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# The Yield Stability and Adaptability of Bambara Groundnut at Three Locations

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## ABSTRACT

Varieties with high yield stability are required to increase the yield. This study examines the strength and adaptability of seven Bambara groundnut lines in three areas. The seven lines used are CCC 1.6, PWBG 6, PWBG 521, SS 342, SS 242, BBL 11, and TVSU 86 as checks. The research sites are Brawijaya University Experimental Station, Farmer field in Madiun and Indonesia Legumes, and Tuber Crop Research Institute (ILETRI) Research Station. Research is conducted from February to October 2020. The study used a randomized block design with three replications. The Eberhart-Russel and Finlay-Wilkinson methods were used to analyze stability and adaptability. The Genotype x Environmental interaction (GxE) results of the 7 Bambara groundnut lines are at 50% flowering time, seed weight per plant, 100-seed weight, yield, and harvest age. The stability and adaptability analysis shows that BBL 1.1 line is the variety with an earlier harvest period, highest yield potential, good stability, and wide adaptability. The CCC 1.1, PWBG 6, PWBG 5.2.1, and SS 2.4.2 production lines are stable in all experimental environments but low productivity. The SS 3.4.2 is suitable for planting in a production environment. TVSU 86 is ideal for producing in marginal habitats such as drought conditions.

## INTRODUCTION

Bambara groundnut (*Vigna subterranea* (L.) Verdcourt) is a leguminous plant that originated from Africa (Heller et al., 1997), but now it has spread and developed in America, Asia, and Australia. In Asia, Bambara groundnut has been cultivated in India, Indonesia, Malaysia, the Philippines, and Thailand (Mkandawire, 2007). In Indonesia, Bambara has long adapted well and is found in Bogor and the eastern part of West Java Province, so these plants are better known as Bogor beans. Currently, bambara groundnut have been grown in West Java (Sukabumi, Majalengka, Tasikmalaya, Bandung), Central Java, East Java, Lampung, Nusa Tenggara Barat and Nusa Tenggara Timur (Kuswanto et al., 2012).

It is known that Bambara groundnut is more tolerant and adaptable in marginal areas with dry land and less fertile with low rainfall than other legumes (Goli, 1995; Azam-Ali et al., 2001; Mabhaudhi et al., 2013). In addition, this plant is also relatively resistant to pests and diseases (Berchie et al., 2012). Bambara groundnut is essential in food diversification programs and can be developed as an alternative food source in Indonesia (Alhamdi et al., 2020).

The natural protein of Bambara groundnut can also be used for animal protein (Mazahib et al., 2013). Nutritional analysis shows that 100 g of dry seeds of Bambara groundnut contains 61–69% carbohydrates, 17–27% protein, 3.3–6.4% fiber, and 3.6–7.4% fat (Ijarotimi & Esho, 2009; Murevanhema & Jideani, 2013; Oyeyinka et al., 2018). Bambara groundnut serves as an essential source of protein in the diets of a large percentage of the population in Africa (Chandra et al., 2019).

Until the 2000s, Bambara groundnut is one of the legumes that have not been widely studied, so this plant is less well known. These plants are still considered a less important crop in Indonesia so that no varieties have been developed. The production and productivity are still low. The average productivity of Bambara groundnut in

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Indonesia is 1 t/ha of dry pods, and due to the unavailability of superior varieties, farmers only use local genotypes. Local genotypes have drawbacks, such as low uniformity, low production, and long harvest time (Collinson et al., 1996).

Yield improvement can be made by extensification, but this is not easy because the availability of suitable land is increasingly limited. Therefore, the expansion of the planting area is directed to sub-optimal lands, including dry land. Considering the problem of Bambara groundnut, then the drought-tolerant Bambara groundnut breeding has been carried out. Faculty of Agriculture, Universitas Brawijaya has carried out Bambara breeding by collecting 72 local genotypes from West Java and East Java provinces. These genotypes were evaluated based on seed characters and 30 genotypes were selected. Draweel et al. (2021) considered these 30 genotypes by using Poly Ethylene Glycol (PEG) to determine drought-tolerant genotype and obtained six genotypes. These six genotypes were then evaluated for their yield potential and obtained promising genotypes tolerant to drought stress and homogeneous seeds.

The plant phenotype is influenced by genetics, environment, and interactions (Malosetti et al., 2013). Inconsistent yields with environmental changes indicate genotype x environment interaction (Singh & Chaudhary, 1979). Multi-site testing of promising genotypes is essential for understanding adaptability, yield potential, and stability. On the other hand, this test can determine the adaptability of such genotypes. According to Yan & Hunt (2001), understanding the genotype x environment interactions can establish breeding goals, determine ideal testing conditions, and formulate recommendations for local adaptation. Breeding programs will be successful if the following aspects are considered: (i) genotype level, that is, the average yield compared to the control genotype, (ii) adaptation, the formation of an environment can bring about the best genotype, and (iii) stability, that is, the consistency of the yield of one genotype compared to the other genotypes. These aspects will be integrated into a single measured yield of genotype.

Testing the selected genotypes from previous experiments in various environments is necessary to see their stability and adaptability. The information obtained from this evaluation can provide recommendations for new high-yielding varieties that are adaptive to a particular environment. Some types with stability and high yield are needed by farmers having small plots of land to reduce the risk of crop failure due to unpredicted changes in environmental factors. This study aims to obtain information on the yield stability and adaptability of the selected genotypes at three locations. Genotypes that adapt to all environments and/or specific areas can be obtained.

## MATERIALS AND METHODS

The experiment was carried out at three locations. The first location was in the experimental field of Agro Techno Park, Universitas Brawijaya, located at Jatikerto, Malang. The altitude was 330 meters above sea level, and the soil type is Alfisol. During the research time, the rainfall ranged from 740.1 - 71.0 mm, and the temperature was 23-31$^{o}$C. The second location is in Madiun, with an altitude of 63 meters above sea level and the type of soil is Alluvial. The temperature was 19-30$^{o}$C, and the rainfall ranged from 714.4-91.8 mm. Experiments in the first and second locations were carried out in February - June 2020. The third location was at the Indonesia Legumes and Tuber Crop Research Institute (ILETRI) experimental field, Kendalpayak, Malang, in May - October 2020. During the experimental time, the rainfall ranged from 11.8 - 215.4 mm, and the temperature was 20 - 33$^{o}$C. The altitude of the third location is 445 meters above sea level, the type of soil is Entisol. There were six good lines (PWBG 5.2.2, SS 2.4.2, BBL 1.1, PWBG 6, SS 3.4.2, CCC 1.6) and one check (TVSU 86) used in this experiment. Eleven characters, i.e., 50% germination time day after planting (DAP), 50% flowering time (DAP), number of pods per plant, number of seeds per plant, seed weight per plant (g), the importance of 100 grains (g), yield (t/ha), age of harvest (DAP), seed length (mm), seed width (mm) and seed thickness (mm) were observed.

The experimental method used was randomized complete block design (RCBD) at each location with 3 replications. There were 7 plots in each replication, so there were 21 plots in three replications. The plot size was 4 x 1.6 x 0.3 m with 40 x 40 cm spacing. The number of plants in each plot was 40 plants. In total, the plants at each location were 840 plants. Nested ANOVA analyzed the research data with a combined analysis of variance. The homogeneity of the data was tested previously before ANOVA. The genotype x environmental variance was tested by 5% and 1% significance. The analysis then further tests using the Honestly Significant Difference (HSD) test at the 5% level. Analysis of stability and adaptability refers to the linear regression model of Eberhart-Russel and Finlay-Wilkinson using PBSTAT software.

## RESULTS AND DISCUSSION

Plant diversity is influenced by genetic and environmental factors and their interactions. The environment can be defined as a combination of all non-genetic variables that affect genotypic expression, including location, season, and plant cultivation (Azam-Ali et al., 2001). Plant diversity or inconsistent yields with environmental changes are indications of genotype x environment interactions. The results of combined variance analysis show that there is an interaction between genotypes and the environment for five characters observed, including 50% flowering time (DAP), seed weight per plant (g), weight of 100 seeds (g), harvest age (DAP) and yield (t/ha) (Table 1). The yield is a quantitative character controlled by some genes and is therefore considered a complex trait ( Mabhaudhi et al., 2018)

The genotype x environment interaction made differences in the appearance of Bambara groundnut characters at each location. The suitability of genetic and environmental factors is the main determining factor in increasing crop productivity.

The yield shows that the genotype x environment interactions are significantly different based on the combined variance analysis results. The genotype x environment interaction is caused by changes in the response of each genotype at each location (Molosiwa et al., 2013). A combined analysis of variance was used to examine the effect of genotype and environment and their interactions.

The results of the HSD test are shown in (Table 2). The yield character (t/ha) of Bambara groundnut at three locations shows that at location 1 the SS 3.4.2, CCC 1.6, BBL 1.1, and PWBG 6 lines had high yields, with the average 2.51; 2.39; 2.26, and 2.19 t/ha, respectively. At Location 2, two lines with high results, namely BBL 1.1 and TVSU 86, have an average of 2.30 t/ha and 2.25 t/ha, respectively.

In location 3, two lines have high yields; namely, TVSU 86 and BBL 1.1, with average results of 2.06 t/ha and 2.02 t/ha, respectively. The BBL 1.1 line shows high results at three locations. According to (Massawe, Mwale, & Roberts, 2005), there are significant differences in the characters, such as the number of flowers, age of harvest, number of pods, and yield of Bambara groundnut due to the influence of genotype x environment interaction.

The existence of genotype x environmental interactions causes lines that have good yields at one location not necessarily produce the same good at other places (Feldman et al., 2019). According to Hillocks et al. (2012), the yield of Bambara in marginal areas ranges from 80-400 kg/ha. However, some accessions that have been selected from the experiment can produce more than 500 kg/ha at dry locations, 2 t/ha at the optimum site, and 4 t/ha at additional irrigation conditions.

Table 2 describes that Location 1 has a higher average yield than other locations. The average result at Location 1 is 2.21 t/ha, with a positive environmental index value of 0.12. They are then followed by Location 2, an average yield of 1.80 t/ha with a positive environmental index value of 0.002. While the Location 3 location has a lower average result than the other two locations, namely 1.68 t/ha with a negative environmental index value of -0.12 (Table 3).

The environment affects plant growth which can be seen from the environmental index value. There were variations in environmental conditions in the three test locations for Bambara groundnut. Differences in the environmental conditions of Bambara groundnut can be caused by altitude, rainfall, land type, soil type, temperature, and various other factors. A location with a positive environmental index contribution (high fertility rate) will have high average productivity. On the other hand, an area with a negative environmental index contribution (low fertility rate) will have a low average yield. Pungulani et al. (2012) stated that the selection of Bambara groundnut at three Malawian locations in South Africa showed a significant genotype x environment interaction due to differences in rainfall, temperature, and soil fertility. Location 1 also had better environmental conditions for growing Bambara groundnut than Location 3. It indicates by the environmental index value, which is more favorable than Location 3.

**Table 1.** The combined variance of locations, replication/location, genotype, and GXE for the observed characters

| Characters | Locations | | Replication/ location | | Genotype | | GXE | |
|---|---|---|---|---|---|---|---|---|
| 50% germination time (DAP) | 2.29 | ns | 1.14 | ns | 0.88 | ns | 0.64 | ns |
| 50% flowering time (DAP) | 123.35 | ** | 3.59 | ns | 3.47 | ** | 3.98 | ** |
| Number of pods per plant | 1.790,38 | ns | 1.435,63 | ** | 3.019,38 | ** | 252.89 | ns |
| Number of seeds per plant | 1.792,86 | ns | 1.724,62 | ** | 3.796,90 | ** | 332.65 | ns |
| Seed weight per plant (g) | 453.90 | ns | 185.3 | ** | 201.30 | ** | 141.17 | * |
| Weight of 100 seeds (g) | 297.76 | ns | 80.29 | ** | 745.89 | ** | 99.98 | ** |
| Yield (t/ha) | 1.23 | * | 0.33 | ** | 0.32 | ** | 0.33 | ** |
| Age of harvest (dap) | 19.63 | ns | 6.41 | ns | 27.74 | ** | 17.51 | ** |
| Seed length (mm) | 7.02 | ns | 1.74 | ** | 11.53 | ** | 0.42 | ns |
| Seed width (mm) | 4.98 | ns | 1.15 | ** | 1.10 | ** | 0.29 | ns |
| Seed thickness (mm) | 3.15 | ns | 1.57 | ** | 2.65 | ** | 0.26 | ns |

Remarks = GXE: Genetic X Environment interaction; *: significantly different at 5%, **: significantly different at 1%, ns: not significant

**Table 2.** Yield average (t/ha) of Bambara groundnut genotypes at location 1, location 2, and location 3

| Genotype | Yields | | | Average |
|---|---|---|---|---|
| | Location 1 (Mean±SD) | Location 2 (Mean±SD) | Location 3 (Mean±SD) | |
| CCC 1.6 | 2.39 ±0.63 cd C | 1.92 ±0.60 b B | 1.27 ±0.17 a A | 1.86 |
| PWBG 6 | 2.19 ±0.27 cd C | 1.58 ±0.29 a B | 1.21 ±0.10 a A | 1.66 |
| PWBG 5.2.1 | 1.79 ±0.41 ab B | 1.55 ±0.17 a A | 1.77 ±0.06 c B | 1.71 |
| SS 3.4.2 | 2.51 ±0.51 d C | 1.39 ±0.19 a A | 1.85 ±0.19 c B | 1.92 |
| SS 2.4.2 | 2.10 ±0.33 bc B | 1.60 ±0.18 a A | 1.56 ±0.15 b A | 1.75 |
| BBL 1.1 | 2.26 ±0.52 cd B | 2.30 ±0.53 c B | 2.02 ±0.22 d A | 2.19 |
| TVSU 86 | 1.76 ±0.33 a A | 2.25 ±0.45 c C | 2.06 ±0.23 d B | 2.02 |
| Average | 2.21 C | 1.80 B | 1.68 A | 1.87 |

Remarks: Numbers followed by the same lowercase notation in the same column or uppercase notation in the same row means that they are not significantly different in the HSD test at the 5% level.

Genetic x environmental interactions that are significantly different in the combined analysis of variance need to be tested for stability and adaptability. The stability and adaptability evaluation was conducted based on yield characters per hectare (Table 3). Based on the stability and adaptability analysis results, the BBL1.1 line showed average stability with higher productivity than the general average with an average yield of 2.19 t/ha. It is higher than the comparison variety TVSU 86, with an average product of 2.02 t/ha. So that, the BBL 1.1 line had good general adaptability to all environments. While the CCC 1.6, PWBG 6, PWBG 5.2.1, and SS 2.4.2 lines with an average yield of 1.86; 1.66; 1.71, and 1.75 t/ha, respectively. It shows average stability but had an average yield lower than the general average, so that it had poor adaptability to all environments.

The regression coefficient is more significant than one. The regression deviation was not significantly different from zero, so the SS 3.4.2 line had below-average stability. It adapts specifically to production environments and is sensitive to environmental changes. Under suitable conditions, the productivity of these lines could be better. Meanwhile, the TVSU 8.6 variety showed above-average stability and was adaptive to marginal environments such as drought stress. Because it had a regression coefficient value of less than one, and the regression deviation was not significantly different from zero. Location 1 and 2 show better yields than Location 3. The environmental index value can also be seen, where the Location 1 and Location 2 locations have a higher positive location index value than location 3. According to (Alghamdi, 2004), the environmental index is the basis for measuring environmental productivity. A high environmental index value indicates that the environment is more productive to produce pods per hectare.

On the other hand, a low environmental index value means that the environment is less productive (Table 4). This is because the environment at Location 1 and Location 2 is suitable for bambara groundnut growth. Bambara groundnut planted at locations 1 and 2 have a level of rainfall, temperature, soil type, and humidity that supports the development of Bambara. Meanwhile, location 3 has deficient rain, high temperatures, clay soil types, and low humidity, which makes the growth of Bambara groundnut not optimal. The rainfall at Location 3 is lower than location 1 and location 2. According to Jorgensen, Ntundu, Ouédraogo et al. (2011), Bambara groundnut requires moderate rain in the early growth and flowering stages. In addition, high temperatures make the evaporation process faster, thus affecting the availability of water in plants. Sufficient moisture is vital in the pod filling process. The optimum average temperature for growing Bambara groundnut is 20-28°C (Damfami & Namo, 2020). Scientist argues that the lack of water reduces the number of pods because the gynophores dry out before the pods are formed. The texture and soil structure can increase the land aeration, so it is essential to determine the soil's suitability for Bambara groundnut production. This plant prefers sandy clay soil because it can optimize water that goes into the ground, while clay can damage the seeds (Swaneveider, 1998).

**Table 3.** Stability and adaptability of yield characters (t/ha) of genotypes at three locations

| Genotype | Average | Range | bi=1 | $S^2d=0$ | S (ER) | A (FW) |
|---|---|---|---|---|---|---|
| CCC 1.6 | 1.86 | 1.27-2.39 | 2.18 ns | 0.05 ns | Stable | A |
| PWBG 6 | 1.66 | 1.21-2.19 | 2.03 ns | -0.02 ns | Stable | A |
| PWBG 521 | 1.71 | 1.55-1.79 | 0.19 ns | 0.00 ns | Stable | A |
| SS 3.4.2 | 1.92 | 1.39-2.51 | 1.81 ns | 0.21 ** | Unstable | A+ |
| SS 2.4.2 | 1.75 | 1.56-2.10 | 1.24 ns | -0.02 ns | Stable | A |
| BBL 1.1 | 2.19 | 2.02-2.30 | 0.37 ns | 0.00 ns | Stable | A |
| TVSU 86 | 2.02 | 1.76-2.25 | -0.83 ** | 0.01 ns | Unstable | A- |
| Average | 1.87 | | | | | |

Remarks: B = regression coefficient, $S^2d$ = regression deviation, * = significant differently from 1 or 0, S (ER) = stability (Eberhart-Russel), A (FW) = adaptability (Finlay-Wilkinson), A = wide adaptation in all environments, A + = narrow adaptation in the productive environment, A- = narrow adaptation in the marginal environment.

**Table 4.** Value of environmental index of genotypes at three locations based on eleven characters

| Characters | Environmental index value | | |
|---|---|---|---|
| | Location 1 | Location 2 | Location 3 |
| 50% germination time (DAP) | -0.04 | 0.09 | -0.04 |
| 50% flowering time (DAP) | -3.78 | 0.78 | 3.00 |
| Number of pods per plant | -5.48 | 10.98 | -5.50 |
| Number of seeds per plant | -7.90 | 10.90 | -3.00 |
| Seed weight per plant (g) | 2.76 | 1.67 | -4.44 |
| Weight of 100 seeds (g) | 2.88 | -3.57 | 0.69 |
| Yield (t/ha) | 0.12 | 0.22 | -0.12 |
| Age of harvest (DAP) | 0.01 | 0.01 | -0.03 |
| Seed length (mm) | 0.22 | -0.20 | -0.01 |
| Seed width (mm) | 0.19 | 0.05 | -0.24 |
| Seed thickness (mm) | 0.01 | 0.01 | -0.03 |

The type of soil at location 1 and location 2 are more suitable for bambara groundnut. The type of soil at location 1 is Alfisol which has a sandy clay texture, therefore the location 2 is alluvial with sandy soil texture and at location 3 is entisol with very clay texture. The type of soil can cause loss of harvest or damage to seeds. Because when harvesting seeds cannot be harvested optimally because the soil texture is hard.

Selection in genotype x environment interaction is significant for many plant breeders. In any plant breeding program, breeders must plant the line for several years in various locations to test the stability of the line in multiple environments (Mabhaudhi et al., 2018). Tadele & Assefa (2012) stated that experiments on the same factor are usually carried out in several locations and repeated over many years. The influence of most factors varies between places and from year to year due to differences in soil types, agronomic practices, climatic conditions, and other environmental variations. The existence of genotype x environment interaction indicates that genetic factors and environmental factors determine the yield of a line. The yield ranking of each line has the opportunity to change between locations. There are genetic differences between the lines and environmental productivity or regression coefficients between the tested lines. The regression coefficient represents the performance of each line in different environments on the environmental mean for all genotypes (Kaya et al., 2002). Stability analysis is carried out to reduce the effect of interaction with the environment and to select stable and specific lines (Farshadfar et al., 2012). The ideal line is durable, adaptive in various settings, and yields high (Jackson et al., 1996). The stability of the yields was based on the regression coefficient (bi), the regression deviation ($Sd^2$), and the general mean of all locations (Eberhart & Russell, 1966).

Meanwhile, according to Finlay & Wilkinson (1963), the adaptability analysis is based on the regression coefficient of each line. If the regression coefficient is not significantly different from one or equal, the line stability is average. In this condition, if the average yield of the line is higher than the general average of all lines, then the line has good general adaptability. On the other hand, if the average line is lower than the general average, then the adaptability of the line is poor in all environments. If the regression coefficient is more than one, then the stability of the line is below the average and adaptive to the productive environment and sensitive to environmental changes. Under suitable environmental conditions, these lines are capable of high yields. However, if the environmental conditions are not suitable then productivity will decrease. If the regression coefficient is less than one, then the stability of the line is above average and able to adapt to a marginal environment (Finlay & Wilkinson, 1963)

Bambara groundnut has become a model drought tolerant crop due to its ability to grow in various agroecological zones to produce significant seeds under moderate or extreme drought conditions (Mkandawire, 2007). Tolerance to different environmental stress conditions makes Bambara a vital crop to be cultivated in dry environments. The BBL 1.1 line is a drought-tolerant line that can be grown in various environmental conditions because it has wide adaptability. Begemann (1988) B stated that through effective breeding, the yield stability of a line can be increased. Therefore, choosing high yields and stable varieties is crucial under different agroecological conditions. Information on adaptability, potential, and yield stability of candidate varieties is one of the requirements for releasing a variety in Indonesia (Syukur et al., 2012).

## CONCLUSION

Five characters are significantly influenced by genotype x environment interactions, including 50% flowering time (DAP), seed weight per plant (g), 100 seed weight (g), yield (t/ha), and harvest age (DAP). The BBL 1.1 line is a line that has average stability and adapts well to all environments. The CCC 1.6, PWBG 6, PWBG 5.2.1, and SS 2.4.2 lines have moderate stability and were poorly adapted to all environments. Meanwhile, the SS 3.4.2 line is a line that has below average stability, is adaptive to a productive environment, and is sensitive to environmental changes. The TVSU 86 variety has above-average stability and is adaptive to marginal habitats. BBL 1.1 is a line that has the highest yield potential and has an earlier harvest age, and is well adapted to all environments.

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