Variability in growth and yield among sweet corn genotypes grown under organic crop management

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Abstract. Organic sweet corn growers depend on the available varieties even though they are bred for intensive farming systems and they have to select the variety most suited for organic production. The present study was addressed to elucidate the pattern of variations among 20 sweet corn genotypes under the organic farming system and to classify them into distinct groups on the basis of their agro-morphological characteristics. Data were collected from two growing seasons for growth and yield characteristic and subjected to univariate and multivariate analyses. Combined analysis of variance across two seasons revealed that tasseling date, harvesting date, kernel-row number, and marketable yield exhibited significant season x genotype interaction effect, while the rest of the observed characters showed significant both season and genotype effects. Principal component analysis showed that first season data had first three principal components with eigenvalues > 1 accounted 82% of the total variation, while second season data had first two principal components with eigenvalues > 1 accounted for 79%. In both seasons, ear length, ear diameter, ear weight, and marketable yield were the most important characters in the first principal component. Based on cluster analysis, the genotypes could be classified into 5 clusters for both seasons. These results can be used by the growers in deciding the most suitable sweet corn variety for organic production.

1. Introduction
Sweet corn is a relatively new horticultural crop known by Indonesian people; presumably, it was not earlier than 1980’s. The growing interest in sweet corn production in recent years is mainly driven by high market demand for both fresh and processed products. This situation, in turn, has led to the development of new varieties. During the period of 2005-2011, there were 28 sweet corn genotypes had been released as new varieties and other 15 genotypes had been registered for plant variety protection [1], and more varieties were made available for the farmers in the following years.

With the increasing recognition of organic agriculture for its contribution to food quality and safety as well as environmental conservation, there is significant interest from vegetable processors, growers, and consumers in organic produce [2]. One major drawback from such phenomenon is that the organic sweet corn growers have to use seeds from varieties mostly bred for intensive farming systems. Sweet corn is a heavy feeder on soil nutrients, primarily nitrogen, phosphorous, and potassium [3]. Under intensive farming system amount of nutrients required by the plant can be readily fulfilled with inorganic fertilizers application, but it becomes a challenge for the organic growers as organic fertilizers are comprised mainly of plant and animal materials with a small amount of the macronutrients [4].

The correct choice of plant varieties for a given farming system is a critical stage in obtaining a good yield. In the organic farming system, a good yield should be more interpreted as organic product
quality and yield stability [5]. Under current situations where most sweet corn varieties were not designed for organic farming, optimization of the yield stability should inevitably be made by evaluating the existing varieties for better adaptation under organic farming environment since some varieties may not produce consistent performances under different farming systems [6]. Principal component and cluster analyses are useful multivariate methods for reducing variable dimensionality and grouping of genotypes [7,8]. Objectives of this study were to elucidate the pattern of variations among 20 sweet corn genotypes under the organic farming system and to classify them into distinct groups on the basis of their agro-morphological characteristics.

2. Materials and Methods
Two consecutive season experiments were conducted at the field laboratory of Closed Agriculture Production System (CAPS) at Air Duku, Rejang Lebong, Bengkulu, Indonesia (about 950 m above sea level). The first growing season was characterized by higher rainfall than the second growing season. A randomized complete block design with three replications was employed in both experiments, involving 20 commercial sweet corn varieties (Table 1). Seeds from each variety was planted in the experimental plot consisting of four hills spaced 70 cm apart with 3 m length. The planting space with row was 20 cm to obtain planting density 60 plants plot-1. Previously, the field has been used for vegetables organic production since 2009. Cow manure at 10 t ha-1 was applied to the experimental plots as basal fertilizer. Additional foliar fertilizer made from local materials was given at 35 days after planting (DAP). Weed control was done manually at 21 and 45 DAP. No pesticide was applied, but Trichoderma solution for controlling leaf blight that appeared during vegetative stages.

| Code | Genotype     | Type           |
|------|--------------|----------------|
| A    | Billy Sweet  | Hybrid variety |
| B    | Radja        | Unknown        |
| C    | Gendis       | Hybrid variety |
| D    | Sweet Boy Golden | Hybrid variety |
| E    | London       | Unknown        |
| F    | Secada       | Hybrid variety |
| G    | Jambore      | Hybrid variety |
| H    | New Kencana  | Unknown        |
| I    | Virginia 2   | Hybrid variety |
| J    | OR Holili    | Hybrid variety |
| K    | Cosmos       | Unknown        |
| L    | Sweet Boy    | Hybrid variety |
| M    | Elma         | Hybrid variety |
| N    | King Sweet   | Hybrid variety |
| O    | Talenta      | Hybrid variety |
| P    | Bonanza      | Hybrid variety |
| Q    | Bimmo        | Unknown        |
| R    | Saigon       | Hybrid variety |
| S    | Sweet Vaganza| Hybrid variety |
| T    | Lambada      | Hybrid variety |

Data were collected from each plot for 13 plant traits (Table 2): plant height, stem diameter, leaf number, tasseling date, silking date, harvesting date, ear number plant-1, ear length, ear diameter, green ear weight, kernel-row number, kernel number row-1, and marketable yield. Except for marketable yield, the traits were recorded from 5 samples taken from central rows in each plot. All statistical
analyses were carried out using SAS Version 9.4 (SAS Institute Inc. Cary, NC). A combined analysis of variance over two seasons as employed by [9] was performed for each trait using procedure GLM with varieties assumed to be fixed and other effects were random. The pattern of variation amongst the sweet corn varieties was examined using Principal components analysis (PCA) based on correlation matrix [10]. Procedure PRINCOMP was employed to run PCA on the data cross seasons and within a season. The principal component (PC) axes with eigenvalue larger than 1 were selected to rationalize the dimensionality of variation amongst the genotypes as adopted by [11]. Cluster analysis based on similarity matrices was also employed Procedure CLUSTER on first few principal component scores whose cumulative proportion of variance more than 75%. Ward’s minimum variance clustering method was selected to joint of each level of the hierarchy. Procedure TREE was used to draw the dendrogram.

### Table 2. Traits observed in 20 sweet corn genotypes

| Traits                      | Unit | Description                                      |
|-----------------------------|------|--------------------------------------------------|
| Plant height                | Cm   | The first node to uppermost leaf tip             |
| Leaf number                 | count| All formed leaves                                 |
| Stem diameter               | Mm   | First node                                       |
| Tasseling date              | Day  | Days to 50% tasseling                            |
| Silking date                | Day  | Days to 50% silking                              |
| Harvesting date             | Day  | Days to                                          |
| Ear number plant\(^1\)      | count| Developed ear                                    |
| Ear length                  | Cm   | Basal to tip                                     |
| Ear diameter                | Cm   | Middle ear                                       |
| Green ear weight            | G    | Weight of fully developed ear                    |
| Kernel-row number           | count| Row bearing kernel                                |
| Kernel number row\(^1\)     | count| Fully developed kernel                            |
| Marketable yield            | Kg   | Ear fresh weight plot\(^1\)                      |

3. Results and Discussion

3.1. Analysis of variance

The combined analysis of variance across two growing seasons indicated that large proportions of traits variation were attributed to seasonal effect (Table 3). These are common phenomena where the environmental portion of the sum of squares in the multi-environmental trial has been usually known to be the largest among all sources of variation, the remaining portions are spread out amongst replication within locations, genotype, genotype x location, and pooled error effects [12]. The significant effect of season on most of the observed traits suggested that the planting date plays an important role in determining the general plant performances. In this study, the amount of rainfall was the climatic component that markedly characterizes between the growing seasons. Sweet corn, akin to field corn, is sensitive to seasonal water supply, especially to water shortage [13], although the degree of sensitivity is dictated by plant growth stages [14]. As it has been expected that the variability in the observed traits was also pronounced by the genotypic effect, indicating the sensibility of grouping the genotypes for a given farming system. Similarly, the presence of season x genotype interaction effect on tasseling date, harvesting date, kernel-row number, and marketable yield indicated the inconsistency of some genotypes in expressing these traits across seasons. As earliness and ear yield always become the main consideration in sweet corn production, further analyses will be performed on the season basis to elucidate the performances of the genotypes, mainly for these traits, on each season.
Table 3. Mean squares from analysis of variance on 13 agro-morphological traits of 20 sweet corn genotypes grown under organic cropping system

| Trait               | Source of variation               | Season | Block (Season) | Genotype | Season x Genotype | Error |
|---------------------|----------------------------------|--------|---------------|----------|-------------------|-------|
| Plant height        |                                  | 5364.58** | 1560.04**    | 1324.61** | 176.01**          | 118.51|
| Leaf number         |                                  | 15.41**  | 2.38**        | 1.44**    | 0.20              | 0.22  |
| Stem diameter       |                                  | 8.14**   | 0.54**        | 0.21**    | 0.05              | 0.03  |
| Tasseling date      |                                  | 11.66*   | 9.00**        | 40.14**   | 3.86*             | 2.03  |
| Silking date        |                                  | 48.01**  | 12.67**       | 30.03**   | 3.67              | 2.33  |
| Harvesting date     |                                  | 9441.23**| 6.85*         | 8.44**    | 4.76**            | 1.99  |
| Ear number plant$^{-1}$ |                              | 0.15    | 0.34**        | 0.20**    | 0.07              | 0.09  |
| Ear length          |                                  | 64.46**  | 31.30**       | 21.98**   | 3.10              | 2.33  |
| Ear diameter        |                                  | 0.52**   | 0.61**        | 0.82**    | 0.09              | 0.09  |
| Green ear weight    |                                  | 9414.64**| 12381.43**   | 17840.58**| 1480.20           | 1201.00|
| Kernel-row number   |                                  | 0.03    | 0.79         | 8.27**    | 0.71*             | 0.36  |
| Kernel number row$^{-1}$ |                            | 83.68** | 38.46**      | 102.71**  | 10.54             | 10.53 |
| Marketable yield    |                                  | 0.92    | 27.39**       | 34.51**   | 7.15**            | 3.24  |

Values with *, ** are significant at P=0.05, 0.01; values without asterisks are not significant.

3.2. Principal Component Analysis

The principal component analysis (PCA) had captured the variations in all observed traits in the experimental population and extract specific traits relevant to the genotypic discrimination. Based on the criterion of eigenvalue larger than unity [15], PCA yielded three PC axes accounted for 82% of the total variance in first season data and two PC axes accounted for 79% of the total variance in second season data (Table 1). The eigenvalues in PCA have primary importance for numerical diagnostics to assess variation attributed to a number of large variables on the dependent structure and their data matrix in a graphical display [16].

The importance of traits to each PC axis can be seen on the loading to their corresponding eigenvectors. It has been commonly adopted that a loading having greater than an absolute value of 0.3 is considered as important [17,18]. For first season data, PC 1 axis accounted for 40.51% of the total variance was characterized by plant height, ear length, ear diameter, kernel number row$^{-1}$, green ear weight, and marketable yield, PC 2 axis explained 30.52% of the total variation was characterized by stem diameter, plant maturity (tasseling, silking and harvesting dates), ear number plant$^{-1}$, and kernel-row number, whereas PC 3 accounted for 11.36% of total variance was characterized by plant height, leaf number, stem diameter, and ear number plant$^{-1}$. For second season data, plant height, leaf number, stem diameter, ear length, ear diameter, green ear weight, marketable yield had characterized PC 1 axis accounted for 52.10% of total variance, while plant maturity and kernel-row number were the main characteristics of PC 2 axis accounted for 26.90% of total variance. PC 3 axis was characterized by plant height, stem diameter, ear number plant$^{-1}$, and kernel-number row$^{-1}$ but its contribution to total variance was trivial.

The plots of genotypes in PC 1 and PC 2 axes illustrated the pattern of variation amongst the genotypes in both seasons (Figure 1). The upper right quadrants of the plots refer to the genotypes with high plant stature, high yield, but late in maturity. The lower right quadrants refer to the genotypes with high plant stature, high yield, and early in maturity. These results have demonstrated that principal component analysis provides the insight structural feature of genotypic variations as to delineating the suitability of a given genotype for organic production system on a particular seasonal condition. Due to such usefulness, principal component analysis has been commonly used for determination of crop adaptation [19, 20].
3.3. Cluster analysis

Cluster analysis on principal scores in each PC axis had sorted and grouped the genotypes into clusters. A principal scores-based clustering could produce a dendrogram that group the crop accessions with the highest level of similarity [21]. Figure 2 depicts the dendrogram resulted from cluster analysis of both seasons. The determination of cluster numbers was carried out in such a way that a cluster contains at least two genotypes. Using the cut-off criterion of 0.10 semi-partial R-squared distance, the genotypes performances under organic cropping system could be grouped into 5 clusters in the first season and 4 clusters in the second season. Table 5 presents the group membership of the genotypes in each cluster. It can be noted that Secada was a distinctive genotype as it could not be grouped with the other genotypes in both seasons. In this case, Secada was high-yielding genotype, but latest in maturity. In the first season, Cluster 1 was a group of three genotypes exhibited low yield and late maturing. Cluster 2 consisted of four genotypes having low to moderate yield but early in maturity. Cluster 3 was contained eight genotypes with moderate yield and maturity. Cluster 4 contained four high-yielding and early maturing genotypes. Furthermore, Cluster 1 and Cluster 2 in the second season had the common characteristics as described for Cluster 1 and Cluster 2 in the first season, respectively, and had the similar group membership excepting Bimmo, Sweet Boy Golden, OR Holili, and Radja. These later genotypes were consistent in their productivities across the season but they tended to delay their maturity in the second season, as indicated by a change in their cluster membership. Cluster 3 in the second season seemed to accommodate the genotypes belonged to Cluster 3 and Cluster 4 in season 1 into a single cluster for moderate to high yielding and early maturing genotypes.

Table 4. Eigenvector, eigenvalue, and cumulative variance accounted for by the first three principal components axes contributed by 13 agro-morphological traits

| Trait                | First Season |          |          | Second Season |          |          |
|----------------------|--------------|----------|----------|---------------|----------|----------|
|                      | PC 1         | PC 2     | PC 3     | PC 1          | PC 2     | PC 3     |
| Plant height         | 0.33         | -0.14    | 0.39     | 0.30          | -0.11    | -0.54    |
| Leaf number          | 0.17         | 0.28     | 0.50     | 0.31          | 0.19     | -0.28    |
| Stem diameter        | 0.21         | 0.30     | -0.38    | 0.33          | 0.13     | 0.30     |
| Tasseling date       | -0.20        | 0.43     | 0.16     | -0.06         | 0.51     | 0.03     |
| Silking date         | -0.16        | 0.41     | 0.27     | -0.07         | 0.51     | -0.01    |
| Harvesting date      | -0.11        | 0.38     | -0.25    | -0.07         | 0.51     | -0.02    |
| Ear number plant     | 0.01         | 0.34     | -0.39    | 0.23          | 0.01     | 0.59     |
| Ear length           | 0.38         | 0.02     | -0.15    | 0.36          | 0.04     | 0.13     |
| Ear diameter         | 0.41         | 0.11     | 0.04     | 0.35          | -0.01    | -0.27    |
| Green ear weight     | 0.39         | 0.18     | -0.02    | 0.38          | 0.02     | -0.05    |
| Kernel-row number    | 0.03         | 0.39     | 0.22     | 0.17          | 0.38     | -0.07    |
| Kernel number row    | 0.37         | 0.01     | -0.22    | 0.29          | -0.09    | 0.30     |
| Marketable yield     | 0.37         | -0.07    | 0.10     | 0.36          | -0.06    | 0.03     |
| Eigenvalue            | 7.77         | 3.97     | 1.48     | 6.77          | 3.50     | 0.98     |
| % Variance            | 40.51        | 30.52    | 11.36    | 52.10         | 26.90    | 7.57     |
| Cumulative % variance | 40.51        | 71.03    | 82.39    | 52.10         | 79.00    | 86.57    |
Figure 1. Pattern of variations of 20 sweet corn genotypes configured on first two principal component axes in two growing seasons under an organic environment

Table 5. Grouping 20 sweet corn genotypes performances under organic cropping system in two growing seasons using cluster analysis based on principal component analysis

| Clusters | Genotypes | Characteristics               |
|----------|-----------|------------------------------|
| **First season** | | |
| 1 | Elma, Bonanza, Billy Sweet | Low yield – late maturing |
| 2 | New Kencana, Virginia 2, OR Holili, Radja | Low to moderate yield – early maturing |
| 3 | Sweet Boy Golden, Lambada, Cosmos, Bimmo, Saigon, London, Talenta, Jambore | Moderate yield – moderate maturing |
| 4 | Sweet Boy, Gendis, King Sweet, Sweet Vaganza | High yield – early maturing |
| 5 | Secada | High yield – late maturing |
| **Second season** | | |
| 1 | Elma, Bimmo, Billy Sweet, Sweet Boy Golden, Bonanza | Low to moderate yield – late maturing |
| 2 | New Kencana, Virginia 2 | Low yield – early maturing |
| 3 | OR Holili, King Sweet, Radja, Sweet Boy, Cosmos, London, Saigon, Sweet Vaganza, Gendis, Jambore, Lambada, Talenta | Moderate to high yield – early maturing |
| 4 | Secada | High yield – late maturing |
4. Conclusion
Considerable variations in growth and yield performances amongst 20 sweet corn genotypes grown under organic cropping system due to seasonal fluctuation, varietal different, or the interaction effects of both factors. It also indicated that growth and yield performances were not necessarily associated with the plant maturity. Growing season should be taken into account when choosing sweet corn variety for organic production, as it has been indicated that some varieties performed inconsistently under different growing seasons.

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