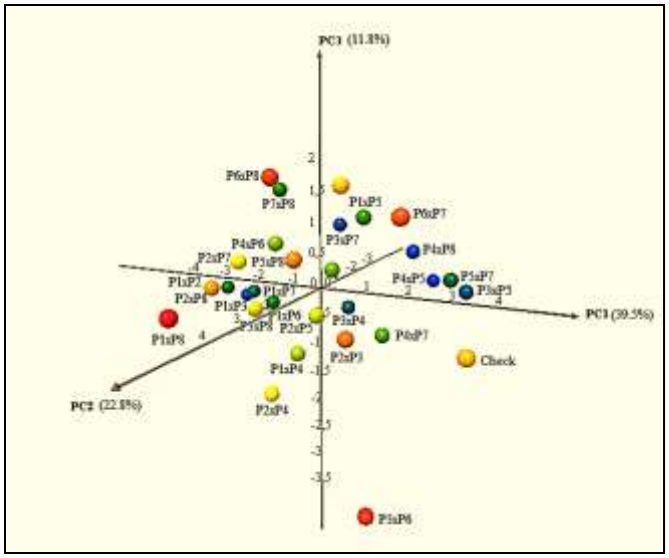

Figure 6. The pattern of variation among the sweet corn hybrids as plotted against three principal axes

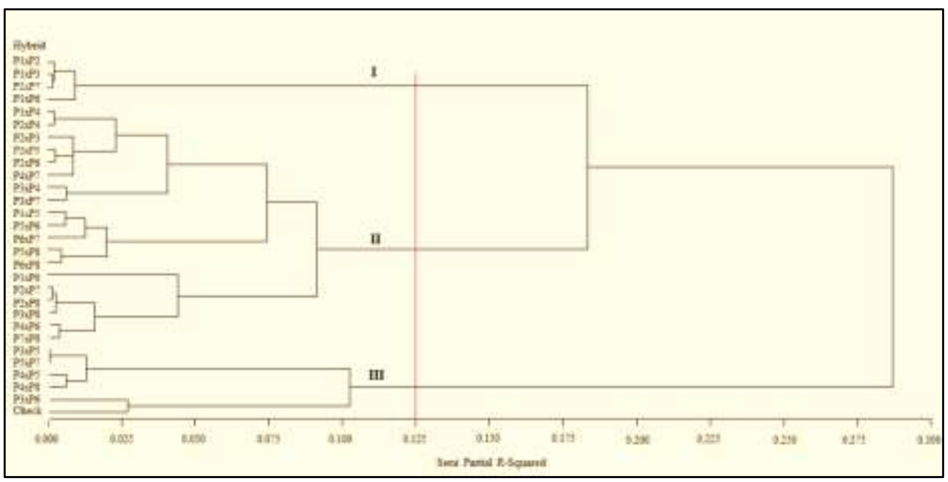

Figure 7. The dendrogram of 29 hybrids resulting from cluster analysis using ward method on scores derived from three principal axes in principal component analysis. (P1 = Caps 2, P2 = Caps 3, P3 = Caps 5, P4 = Caps 15, P5 = Caps 17A, P6 = Caps 17B, P7 = Caps 22, P8 = Caps 23, and Check = Lorenza)

The cluster analysis based on the three PC scores has sorted and grouped the hybrids into a number of clusters of similarity as depicted in the dendrogram (Figure 7). Using 0.125 semi-partial R-squared distance as the dendrogram cut-off criterion, the hybrids could be grouped into three distinct clusters. Cluster I is consisted of four hybrids (Caps 2 x Caps 3, Caps 2 x Caps

5, Caps 2 x Caps 17B, and Caps 3 x Caps 22) having lower ear performances but earlier in maturity and shorter plant stature. The opposite features were exhibited by the hybrids grouped in cluster III which consisted of five hybrids (Caps 5 x Caps 17A; Caps 5 x Caps 17B, Caps 15 x Caps 17A, Caps 15 x Caps 23, and Caps 17A x Caps 22) having good ear performances but slightly later in maturity and taller plant stature. Cluster II was comprised the remaining hybrids having performances in-between those grouped in Cluster I and Cluster III.

Discussion

The overall plant performances across climatic zones strongly suggested that the evaluated hybrids had amenable adaptability to organic environments, although the shift occurred along the elevational gradients. The non-significant effect of hybrid x environment interaction for all observed traits indicated that the ranks of hybrids for each trait were consistent in each location. The plant growth tended to be more vigorous, but delayed in phonological development, along with the increasing elevations. In term of overall ear characteristics, the lowest performances were observed in lowland, while highland and midland produced were comparable. Similar findings on field corn were reported by Cooper (1979).

The principal component analysis (PCA) is a dimensionality reduction technique widely used in the genetic diversity studies (Khodadadi *et al*., 2011; Maji and Shaibu, 2012; Stoilova and Pereira, 2013). In this study, the PCA has captured the pattern of traits variation among the hybrids and discriminated the hybrids on basis of three principal axes; each represents ear yield characteristics, phonological development, and plant stature, respectively. Moreover, the cluster analysis performed on the principal scores derived from the three principal axes has distributed the hybrids into three clusters with high similarity within a cluster and high dissimilarity between clusters. Among the clusters, Cluster III contained five hybrids Caps 5 x Caps 17A; Caps 5 x Caps 17B, Caps 15 x Caps 17A, Caps 15 x Caps 23, and Caps 17A x Caps 22) had exhibited their potential for organic production.

As the conclusion, the current study has revealed that agro-climatic zones in the tropics as represented by elevational alteration play important roles in determining the sweet corn growth, phonological development, and ear performances. The plants tended to grow taller in highland but become shorter in midland and lowland. Tasseling and silking dates are delayed with the increasing elevation. Ear performances are comparably high when the plants are grown in highland and midland. The hybrids made from crosses of Caps 5 x Caps 17A; Caps 5 x Caps 17B, Caps 15 x Caps 17A, Caps 15 x Caps 23, and

Caps 17A x Caps 22 offer their potential for organic production across agro-climatic zones in the tropics.

References

Abadassi, J. (2015). Maize agronomic traits needed in tropical zone. International Journal of Environmental Science and Technology. 4:371-392.

Ben-Asher, J., Garcia, A. G., and Hoogenboom, G. (2008). Effect of high temperature on photosynthesis and transpiration of sweet corn (*Zea mays* L. var. *rugosa*). Photosynthetica. 46:595-603.

Brewbaker, J. L. (2003). Corn production in the tropics: The Hawaii experience. University of Hawaii.

Cicchino, M., Edreira, J. I. and Otegui, M. E. (2010). Heat stress during late vegetative growth of maize: effects on phenology and assessment of optimum temperature. Crop Science 50:1431-1437.

Cooper, P. J. M. (1979). The association between altitude, environmental variables, maize growth and yields in Kenya. Journal of Agricultural Science. 93:635-649.

Franco, A. A. N., Scapim, C. A., Okumura, R. S., Marques, O. J. and Numoto, A. Y. (2016). Effect of sowing time on the growth and yield of sweet corn ('*Zea mays*' L.) cultivated during fall-winter period in Subtropical climate. Australian Journal of Crop Science. 10:831-841.

George, D. L., Gupta, M. L., Tay, D. and Parwata, I. G. M. A. (2003). Influence of planting date, method of handling and seed size on supersweet sweet corn seed quality. Seed Science and Technology. 31:351-366.

Iezzoni, A. F. and Pritts, M. P. (1991). Applications of principal component analysis to horticultural research. HortScience. 26:334-338.

Jolliffe, I. T. (2002). Principal component analysis. 2nd ed. New York: Springer-Verlag.

Khan, Z. H., Khalil, S. K., Nigar, S., Khalil, I., Haq, I., Ahmad, I., Ali A. and Khan, M. Y. (2009). Phenology and yield of sweet corn landraces influenced by planting dates. Sarhad Journal of Agriculture. 25:153-157.

Khodadadi, M., Fotokian, M. H. and Miransari, M. (2011). Genetic diversity of wheat (*Triticum aestivum* L.) genotypes based on cluster and principal component analyses for breeding strategies. Australian Journal of Crop Science. 5:17-24.

Lazcano, C., Revilla, P., Malvar, R. A. and Dom ńguez, J. (2011). Yield and fruit quality of four sweet corn hybrids (*Zea mays*) under conventional and integrated fertilization with vermicompost. Journal of the Science of Food and Agriculture. 91:1244-1253.

Maji, A. T. and Shaibu, A. A. (2012). Application of principal component analysis for rice germplasm characterization and evaluation. Journal of Plant Breeding and Crop Science. 4:87-93.

Peres-Neto, P. R., Jackson, D. A. and Somers, K. M. (2003). Giving meaningful interpretation to ordination axes: assessing loading significance in principal component analysis. Ecology. 84:2347-2363.

Shrestha, S., Asch, F., Dusserre, J., Ramanantsoanirina, A. and Brueck, H. (2012). Climate effects on yield components as affected by genotypic responses to variable environmental conditions in upland rice systems at different altitudes. Field Crops Research. 134:216-228.

Stoilova, T. and Pereira, G. (2013). Assessment of the genetic diversity in a germplasm collection of cowpea (*Vigna unguiculata* (L.) Walp.) using morphological traits. African Journal of Agricultural Research. 8:208-215.

Tracy, W. F. (1997). History, genetics, and breeding of supersweet (shrunken2) sweet corn. Plant Breeding Reviews. 14:189-236.

Van Wart, J., van Bussel, L. G., Wolf, J., Licker, R., Grassini, P., Nelson, A. and van Ittersum, M. K. (2013). Use of agro-climatic zones to upscale simulated crop yield potential. Field Crops Research. 143:44-55.

Williams, M. M. (2008). Sweet corn growth and yield responses to planting dates of the North Central United States. HortScience. 43:1775-1779.

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