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Selection for representative environment to identify high yielding and sweetness levels of sweet potato (*Ipomoea batatas*) in Indonesia

ESO SOLIHIN[1,2,♥], DWI ANDREAS SANTOSA[2], BUDI NUGROHO[2], PURWONO[3], RIJA SUDIRJA[1], HARIS MAULANA[5], NADIA NURANIYA KAMALUDDIN[1], AGUNG KARUNIAWAN[4], SYAIFUL ANWAR[2,♥♥]

[1]Department of Soil Science and Land Resource, Faculty of Agriculture, Universitas Padjadjaran. Jl. Raya Jatinangor, Sumedang 45363, West Java, Indonesia. Tel./fax.: +62-22-7796316, ♥email: eso.solihin@unpad.ac.id
[2]Department of Soil Science and Land Resource, Faculty of Agriculture, Institut Pertanian Bogor. Jl. Meranti, Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia. Tel.: +62-251-8629354, Fax.: +62-251-8629352, ♥♥email: phuy@apps.ipb.ac.id
[3]Department of Agronomy and Horticulture, Faculty of Agriculture, Institut Pertanian Bogor. Jl. Meranti, Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia
[4]Department of Agronomy, Faculty of Agriculture, Universitas Padjadjaran. Jl. Raya Jatinangor, Sumedang 45363, West Java, Indonesia
[5]Research Center for Horticulture, Research Organization for Agriculture and Food, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor KM 46, Cibinong 16911, West Java, Indonesia

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Abstract. *Solihin E, Santosa DA, Nugroho B, Purwono, Sudirja R, Maulana H, Kamaluddin NN, Karuniawan A, Anwar S. 2024. Selection for representative environment to identify high yield and sweetness levels of sweet potato (*Ipomoea batatas*) in Indonesia. Biodiversitas 25: 386-391.* Sweet potato is one of the important and commercial agricultural commodities in the world. Yield and sweetness levels are important traits that can influence consumer preferences. Environment is an important factor in the development of sweet potatoes. A suitable environment will provide high yields and good quality. The objectives of this study were to examine the significance and relevance of sweet potato yield and sweetness levels in two locations (Sumedang and Bandung District) and to select representative environments for sweet potato yield and sweetness levels. The research was conducted in Sumedang and Bandung districts on lowland paddy field and dry land. The field experiment used a factorial randomized completed block design with three repetitions. The significance and relevance of sweet potato yield and sweetness levels was analysis using T-test. Representative environments were identified by GGE biplot. The results showed that the Bandung and Sumedang environments showed significant differences in yield but not in sweetness. The Bandung paddy field is the most representative environment for yield, while the Sumedang dry field and Bandung dry field are the most representative environments for sweetness. The results of this research can be used by researchers, farmers and industrial users in the sweet potato development program, especially the yield and yield quality.

Keywords: Dryland, paddy field, sweetness, sweet potato, yield

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is a commercial commodity that is often utilized for the food, feed, and food industry. Sweet potatoes contain high carbohydrates that are beneficial for human health (Van Chuyen and Eun 2013). Besides carbohydrates, sweet potato also contains fiber, beta-carotene, minerals, protein, and vitamins (Wang et al. 2016; Alam 2021). Sweet potato leaves contain more lutein than broccoli, spinach, kale, and lettuce (Ishiguro et al. 2010; Alam 2021). Sweet potato leaves also contain high levels of protein and amino acids, hence is suitable as a substitute for daily vegetables (Suárez et al. 2020; Tang et al. 2021). High nutritional status has made sweet potato as one of the most important commodities in this world.

Indonesia is one of the sweet potato-producing countries in the world. There are many local sweet potato genetic variations in Indonesia with diverse yield and quality potential (Maulana et al. 2022). One of the sweet potato centers in Indonesia is West Java (Maulana et al. 2023) with a very famous sweet potato variety, Cilembu sweet potato. Cilembu variety has its own characteristics, especially its sweet taste, and it produced honey-like caramelization when roasted. This variety has been widely used as a food export commodity as well as an industrial raw material. However, in the development process, there are several problems, including declining productivity and quality of yields. One of the solutions to overcome the problems is to develop new areas that have similarities to Cilembu agroecosystem through environmental selection.

Environment is one of the most important factors in the development of superior varieties. Bandung and Sumedang districts were used as research locations because they are the central locations for sweet potato production in West Java, Indonesia. Especially for Cilembu sweet potatoes. Environment has an impact on changes in crop yields and also the quality of the results (Solihin et al. 2018; Maulana et al. 2023). In addition to sweet potatoes, it also affects other crops' yield (Ruswandi et al. 2023) such as rice (Utami et al. 2023) and soybeans (Wijaya et al. 2022). Environmental selection needs to be done to obtain information on locations that have the potential as a development area for a variety of some environmental factors are considered very specific in influencing crop yields, such as temperature, rainfall, altitude, and soil properties (Markos et al. 2022; Maulana et al. 2022; Solihin et al. 2023). These factors can also affect the availability of nutrients and moisture needed by plants, thus impacting the growth and quality of these plants. The results of research by Tangapo et al. (2018) stated that the diversity of bacteria associated with Cilembu sweet potatoes grown in the Cilembu area was higher than that outside Cilembu. This indicates that the environment in Cilembu has conditions that support the diversity of microorganisms that live in symbiosis with sweet potato plants. Environmental factors such as temperature, humidity, and soil properties in the Cilembu area may provide optimal conditions for the growth and development of these supporting bacteria. Therefore, further identification is needed to be conducted to identify the environmental properties that yielded the specific Cilembu sweet potato characteristics.

Genetic factors also influence differences in response to environmental changes, resulting in variations in yield quality and quantity. This has been reported by several researchers, where genetics significantly contribute to variations in sweet potato yields in different growing environments (Andrade et al. 2016; Maulana et al. 2022). In other studies, sweetness levels in sweet potatoes also showed significant differences in different locations (Anda et al. 2018; Solihin et al. 2018). This shows that the environment in which plants grow can affect the quality and chemical composition of the plants. Therefore, to determine a representative location, environmental selection is carried out. Some researchers use the biplot approach to determine the favorable environment (Maulana et al. 2022; Ruswandi et al. 2023; Utami et al. 2023). The use of biplots in representative environment selection is considered more informative because it provides a visualization of the environment. Environmental selection is important to ensure that the selected location is in accordance with the surrounding environmental conditions. In environmental selection, several factors must be considered, such as land availability, climatic conditions, soil conditions, and plant adaptability. This study aimed to obtain representative environmental information for sweet potato cultivation.

MATERIALS AND METHODS

Plant materials and research design

The field experiment used a Factorial Randomized Block Design which was repeated three times. The first factor is the sweet potato variety and the second factor is the experimental field. The three varieties used in this experiment were Biang, Mencrang, and Rancing. Rancing is one type of cilembu sweet potato that has a sweet and honey-like flavor when roasted. The land used was four environments, namely paddy field - Sumedang, dry field - Sumedang, paddy field - Bandung, and dry field - Bandung. The treatment combinations formed for each replication were 12, so the total combination of plots in the field experiment was 36 plots. The plant material used was stem cuttings (25 cm in length).

Cuttings were planted in experimental plots measuring 5 m x 5 m consisting of five mounds measuring 5 m x 0.7 m with a height of 0.4 m and a distance between mounds of 0.3 m. The planting distance used is 25 cm x 100 cm, so that in one mound there are 20 cuttings. The fertilizer used is organic and inorganic fertilizer. The organic fertilizer used is chicken manure which is applied during land processing at a dose of 10 tons/ha. Inorganic fertilizer using NPK Phonska (16-16-16) at a dose of 200 Kg/ha was given 2 times, namely at 7 Days After Planting (DAP) and 45 DAP.

This research was conducted from September 2022 to February 2023. The research were conducted in two locations (District): Cilembu Village, Pamulihan Subdistrict, Sumedang District, and the second location was Arjasari Village, Arjasari Subdistrict, Bandung District, with the land used in each of the location was paddy fields and dry fields. Sumedang - paddy field is at coordinates 6054'13.1”S (latitude), 107050'41.7"E (longitude); Sumedang - dry field is at coordinates 6054'17.2”S, 107050'39.7”E; Bandung - Paddy field is at coordinates 703.4440”S, 107038.7470”E; Bandung - dry field is at coordinates 703.6310”S, 107038.7480”E. Paddy fields and dry field in Sumedang Regency have an altitude of 845 meters above sea level (m asl.) and 863 m asl., inceptisol soil type with an average rainfall of 282.78 mm per month, and air temperature ranging from 23 to 32°C. The paddy fields and dry fields of Bandung Regency have an altitude of 920 m asl. and 965 m asl., inceptisol soil type, an average rainfall of 218.87 mm per month, and an air temperature ranging from 19 to 29°C. The two locations were selected because they are the centers of sweet potato production in West Java. The field experiment used was factorial group randomized design with three repetition.

Data collection

Parameters observed included yield per unit planting area converted into hectares and sweetness level of sweet potato expressed in Brix units. Yield measurements were carried out by collecting sweet potato samples from each variety planted on each field, which were then weighed and converted into hectares. Sweetness level measurement was conducted through the selection of sweet potato samples from each variety—as many as three pieces from each field. Measurements were taken at harvest time (16 Week After Planting (WAP)). The sweetness level of sweet potato was measured based on total sugar content using a refractometer (Magwaza and Opara 2015). The tool measures sugar content in units of Brix percentage per 100 g. Brix measurement is a method to determine the sweetness level of the sweet potato sample. The higher the Brix percentage obtained, the sweeter the sweet potato. The brix refractometer used in this research is an ATAGO Pal 1 brand digital refractometer. Measurements were made by portioning fresh sweet potatoes into 3 parts vertically; each side was thinly sliced and then mashed with a mortar and pestle, after which the water was squeezed and dripped on the glass hole of the tool. Each measurement of sweet potato sugar content was calibrated with distilled water.

Data analysis

Yield and sweetness levels were analyzed based on location, Sumedang and Bandung Districts and based on land type, which were Sumedang paddy field, Sumedang dryland, Bandung paddy field, and Bandung dry land. The analysis used the t-test with a significance level of α = 0.05. The equation is as follows (Al-kassab 2022):

$$t = \frac{(x - \mu 0)}{\left(\frac{s}{\sqrt{n}}\right)}$$

Where:
T : Calculated t value
X : Sample mean
µ0 : Parameter value
s : Sample standard deviation
n : Number of samples

Representative environment selection performed using GGE biplot. The model for GGE biplot following (Yan and Tinker 2006) with the formula:

$$Y_{ij} - \overline{Y_j} = \lambda_1 \zeta_{i1} \eta_{j1} + \lambda_2 \zeta_{i2} \eta_{j2} + \varepsilon_{ij}$$

Where:
Yij : Average yield and sweetness level of sweet potato *i* in environment *j*
$\overline{Y_j}$: Average yield and sweetness level over all sweet potato in environment *j*
λ_1 and λ_2 : Singular values for PC1 and PC2, respectively
ζ_{i1} and ζ_{i2} : PC1 and PC2 scores, respectively, for sweet potato i
η_{j1} and η_{j2}: PC1 and PC2 scores, respectively, for environment *j*
ε_{ij} : Residual of the model associated with the sweet potato *i* in environment *j*

In biplot pattern, representative environments were those that have a long vector and have a small angle with the ideal line. Data analysis was performed with R software program.

RESULTS AND DISCUSSION

Comparison of yield and sweetness of sweet potato in various locations

The t-test showed that there was a significant difference between the average yield of sweet potatoes in Sumedang and Bandung. However, there was no significant difference between the locations when it came to the sweetness level (Table 1). From the test results, it is known that the production yield in the Sumedang location was higher than the Bandung location. This result shown by the average production in the Sumedang location of 17.63 ton, while in the Bandung location was 12.45 ton.

The variation in production yields in the research locations can be related to variations in environmental factors in each cultivation location. Table 2 shows the comparison of sweet potato production yields in paddy fields and dry field, both in Sumedang and Bandung locations. The average value of production yields from highest to lowest is the location of Sumedang location of paddy fields, Sumedang dry field, Bandung location of paddy fields, and Bandung location of dry field. The results of the comparative analysis of the average yield showed significant differences in the location of Sumedang paddy fields with Bandung paddy fields and the location of Bandung dry fields.

Table 3 shows a comparison of the sweetness levels of sweet potatoes in paddy fields and dry fields in Sumedang and Bandung locations. The average value of sweetness content from the highest to the lowest in each location was Sumedang location of dry field, Bandung location of dry field, Bandung location of paddy field, and Sumedang paddy field. The analysis of the average sweetness levels comparisons in the T-test showed no significant differences between the land used.

Representative environment selection on yield and sweetness of sweet potatoes

The results of the combined Analysis of Variance (ANOVA) on the two traits tested are presented in Table 4. The yield trait, environment, replication, variety, and variety-by-environment interactions (GEIs) showed significant differences. Replication provided the most contribution (38.00%), followed by environment (22.55%), varieties (22.37%), and GEIs (17.09%). In the sweetness level trait, variety and GEIs showed significant differences, while the environment and replications did not show significant differences. Variety provided the most contribution, namely 50.10%, while the environment provided the smallest contribution (4.35%). The presence of GEIs in the two traits tested requires further testing to determine the most superior/representative genotype and environment.

In this study, the representative environment was estimated using the GGE biplot 'representative versus discriminative' pattern. Based on this measure, test sites can be classified into three types: Type I environments have short vectors and provide little information about the genotypes or varieties being tested, so they should not be used as test environments. Type II environments have long vectors and small angles with the average abscissa environment, making them ideal for selecting superior genotypes. Type III environments have long vectors and large angles with the abscissa mean environment, so they cannot be used to select ideal genotypes but are useful for selecting unstable genotypes (adaptive to specific environments) (Yan et al. 2007). Figure 1 presents a biplot graph for sweet potato yield in four growing environments. PC1 and PC2 accounted for 70.2% and 29.8% of the total yield variation, respectively. This result shows that the planting environment contributes highly to the different of sweet potato yield. Figure 1 also shows that the Sumedang paddy field has a short vector and belongs to a Type 1 environment. This means that this environment was unsuitable for test. The Bandung paddy field environment was an ideal location (Type II) for selecting high-yielding genotypes due to its high discriminating power, representativeness, and small angle with the abscissa. This environment is the most representative environment for sweet potato yield testing. The Bandung dry field and Sumedang dry field environments were Type III environments and should not be used to select superior genotypes but can be used to select adapted or region-specific genotypes. This means that these environments will produce good yields for certain genotypes.

Figure 2 presents the GGE biplot graph for the sweetness of sweet potatoes in four growing environments. PC1 and PC2 accounted for 91.8% and 8.2% of the total variation in sweetness, respectively. These results indicate that the growing environment contributes highly to the variation in sweetness of sweet potatoes. In Figure 2, the Sumedang dry field and Bandung dry field environments show proximity to the abscissa line and have a long vector, so both are included in the type II environment. This environment was very representative for genotypes selection that have ideal sweetness levels. The Bandung paddy field environment has a short vector and was included in the Type 1 environment. This means that this environment was less suitable for test sweetness level selection. The Sumedang paddy field environment has a long vector and has an obtuse angle to the abscissa line, so it was included in the Type III environment, which should not be used to select superior genotypes with ideal sweetness levels but can be used to select adapted or region-specific genotypes. This means that this environment will produce high sweetness for certain genotypes.

Discussion

The existence of significant differences between cultivation environments on yield indicates the variation in production yields of each variety in each environment (Table 1). This difference in yield potential can be related to variations in environmental factors at each cultivation location. According to some researchers, environmental differences have a significant effect on variations in sweet potato yields (Karuniawan et al. 2021; Maulana et al. 2022). The difference in yield was inseparable from the difference in soil composition of each environment (Solihin et al. 2023). This condition shows that the appropriate environment will have an impact on high yields. Thus, the determination of a representative environment is needed to obtain optimal yields.

Table 1. Comparison of yield and sweetness content of sweet potato in various locations

	Location	Average	Standard deviation	df	Sig.
Yield	Sumedang	17.6296	5.8435	34	0.0101*
	Bandung	12.4517	5.5516		
Sweetness	Sumedang	11.8185	1.8666	34	0.7173
	Bandung	11.6000	1.7212		

df: Degree freedom, Sig.: Significant, *Significant at the α = 0.05

Table 2. Comparison of average yields in paddy fields and drylands for each location

Land	Average yields (ton/ha)	T-test on comparison of means			
		Sumedang paddy fields	Sumedang dry land	Bandung paddy fields	Bandung dry land
Sumedang paddy field	19.00	-			
Sumedang dry field	16.26	0.33472	-		
Bandung paddy field	13.58	0.04653*	0.35983	-	
Bandung dry field	11.33	0.00815*	0.10487	0.40587	-

Note: *Significant at the α = 0.05

Table 3. Comparison of sweetness in paddy fields and drylands for each location

Land	Average sweetness (%Brix)	T-test on comparison of means			
		Sumedang paddy field	Sumedang dry field	Bandung paddy field	Bandung dry field
Sumedang paddy field	11.31	-			
Sumedang dry field	12.33	0.2573	-		
Bandung paddy field	11.56	0.7372	0.3892	-	
Bandung dry field	11.64	0.6906	0.4872	0.9167	-

Note: *Significant at the α = 0.05

Table 4. Variety-by-environment interaction (GEIs) on the yield and sweetness level in four environments

Source	df	Yield			Sweetness		
		SS		SS explained (%)	SS		SS explained (%)
Environment	3	255.47	*	22.55	3.58		4.35
Replication (Environment)	8	430.61	**	38.00	21.17		25.74
Variety	2	253.44	**	22.37	41.20	**	50.10
Variety-by-environment interactions (GEIs)	6	193.62	*	17.09	16.28	*	19.80
Error	16	212.24			27.86		
CV (%)		24.21			11.27		

Note: *Significant at the α = 0.05, **Significant at the α = 0.01, df: Degree freedom, SS: Sum of Square, CV: Coefficient of Variation

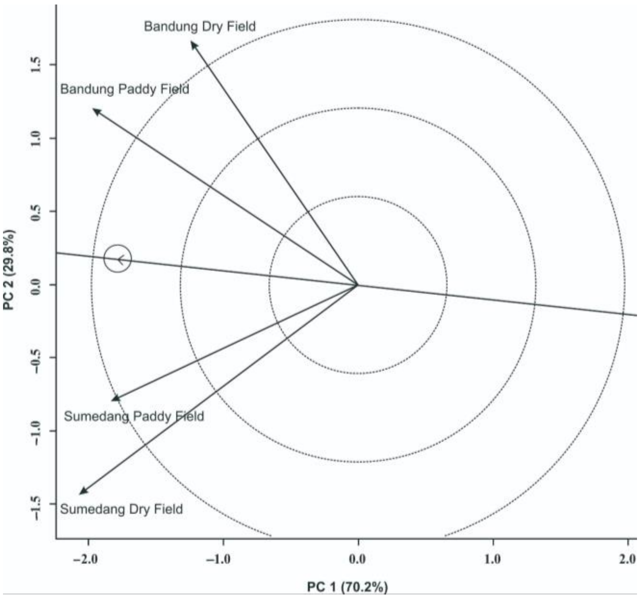

Figure 1. Representative environments for yield based on the GGE biplot

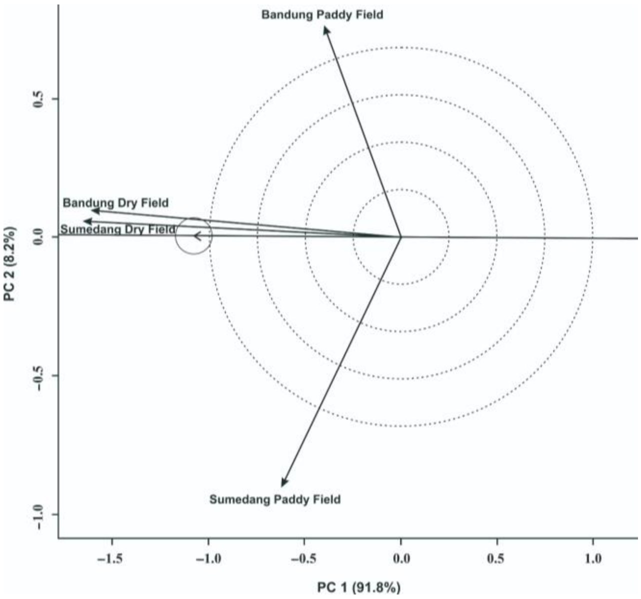

Figure 2. Representative environments for sweetness based on GGE biplot

Unlike the yield, the sweetness level showed no significant difference (Table 1). This indicates that the sweetness level was not affected by the research location. This means that the differences in the testing environment in this research had an insignificant effect on the sweetness level changes of sweet potatoes. This is different from the report of Solihin et al. (2018) where the planting location showed differences in the sweetness potential of sweet potatoes. The difference is likely due to the response of each variety, where each variety has a different sweetness potential. The interaction pattern between each variety and the planting environment is also likely to have an impact on the difference (Table 4). The emergence of GEIs in multi-environment trials, necessitates further testing to identify the best varieties and representative environments (Maulana et al. 2023). Each environment has different soil and weather conditions. To visually see the differences in planting environment on yield and sweetness levels, GGE biplot analysis was used with a "representative vs. discriminative" pattern.

The "representative vs. discriminative" pattern on the GGE biplot shows that the effect of growing environments on yield is almost the same, which means that the four don't have much of an effect (Figure 1). However, when compared in detail, the four have quite different vector lengths. The Sumedang paddy field has the shortest vector compared to the others, indicating that this environment provides less information about the variation in yield produced by each genotype tested. Similar result was also shown by several researchers, where the environment with the shortest vector is unsuitable as a test environment, especially for superior plant selection (Maulana et al. 2023). A representative environment is indicated by the length of the environmental vector and the resulting angle to the abscissa (Utami et al. 2023). In this study, the Bandung paddy field environment is the ideal location (Type II). This environment was the most representative environment for sweet potato yield test. This environment was suitable for selecting high-yielding genotypes because of its high discriminating power and representativeness and its small angle with the abscissa (Pobkhunthod et al. 2022; Ruswandi et al. 2023; Tabu et al. 2023). The Bandung dry field and Sumedang dry field environments are Type III environments because they have long vectors but large angles to the abscissa. These two environments should not be used to select superior genotypes but can be used to select adapted or region-specific genotypes (Mustamu et al. 2018; Amien et al. 2022). This means that these environments will produce good yields for certain genotypes. The results shown by this pattern indicate that environmental selection should be carried out in different environments and seasons with additional variation in the genotypes tested to see changes in the pattern of each environment. Thus, to obtain the ideal environment for sweet potato, additional environments and growing seasons are needed with specific information on soil conditions and climate.

At the sweetness level, all environments showed almost the same vector but have different closeness to the ideal point. The Sumedang dry field and Bandung dry field environment show closeness to the abscissa line and have a long vector, therefore both were included in the type II environment (Figure 2). These two environments show a strong, representative level of sweetness in the sweet potato. This is because both environments have relatively high potassium (K) content (Sumedang dry field = 1.22 cmol kg^{-1} and Bandung dry field = 0.89 cmol kg^{-1}). K content in the soil can affect the increase in sweetness levels in sweet potatoes (Anda et al. 2018). The nutrient content in the Sumedang paddy field environment was relatively high, therefore it was only suitable for certain types or genotypes. Thus, the Sumedang paddy field was included in the type III environment. In contrast, the

Bandung paddy field showed the shortest vector among the four test environments, which indicates that this environment belongs to type I. Therefore, it was not suitable for use as a test environment. In this study, Bandung paddy fields had the lowest K content (0.24 cmol kg^{-1}) compared to other environments.

In conclusion, the environments of Bandung and Sumedang showed significant differences in yield but showed insignificant differences in sweetness. The Bandung paddy field environment was the most representative environment for yield, and the Sumedang dry field and Bandung dry field were the most representative environments for sweetness.

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