Australian Journal of Crop Science

AJCS

Aust J Crop Sci. 18(10):643-649 (2024) | https://doi.org/10.21475/ajcs.24.18.10.p52

ISSN:1835-2707

Effectiveness of principal component analysis on optimization of N:P:K fertilization on various maize varieties

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Submitted: 21/11/2023

Revised: 07/02/2024

Accepted: 24/04/2024

Abstract: Maize cultivation through the interaction of fertilizer and variety has been widely studied. However, the focus has been mainly on the yield, even though it is greatly influenced by many factors. This indicates that maize cultivation needs to involve several combinations of selection characters in its evaluations, such as those through principal component analysis. Therefore, the purpose of this study was to evaluate the effectiveness of PCA and to detect the interaction pattern between each variety to the fertilizer dose. The study was organized in a split-plot design. The main plot was the N:P:K fertilizer dose consisting of 5 levels (60%, 80%, 100%, 120%, and 140%), while the subplots consisted of seven maize varieties (Sinhas I, Jakarin 1, Nasa 29, HJ 36, Bisi 18, ADV and NK 212). The whole combination was repeated three times, resulting in 105 treatment units. Based on the results of this study, PCA was considered effective in evaluating fertilizer and varieties interaction. The PCA determination values (R^2) were relatively higher on several varieties than only based on the yield. Jakarin, HJ 36, Bisi 18 and ADV varieties had a good response with increasing fertilizer doses. Especially, Bisi 18 and ADV varieties can be recommended for high fertilizer doses. Meanwhile, the NK 212 variety is recommended for the general fertilizer dose in alluvial soil of tropical climate in South Sulawesi (N:P:K (200:150:100) kg ha^{-1}).

Keywords: Intensification, Maize, multivariate analysis, N:P:K fertilizer, Principal Components.

Introduction

Maize is a cereal crop that has promising prospects. Several countries in the world make this crop as one of the main sources of carbohydrates (Zhang et al., 2021; Rozi et al., 2023). In addition, Maize has great potential as a source of feed. The percentage of corn use in Indonesia is dominated as a feed source by 70% (Susilowati et al., 2021; Rozi et al., 2023). Corn kernels contain high starch that is easily digested by animals and other nutrients, such as protein, flavonoids and carotene, which can improve the quality of livestock products (Zhang et al., 2021; Buiatte et al., 2022; Rozi et al., 2023). According to Vargas et al. (2023), starch contained in corn has high potential as apparent metabolizable energy in broiler chickens. This indicates that corn is a major source in chicken feed and some other livestock (Zhang et al., 2021; Buiatte et al., 2022). Therefore, the demand for corns in Indonesia will continue to increase every year, especially as a feed source.

Increasing corn production is possible through intensification. Corn intensification can be acheived through both genetic and environmental improvements. Both improvements are believed to increase the productivity potential of corn (Chozin and Sudjatmiko, 2019; Abduh et al., 2021; Farid et al., 2022). The genetic approach can be accomplished through the assembly of hybrid and synthetic varieties (Fromme et al., 2019; Farid et al., 2022). Both varieties have high productivity potential, although they have different genetic constitution concepts (Fromme et al., 2019). In addition, the potential of hybrid varieties will relatively always be superior on optimal land. In contrast, the potential of synthetic varieties is relatively superior on less optimal land, so the application of both types of varieties must be in accordance to the growing environment (Wolde et al., 2018; Fromme et al., 2019; Nurdin et al., 2023). Improving the growing environment, especially through application of chemical fertilizers, may boost the genetic potential of corn (Baghdadi et al., 2018; Jjagwe et al., 2020; Nascimento et al., 2020; Kong et al., 2022). N:P:K fertilizer is the main chemical fertilizer in inducing growth and productivity of corn, so it is important to explore the potential interaction between varieties on N:P:K fertilization. The optimization has also been widely reported (Abduh et al., 2021; Farid et al., 2023; Fikri et al., 2023). However, the evaluation of optimization is still considered independent and focused on productivity alone. Thus, the role of other evaluation characteristics, such as vegetative and yield components, is not optimized as a whole. Therefore, combining all observation characters could be a solution in the evaluation process of the interaction of chemical fertilization doses and varieties.

Combining several observation characters is possible with several methods, one of which is principal component analysis (PCA) (Jolliffe and Cadima, 2016; Padjung et al., 2021; Yassi et al., 2023; Fikri et al., 2023). This is one of the multivariate analyses that can partition and condense the dimensional diversity of big data into simpler dimensions, without reducing most of the information from the previous data (Balabanova et al., 2015; Jolliffe and Cadima, 2016). This is very effective in gathering all criteria in the evaluation process into the same dimension with a certain level of diversity (Balabanova et al., 2015; Farid et al., 2022). In addition, the mapping of diversity between each dimension is also independent, so that the assessment can be more objective and comprehensive in the evaluation process (Meira et al., 2020; Filho et al., 2021). These advantages are also the basis for various studies using this analysis as their analysis procedure (Padjung et al., 2021; Farid et al., 2022; Ullah et al., 2022). Concerning all those information, the use of PCA analysis in detection of chemical fertilization dose interactions on various varieties is a potential research topic. This study aimed to assess the effectiveness of PCA-based simultaneous evaluation and to explore how different varieties interact with varying fertilizer doses, as determined by the PCA analysis.

Results

Evaluation of criteria based on maize growth characters

The results of variance analysis showed that all treatments had a low coefficient of variation, except for the anthesis silking interval (ASI) character (Supplementary table 1). The diversity of fertilizer packages significantly affected most growth parameters, such as plant height, stem diameter, ASI, cob height at the plant, cob diameter, number of rows per cob, weight of 1000 seed and yield. This was inversely proportional to varietal diversity which showed significant effects on all growth characters, except ASI. Meanwhile, the source of diversity of the interaction between fertilizer packages and varieties also had a significant effect on all growth parameters, except male flowering age, female flowering age, ASI and yield. The characters that were not influenced by the interaction diversity were not included in further analysis in this evaluation.

The correlation results were focused on productivity (Figure 1). Based on these characteristics, cob weight (0.40), cob diameter (0.33), and plant height (0.30) were significantly and positively correlated with productivity (Figure 1). In contrast, cob height (-0.25) was significantly negatively correlated with productivity. Cob weight character was also significantly correlated with several other growth characters, such as cob diameter (0.27), length of seeded cob (0.30), stem diameter (0.37), number of rows per cob (0.21), and plant height (0.22). In contrast, the parameter of cob height at the plant (-0.31) was also significantly negatively correlated with the cob weight character. Meanwhile, other characters that had a significant positive correlation were stem diameter, length of grain (0.25), plant height, number of leaves (0.35), and length of grain, number of rows per spike (0.29). The characters that correlated with productivity were subjected to principal component analysis.

Identification of PC variables based on corn evaluation

The results of PCA analysis show that there are 3 PCs that can describe the diversity of this study (Table 1 and Figure 2). PC1 is the PC with the largest diversity with a cumulative proportion value that reaches 0.42, followed by PC2 and PC3 with a proportion variance of 0.21 and 0.18. Based on PC1, cob weight and the yield are the characteristic of the PC dimension. The characters of plant height and cob diameter also have relatively the same direction of variance as the previous two characters. In contrast, cob height has a different direction. The results of the PC1 analysis became the basis for the multivariate mean test.

Interaction analysis of N:P:K fertilizer doses and varieties to PC variables

The results of the interaction analysis of varieties and fertilizer doses are shown in Figure 3 (PCA-based) and Figure 4 (yield-based). Based on Figure 3, the varieties Jakarin 1, Nasa 29, Bisi 18 have a linear PC1 response pattern to fertilizer doses with determination values of 0.659, 0.428, 0.637, respectively. Meanwhile, the Sinhas 1, HJ 36, ADV and NK 212 varieties had a PC1 quadratic response pattern to fertilizer doses with determination values of 0.770, 0.732, 0.815 and 0.464, respectively. Based on Figure 4, the NASA 29 and HJ 36 varieties have a linear pattern of yield response with determination values of 0.966 and 0.711, respectively. On the other hand, the Sinhas 1, Jakarin 1, Bisi 18, ADV, and NK 212 varieties had quadratic yield response with determination values of 0.571, 0.379, 0.607, 0.304, and 0.067, respectively.

Based on Figure 3 and Figure 4, all PCA-based varieties showed relatively higher determination values than only focusing on the yield. In the PCA-based regression, each variety has a response pattern with dynamic diversity to increasing doses of NPK fertilizer. In contrast, the regression response pattern of varieties based on the yield character showed relatively less dynamic diversity. Varieties V6 and V5 have good morphology and yield potential with increasing doses of NPK fertilizer. Variety V5 has a linear curve and V6 has a polynomial regression curve on increasing doses of fertilizer based on PCA analysis.

Discussion

The results of variance analysis showed that the effect of varieties and the interaction of varieties-fertilization packages are more dominant compared to the effect of fertilization packages. This phenomenon has also occurred in several studies that used varieties as one of the factors (Abduh et al., 2021), especially, in open pollinated varieties with different genetic backgrounds such as this study. In general, maize is a cross-pollinated plant that has a heterozygous genetic constitution (Fromme et al., 2019; Abduh et al., 2021; Fikri et al., 2023). This genetic constitution makes the potential between each variety very diverse, especially for the two types of genetic constitution. Hybrid varieties are more responsive to optimal environments, while open-pollinated varieties more responsive to suboptimal environments (Lana et al., 2017; Alamu et al., 2021). This is what underlies the effect of the interaction between different varieties of responses to differences in their environment, so that the effect of the interaction between varieties-fertilization packages is also significant. However, the effect of fertilization packages in the study did not show a

Table 1. Principal component analysis toward correlated characters to the yield.

character	PC1	PC2	PC3	PC4	PC5
Shelled cob weight (SCW)	0.5542	-0.0468	0.1224	-0.6799	0.4620
Plant Height (PH)	0.3285	0.5709	-0.6319	-0.1449	-0.3820
Cob diameter (CD)	0.4102	-0.7035	-0.0694	-0.0210	-0.5759
Cob height at the plant (CHP)	-0.3388	-0.4198	-0.7464	-0.1327	0.3663
Yield	0.5495	-0.0278	-0.1542	0.7062	0.4181
Standard deviation	1.4506	1.013	0.9605	0.738	0.6343
Proportion of Variance	0.4209	0.2052	0.1845	0.1089	0.0805
Cumulative Proportion	0.4209	0.6261	0.8106	0.9195	1.0000
EigenValues	2.1043	1.0262	0.9225	0.5446	0.4023

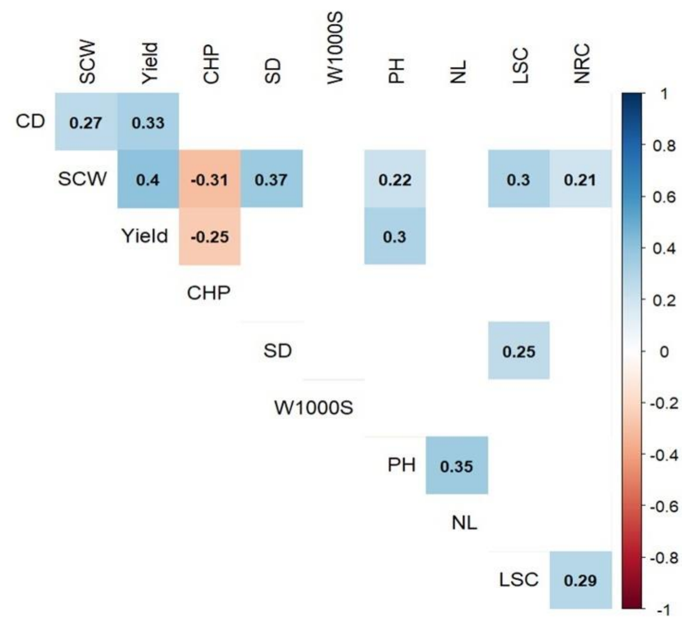

Figure 1. Heatmap correlation analysis of corn growth characters in the evaluation of corn cultivation technology. PH: Plant height; NL: number of leaves; SD: stem diameter; DMF: days to male flowering; DFF: days to female flowering; ASI = anthesis silking interval; CHP = Cob height at the plant; SCW: shelled cob weight; CD: cob diameter; LSC = length of seeded cob; NRC = Number of rows per cob; W1000S: weight of 1000 seeds.

significant effect. Therefore, more in-depth analysis might be necessary, especially on characters that show a real interaction. The use of simultaneous evaluation is identical to the evaluation criteria used. The more characters involved in the simultaneous evaluation may lead to more bias in the evaluation. Moreover, each criterion has a different direction of variation, so the reduction process is important (Oliveira et al., 2016; Nardino et al., 2020). One of them is correlation analysis. Correlation analysis is a general approach that can be used as an initial basis in reducing evaluation criteria (Nardino et al., 2020; Anshori et al., 2022). This analysis can distinguish characters that are significantly related to the main character as the basis for the objectives in a study. Several studies used this analysis in the selection criteria reduction process (Abduh et al., 2021; Padjung et al., 2021; Fikri et al., 2023). Based on this study, the characters of cob weight, cob diameter, plant height and cob height at the plant are characters that are significantly correlated with the yield. Although the cob height at the plant character has a negative value, this character can be included in the in-depth analysis with a note that its nature is reversed to the general response.

Plant height is the only vegetative character that correlates with the yield. This was also reported by Abduh et al. (2021), Padjung et al. (2021), Farid et al. (2022), and Mousavi and Nagy (2021) which showed a significant correlation with productivity. In general, an increase in plant height will support the potential of its generative characters. This will correlate with the number of leaves that act as photosynthetic factories, so that hybrid miazes are relatively taller plants (Mousavi and Nagy, 2021; Padjung et al., 2021). In this study, the cob height at the plant character has the opposite direction to the yield. This is unlike some other research reports that show a positive correlation (Padjung et al., 2021; Ren et al., 2022). This phenomenon may be due to the effect of different fertilizer doses that are above and below the threshold of the general dose. This was also the case in the study of Mousavi and Nagy (2021) which showed the effect of several fertilizer doses on the instability of cob characters. Meanwhile, cob weight and cob diameter are an important part of the yield component. Although there are several other components that affect the yield, the two characters are often reported both as selection criteria and evaluation criteria (Abduh et al., 2021; Padjung et al., 2021; Farid et al., 2022; Mousavi and Nagy, 2021; Ren et al., 2022). This is a very fundamental reason to include both characters as part of the evaluation criteria. Based on all these explanations, the characters of cob weight, cob diameter, plant height and cob height at the plant together with the yield can be used as a basis in the simultaneous evaluation process in this study.

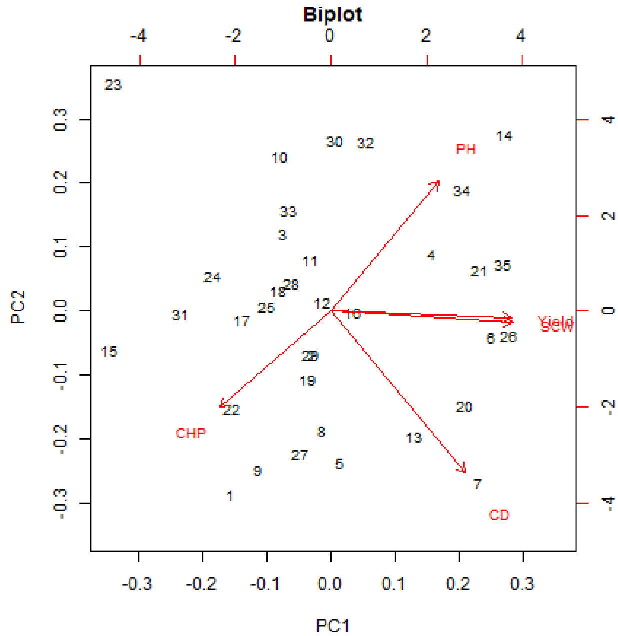

Figure 2. Biplot of principal component analysis to significant correlated characters on the yield. PH: Plant height; CHP = Cob height at the plant; SCW: shelled cob weight; CD: cob diameter.

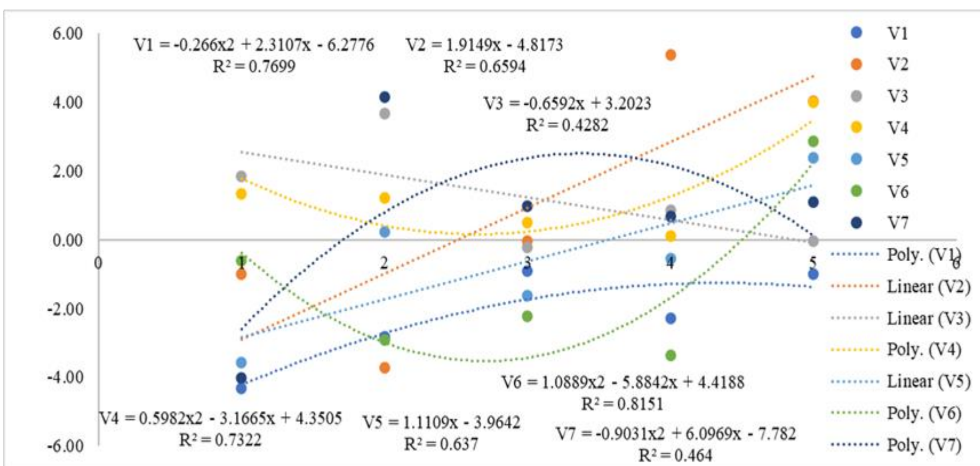

Figure 3. Regression interaction analysis based on PC1 value. (Sinhas I (v1), Jakarin 1 (v2), Nasa 29 (v3), HJ 36 (v4), Bisi 18 (v5), ADV (v6) and NK 212 (v7)).

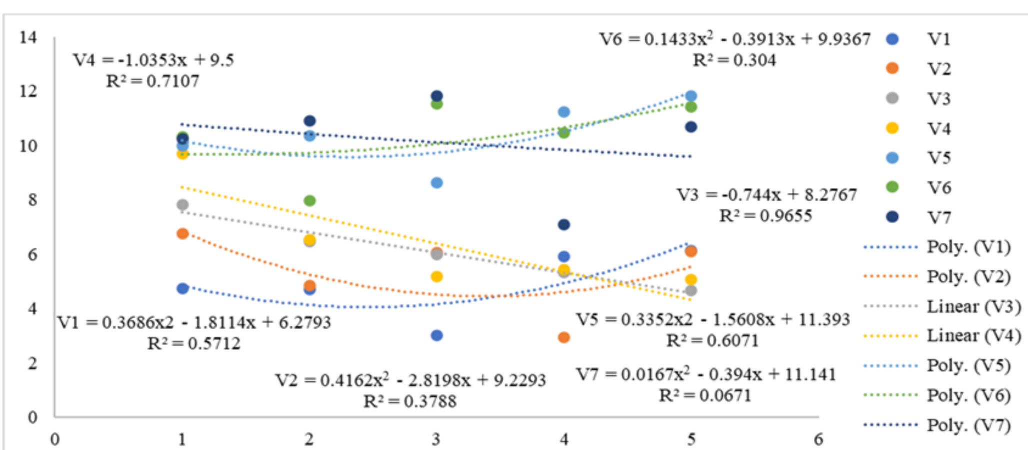

Figure 4. Regression interaction analysis based on the yield. (Sinhas I (v1), Jakarin 1 (v2), Nasa 29 (v3), HJ 36 (v4), Bisi 18 (v5), ADV (v6) and NK 212 (v7)).

Based on the results of PCA analysis, PC1 to PC3 can describe the variance distribution of the five characters. However, PC1 is more considered to represent the main diversity because the yield character has a high eigenvector on the PC compared to PC2 and PC3. This concept has also been reported by Padjung et al. (2021), Farid et al. (2022) and Anshori et al. (2022). In addition, the variance proportion value in the PC is considered quite high, reaching 0.42 or close to 0.5. In general, PC1 is the dimension with the largest variance value. The higher the variance value, the clearer the direction of the diversity of each character towards other characters (Jolliffe and Cadima, 2016; Filho et al., 2021; Tang et al., 2021; Padjung et al., 2021). Based on this, combining these characters is still considered rational to do with the existing considerations. This is also further strengthened by the direction and magnitude of the eigenvector in PC1 which can describe the relationship of the correlation that occurs between these characters. Therefore, combining evaluations based on PC1 is applicable.

The use of PCA as a basis for evaluation also needs to be compared with the single effect of the yield as the main criterion. The results of the interaction analysis based on PC1 show a regression pattern between varieties that is relatively more stable than those solely based on the yield. The determination values for each variety in relation to the technology package are clearly visible when comparing the two figures. Overall, the benefit of PCA analysis in distinguishing the diversity within large datasets is that it prevents overlapping diversity among different dimensions (Jolliffe and Cadima, 2016; Filho et al., 2021). This is very useful in combining the directions of diversity of several characters in a particular dimension. The combined diversity can expose the general potential of a variety simultaneously in accordance with the expected objectives. The use of several characters will support the stability of the evaluation assessment, when the evaluation relies on only one test environment. This has also been reported by Padjung et al. (2021), and Farid et al. (2022) in maize and Anshori et al. (2022) on rice. Therefore, the use of PCA, especially PC1, is feasible to be used as a basis for evaluation in this study.

Based on PC1, increasing the fertilizer dose composition will give a diverse pattern depending on the genotype. The varieties of Jakarin (V2), HJ 36 (V4), Bisi 18 (V5) and ADV (V6) showed a good growth response along with the increase in the fertilizer dose, while HJ 36 and ADV had a quadratic growth regression pattern with FP3 as the lowest point. In contrast, the varieties Sinhas (V1), Nasa 29 (V3) and NK 212 (V7) showed a decreasing growth pattern with linear (Sinhas) and quadratic (Nasa 29 and NK 212) patterns when the fertilizer dose is increased. The optimal point of Nasa 29 and NK 212 varieties was found in F3 (N:P:K (200:150:100) kg ha^{-1}). This indicates that F3 is the turning point of a variety's growth response, both on positive and negative curves. Quadratic regression in some varieties indicated that there was instability in the direction of variation of each character when subjected to several increases in fertilizer dose. However, at a certain point, the overall evaluation criteria began to show the same pattern, so the slope gradient was high on the regression graph. This concept is also explained by Matsui (2020), where the term quadratic reflects the interaction pattern between several predictors at several points until it reaches linear stability. This indicates that the HJ 36 and ADV genotypes are worth considering in the recommendation process. Ultimately, Bisi 18 and ADV varieties are regarded as having superior growth and production potential compared to Jakarin and HJ 36. This can be observed in Figure 3, where V5 and V6 have high productivity potential. In addition, according to Farid et al. (2022), ADV and Bisi 18 were also reported to have high production potential, so both varieties have good stability of production potential at high doses. Meanwhile, NK 212 became the most optimized variety at the FP3 dose. This can also be seen in Figure 3, where NK 212 is the variety with the highest productivity at FP3. The F3 dose is a common dose for corn cultivation in South Sulawesi (Abduh et al., 2021; Farid et al., 2022; Fikri et al., 2023), so NK 212 can be recommended at a common dose for corn cultivation.

Materials and Methods

Location of study and plant materials

The research was conducted at the Experimental Farm of the Bajeng Cereal Crops Research Center, Gowa Regency, South Sulawesi at an altitude of 27.2 meters above sea level, at the coordinates of 5°18'21.5 "N, 119°28'38.6 "E and an average temperature of 28.5 °C. This research took place from September to December 2022. The research used N:P:K fertilizer by Phonska® N:P:K, SP36 and Urea. Meanwhile, the varieties used in this study were Sinhas I (v1), Jakarin 1 (v2), Nasa 29 (v3), HJ 36 (v4), Bisi 18 (v5), ADV (v6) and NK 212 (v7). Sinhas 1 and Jakarin are open-polinated varieties. On the other hand, Nasa 29, HJ 36, Bisi 18, ADV, and NK212 were the hybrid F1 variety.

Experimental design

The study was organized in a split-plot design. The main plot was 5 doses of N:P:K fertilization, namely 60% N:P:K (120:90:60 kg ha^{-1}) (FP1), 80% N:P:K (160:120:80 kg ha^{-1} (FP2), 100% N:P:K (200:150:100 kg ha^{-1}) (FP3), 120% N:P:K (240:180:120 kg ha^{-1}) (fFP), 140% N:P:K (280:210:140 kg ha^{-1}) (FP). The subplots consisted of seven corn varieties. Based on these combinations there were 35 treatment combinations. Each treatment combination was repeated 3 times resulting in 105 treatment units.

Experimental procedures

Land preparation began with optimal tillage using a tractor. Experiment plots were made with a size of 3 x 5.5 m and a distance of 1 m between plots and 2 m between replicates. The seeds were free from pests and diseases (healthy seeds), with a minimum growth rate of 80%, shiny and pure both physically and genetically (guaranteed purity). Before planting, seeds were treated with fungicide (2 grams of Saromyl® for 1 kg of corn seeds). Planting space was 70 x 20 cm. Each hole was planted with 2 corn seeds and applied with Furadan® insecticide. Plant maintenance consisted of replanting, thinning, watering, weeding, fertilizing and controlling plant disruptors.

Replanting was carried out on failed seedlings i.e. died or delayed in growth so that replanting was carried out in the first week after planting (WAP). In addition, at 2 WAP a thinning process was carried out by maintaining one plant per planting hole to optimize the maize growth. Weeding was done by removing grass around the corn plants at 2 WAP and intensely continued periodically in the following weeks. Hilling was done to optimize adventitious growth and to improve soil aeration at 4 WAP. Watering was done with a pump irrigation, inundating the plots up to the level of the plot twice each month. Fertilization was done according to the treatment dose in stages, namely at 15 days after planting and 30 days after planting. The first fertilization applied was Phonska® N:P:K, SP36 and Urea, while the second fertilization only used

Phonska® N:P:K, and Urea. Fertilization was performed by making a punch hole of 10-15 cm next to each plant. Meanwhile, control of plant disruptive organisms was carried out by applying insecticides and fungicides to the plants periodically.
Harvesting was carried out when the plants begin to turn yellow and dry. Harvesting was performed by twisting the cob on each plant until they came off. The cobs then separated as part of the sample for observation of yield components and non-sample according to the treatment plot.

Parameters observation

The observations consisted of two phases, namely vegetative and productive. Vegetative observations include plant height (cm), number of leaves (strands), chlorophyll index, and stem diameter (mm). Meanwhile, productive observations included male flowering age (days after planting-dap), female flowering age (DAP), anthesis silking interval (ASI) (dap), harvesting age (DAP), cob height at the plant (cm), shelled cob weight (kg), cob diameter (mm), seeded cob length (cm), number of seed rows per cob (row), seed yield (%), 1000 seed weight (g) at 15% moisture content, and productivity (tons ha-1).

Statistical analysis and PCA

All observational data were analyzed by variance analysis with 95% confidence level using STAR 2.0.1 software. Characters that showed significance in the source of diversity interaction were progressed to deeper analysis, namely correlation analysis and principal component (PC) analysis. Correlation analysis plays a role in reducing growth parameters that are specific to productivity characters. The characters that correlate with productivity are progressed with PCA analysis. PCs that represent the diversity of productivity were selected and used as the basis for interaction analysis (Jolliffe and Cadima, 2016; Padjung et al., 2021; Fikri et al., 2023). Both analyses also used STAR 2.0.1 software. Data on the selected characters was standardized first before being converted into new data based on the selected PCs. Then, interaction analysis was conducted on the PC parameters with the concept of regression analysis. In addition, regression analysis of productivity was also conducted for comparison. The regression analysis employed Excel Stat software.

Conclusion

PCA application is considered effective in evaluating fertilizer doses for various varieties compared to when it is based on the yield character. The characters of cob weight, cob diameter, plant height, cob height at the plant, and the yield are effective evaluation criteria in this study with a note that the cob height at the plant has an opposite orientation to other characters. Based on PCA-based evaluation, Jakarin, HJ 36, Bisi 18 and ADV varieties have a good response with increasing fertilizer doses. Especially Bisi 18 and ADV varieties can be recommended for high fertilizer doses. Meanwhile, the NK 212 variety is recommended for the general fertilizer dose in alluvial soil of tropical climate like South Sulawesi (N:P:K (200:150:100) kg ha^{-1}).

Acknowledgments

We are grateful to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia through the scheme of UNHAS Fundamental Research Collaborative with grant number: 00323/UN.22/PT.01.03/2023.

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