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Performance of Soybean Genotypes in the Acidic Dryland and Wetland

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***Abstract*— The agroecosystem for soybean cultivation in Indonesia is diverse, such as the acidic dryland and the wetland after rice cultivation. This research aims to evaluate the performance of seed yield and agronomic traits and identify soybean genotypes with good adaptation in the acidic dryland and wetland environments. Twelve soybean genotypes were evaluated for their yield and yield components in Lampung (dry land) and Banyuwangi (wetland). The result showed the similarity in the days to flowering and maturity between land types. The average performance of the plant height, number of branches, number of fertile nodes, and number of filled pods in the wetland was higher than in the acidic dryland. The average 100 seeds weight in acidic dryland and wetland were 13.00 g and 17.13 g, respectively. The seed yield in the acidic dryland and wetland were 2.12 t/ha and 3.37 t/ha, respectively. Based on the seed yield, there were three groups of adaptive genotypes. The first group consists of genotype adaptive in the acidic dryland (SPL-186, 2.85 t/ha), the second group consists of genotype adaptive in the wetland, namely (SPL-183, 3.59 t/ha), and the third group consists of genotypes adaptive in both land types (SPL-182 and SPL-181, 3.05 and 3.07 t/ha, respectively). The SPL-182 and SPL-181 maintained their high potential yield both in the acidic dryland and wetland, implying adaptable genotypes. Those genotypes are recommended to be developed in acidic dryland as well as the wetland. These findings pave the way for increasing soybean yield productivity.**

***Keywords*— Agronomic character; cluster; pH; seed yield.**

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I. INTRODUCTION

The soybean cultivation system in Indonesia is distinct from that of other countries in that it can be cultivated in three growing seasons: the rainy season, the first dry season, and the second dry season. Cropping trends like these have consequences for the soybean seed production system, which can be carried out in many locations and seasons. The soybean development is potentially be performed in acidic soil, dryland, and wetland after the rice planting. Therefore, the availability of soybean varieties adaptive to a wide range of soil types is more advantageous than the variety that only adapts to certain soil types.

A soybean genotype adaptive ability across environments is characterized by its ability to maintain a relatively high yield potential in each growing environment. Yield potential is the maximum yield achieved when a crop is grown without water and nutrient limitations, and with pests, diseases, weeds, lodging, and other stresses effectively managed [1]. One of the constraints in the soybean development in the acidic dryland is associated with soil nutrition availability. In the humid tropics, soils become acidic naturally due to the leaching of basic cations under high rainfall conditions [2], which may inhibit root growth, leading to lower tolerance to drought stress and decreased grain yields [3]. According to Muletaa *et al.* [4], the inoculation of soybean with rhizobial inoculants could be one of the strategies that may increase the performance of soybean in acidic soils.

One of the constraints during wetland soybean cultivation is the low use of recommended soybean cultivation technology. Soybean cultivation technology packages have been used in some studies. A study on soybean adaptation in wetland areas without soil tillage in several soybean production centers yielded a relatively high yield range of 2.78 – 3.01 t/ha. [5]. Another study on the application of the biofertilizer technology for soybean in the rainfed area increased soybean yield 71% higher than the existing technology [6]. In another study, Gaweda *et al.* [7] compared the economic value of soybeans grown in various cropping systems and found that the economic value of monoculture soybeans (including grain yield) was higher than soybeans grown in crop rotation.

Soybean productivity is affected by the genetic potential of the cultivar, environmental conditions, and cultivation techniques [8]. Soybean genotype adaptive to acid soil was supported by higher plant height and followed by a high number of nodes per plant, a number of pods per plant [9], and long days to maturity [10]. Seed yield is a complex trait that is determined by the yield components. The number of pods per m^{-2} was an important feature that determines the yield potential in soybean [11]. A recent study on soybean revealed that the seed yield showed a highly significant and positive correlation with the number of branched nodes, the number of pods with two and three seeds, and the total number of pods [12]. Based on the findings of those studies, it appears that the plant's ability to adapt to a specific environment and produce a high yield is determined by the various agronomic traits that may interact with each other.

Each plant can adapt to different growing environments, which may be caused by morphological or physiological characteristics [13], [14]. Soybean genotypes that can adapt to a variety of growing environments have some advantages, particularly in the tropical farming system of Indonesia. Genotypes with an adaptive response to diverse environments are a powerful option for increasing crop productivity. Therefore, this study aims to evaluate the performance of seed yield and agronomic traits and identify soybean genotypes with good adaptation in acidic dryland and wetland environments.

II. Materials and Methods

A. Plant Materials

The research material consists of ten soybean genotypes derived from crossing between various parental with different genetic variability. The genotypes and the codes were SPL-1811 (G1), SPL-1813 (G2), SPL-1814 (G3), SPL-1819 (G4), SPL-1825 (G5), SPL-186 (G6), SPL-1810 (G7), SPL-183 (G8), SPL-182 (G9), and SPL-181 (G10). The soybean varieties Demas 1 (G11) and Anjasmoro (G12) were used as the check cultivars. The characteristic of Demas 1 was adaptive to acidic dryland. Meanwhile, Anjasmoro was adaptive to the wetland. The flowchart methodology of this research is illustrated in Figure 1.

B. Field Study

The field experiment was performed in two locations of soybean production centers, i.e., on the acidic, dry land in Lampung (Mandah Village, Tegineneng District, Pesawaran Regency), and on the wetland in Banyuwangi (Gambiran Village, Gambiran District, Banyuwangi Regency). The Pesawaran and Banyuwangi Regency have an average rainfall of 2332 mm/year and 4300 mm/year. The randomized block design with four replicates was applied to each location. In Pesawaran, the soil tillage was intensively performed before soybean planting. In Banyuwangi, soybean was planted in wetland after rice planting with zero tillage. Each genotype was sowing in a plot size of 2 m × 4.5 m, with planting spacing of 40 cm × 15 cm, two plants per hill. The pests, diseases, and weeds were intensively controlled

C. Data Observation and Analysis

Data measurement on each location was performed on the days to flowering, days to maturity, plant height (cm), number of branches, number of fertile nodes, number of filled pods, number of empty pods, 100 seed weight (g), and seed yield (t/ha). Data were analyzed using a Combined Analysis of Variance (ANOVA) using statistical analysis package software Minitab 17.1.0 [15]. In addition, a cluster analysis was performed for grouping the genotypes based on the agronomic traits in two locations, visualized in the unrooted dendrogram using PBSTAT-CL 2.1 software [16].

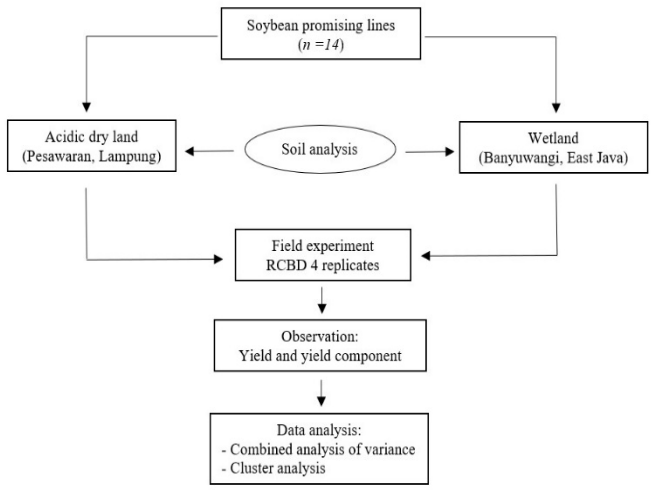

Fig. 1 Flowchart of methodology research

III. Results and Discussion

A. Environmental Characteristics

Pesawaran and Banyuwangi have different environmental characteristics in terms of soil type, soil chemical properties, and climate (Table 1).

TABLE I

Characteristics of locations in the acidic dryland (Pesawaran) and wetland (Banyuwangi).

Location	Soil type	Climate type (Oldeman)	Elevation (asl)	Actual pH H_2O 1:5	P_2O_5 Bray 1 ppm	Concentration	
						Al_{dd} KCl 1N $Cmol^+/kg$	H_{dd}KCl 1N $Cmol^+/kg$
Mandah Village, Tegineneng District, Pesawaran Regency, Lampung	Red, Yellow Podzolic	B	69	5.4	1.50	0.00	0.85
Gambiran Village, Gambiran District, Banyuwangi Regency, East Java	Entisol	C	168	7.1	40.24	0.00	0.43

The Pesawaran is located on a low elevation (69 m a.s.l), climate type of B (Oldeman classification), with Red Yellow Podzolic soil, pH 5.4, and the low availability of Phosphorus (P). Banyuwangi Regency located at medium elevation (168 m a.s.l), climate type of C (Oldeman classification), with soil type of Entisol, pH 7.1, and the relatively high P. Thus, Pesawaran's location can be classified as acidic soil, whereas Banyuwangi was alkaline soil. The combined analysis of variance showed that interaction between genotypes and location was significant for all agronomic characters, except days to flowering.

B. Plant Age

The plant age can be measured based on the days to flowering and days to maturity. The days to flowering of twelve genotypes in the acidic dryland ranged from 29-35 days (an average of 31 days), whereas in the wetland ranged from 33-35 days with an average of 34 days. The days to maturity in the acidic dryland and wetland ranged from 77-84 days (an average of 81 days) and 82-84 days (an average of 83 days) (Table 2).

The character of days to maturity becomes an important consideration for farmers before adopting a new and improved variety. For example, several soybean varieties for acidic dryland in Indonesia have the days to maturity from 82-86 days [9], [10]. Meanwhile, in Bangladesh, the days to flowering and days to maturity of genotypes planted in the acid soil ranged from 53-73 days and 115-126 days, respectively [17]. In Nigeria, the range of days to flowering and days to maturity of genotypes in the acid soil was 39-65 days and 73-94 days, respectively [18].

In this study, three genotypes were found to have days to maturity of 77 days. This fact becomes important for soybean cultivation in Indonesia since the cropping index is one of the economic values of a food crop commodity.

C. Plant Growth Characters

Soybean seed yield is composed of several growth characters, such as plant height, number of branches, number of fertile nodes, number of filled pods, and number of empty pods. Interestingly, the performance of all growth characters in the acidic soil was higher than those in the wetland (Table 2).

Plant height plays an important role as the soybean tolerance indicator of acid soil [9]. In this study, the plant height of Anjasmoro (check cultivar) in the acidic, dry land and wetland was 68.33 cm and 78.83 cm, respectively. Meanwhile, the plant height of Demas 1 was 86.92 cm in the acidic dryland) and 63.92 cm in the wetland. Higher plant performance in the acidic dryland increases the number of branches, the number of nodes, and the number of filled pods, but this also increased the number of empty pods. The empty pods also could be caused by the pod pests' infestation [19], [20].

TABLE II
PLANT AGE AND PLANT GROWTH CHARACTERS OF 12 SOYBEAN GENOTYPES IN THE ACIDIC DRYLAND (PESAWARAN) AND WETLAND (BANYUWANGI).

Genotipe	Days to maturity (day)		Days to flowering (day)		Plant height (cm)		Number of branches		Number of fertile nodes		Number of filled pods		Number of empty pods	
	LPG	BWI	LPG	BWI	LPG	BWI	LPG	BWI	LPG	BWI	LPG	BWI	LPG	BWI
G1	32	35	83	83	71.92	67.08	5.92	3.42	26.92	19.50	45.08	49.33	3.42	0.58
G2	29	34	83	83	92.33	71.42	4.67	3.08	33.25	16.75	120.33	37.83	6.25	0.17
G3	31	35	83	84	77.08	71.25	6.17	4.75	31.33	22.83	71.75	49.17	3.75	0.83
G4	30	32	82	82	69.92	66.42	6.50	3.08	29.67	18.75	65.00	51.92	5.08	0.00
G5	30	35	82	83	82.33	73.92	4.25	3.58	23.42	17.08	64.33	42.58	4.08	1.08
G6	30	34	78	84	81.83	65.83	3.83	3.25	21.83	17.92	65.33	49.50	3.08	0.08
G7	30	34	77	84	66.17	62.50	3.42	3.50	22.58	18.58	47.75	40.67	1.17	0.25
G8	35	33	78	83	71.58	65.17	3.33	2.67	19.00	14.67	31.25	32.08	1.33	0.67
G9	29	34	77	83	73.00	60.17	4.08	2.58	23.67	16.25	50.25	42.42	2.83	0.50
G10	31	34	77	83	69.42	63.25	3.92	3.58	22.33	20.83	65.58	48.92	2.08	0.17
G11	35	33	85	83	86.92	63.92	4.42	3.33	34.42	20.42	148.75	51.33	5.17	0.50
G12	35	35	84	84	68.33	78.83	4.58	3.17	20.25	19.42	41.50	52.00	1.67	0.42
Mean	31	34	80.75	83.25	75.90	67.48	4.59	3.33	26.92	19.50	68.08	45.65	3.33	0.44

LPG = Lampung, BWI = Banyuwangi

D. Seed Yield

Seed yield resulted from the interaction between the plant growth characters in which the magnitude is affected by the genotype and environment, or it can be defined as genotype by environment interaction [21]–[23]. In this study, the character of yield was reflected by the two variables, namely 100 seed weight and seed yield. The seed size, which was measured based on the 100 seed weight, showed a range of 9.00-12.63 g (an average of 13.00 g/100 seeds) in the acidic dryland and 14.37 18.15 g (an average of 17.13 g/100 seeds) in the wetland. The seed size in the acidic dryland was smaller than in the wetland (Fig.2).

The seed yield ranged from 1.73-2.85 t/ha (an average of 2.12 t/ha) in the acidic, dry land and 2.95-3.59 t/ha (an average of 3.37 t/ha) in the wetland (Fig. 3). The performance of check cultivar Demas 1, which was designed to be adaptive to acid soils, was able to produce higher in Pesawaran. On the contrary, Anjasmoro was superior to Demas 1 in the wetland. The amount of yield reduction depends on the level of hydrogen ions [24], climatic conditions, and the genetic background of the cultivar [25].

In this study, the seed yield in the acidic dryland was lower than in the wetland. Acidic soils are suggested as one of the most significant soil factors restricting crop production by inhibiting root growth and influencing the absorption of water and nutrients [26]. Al toxicity causes hindering plant growth and development due to the inhibition of root elongation led by the root apex's destroying cell structure [27]. A low pH may cause plant toxicity in a sensitive genotype leads to a significant yield loss [18].

When the genotypes adaptation was classified based on seed yield, soybean genotypes could be divided into three groups. Group I consists of a genotype adaptive in the acidic dryland, SPL-186, with the yield in acidic soil was 2.85 t/ha. Group II consists of a genotype adaptive in the wetland, namely SPL-183, with the yield in the wetland was 3.59 t/ha. Finally, group III consists of genotypes adaptive in the acidic, dry land and the wetland (SPL-182 and SPL-181), as shown in Fig. 2 and 3.

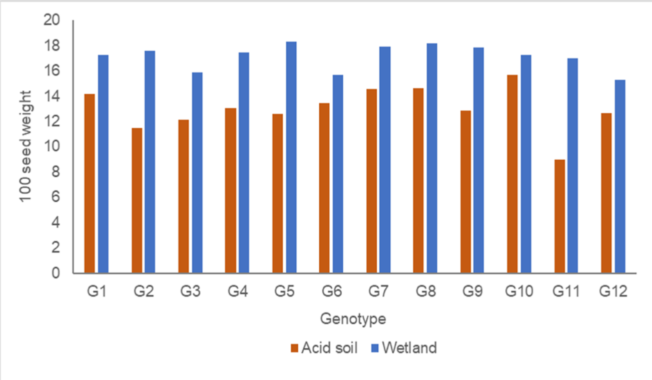

Fig. 2 100 seed weight of 12 genotypes in the acidic dryland and wetland

The average yields of those genotypes in both types of land were 3.05 and 3.07 t/ha, respectively, suggesting that they are well adapted to those land types. The increase of soybean adaptation to acid soil was suggested to be controlled by GmALMT1, a gene that can produce malate exudation [28].

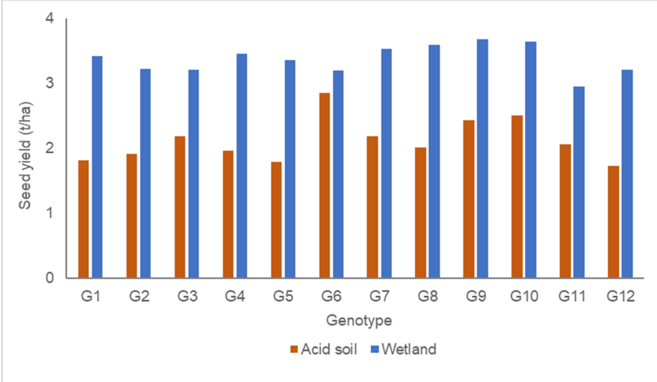

Fig. 3 Seed yield of 12 genotypes in the acidic dryland and wetland

E. The classification of genotypes

The classification of soybean genotypes in the acidic dryland and wetland is expected to understand the agronomic characteristics of each soybean genotype. The twelve genotypes were classified into 4 clusters with a high similarity level (Fig. 4, Fig. 5). In the acidic dryland, cluster I was characterized by genotypes with many pods but small sizes (G1 and G11). In cluster II, it was shown by a low number of filled and empty pods (G8 and G12). Cluster III, which contains four genotypes were characterized by high seed yield. The first subcluster (G7 and G10) were classified as high yield and large seed size. Meanwhile, the other subcluster (G6 and G9) have a high yield and early maturity. In cluster IV, which consists of two subclusters, i.e., G5 with many branches and tall plants, and other sub-cluster (G1, G3, and G4) have the characteristics of many branches (Table 3).

TABLE III
CLASSIFICATION OF 12 SOYBEAN GENOTYPES IN ACIDIC DRYLAND AND WETLAND

Environment		Cluster			
		I	**II**	**III**	**IV**
Acidic dryland	Member	G2, G11	G8, G12	G7, G10	G5
	Description	High pod number Small seeded	A few numbers of pods A few numbers of empty pods	High yield Large seeded	High numbers of branches Higher plant
	Member			G6, G9	G1, G3, G4
	Description			High yield Early maturity	High numbers of branches
Wetland	Member	G3	G6, G12	G4, G11	G8, G9
	Description	High number of nodes	Small seeded	High numbers of pods	High yield A few numbers of nodes
	Member				G5
	Description				High yield Large seeded
	Member				G2
	Description				High yield A few numbers of branches
	Member				G1, G7, G10
	Description				High yield High number of nodes

The genotype responses in the same soil types can differ due to different genetic backgrounds and environmental conditions. For example, similar to genotypes in cluster I (Fig. 4.), a previous study in acid soil was also found genotypes with a large number of empty pods and small seed size [9]. However, plants that cannot adapt well to acid soil could result in a low number of filled and empty pods, as shown by genotypes in cluster II. These also affected their seed yield; as shown in Fig. 3, the G8 and G12 have relatively low yields.

In cluster III, seed size, plant age, and high yield become the characteristic properties in acid soil. Genotypes in this cluster showed adaptability to acid soil due to their ability to produce a high yield. Other agronomical characteristics determine the seed yield, and the large seed size is one of the important characters supporting the yield. The decrease in maturity age was suggested due to the low soil moisture. Also, to escape the harsher conditions in this sub-optimal soil, the plant shortens its life cycle [29]. In cluster IV, a high number of branches and a high plant were the characteristic properties. A previous study showed that decreasing soil pH tends to increase plant height, followed by a high number of branches [5].

In the wetland, cluster I (G3) was characterized by a high number of nodes. A smaller seed size characterized the second cluster (G6 dan G12). Meanwhile, cluster III with two members (G4 and G11) was characterized by a high number of pods. Finally, cluster IV had four subclusters, i.e., genotypes with a high yield but a low number of nodes (G8 and G9), genotypes with high yield and large seed size (G5), genotype with a high yield but a low number of branches (G2), and genotype with high yield and a high number of branches (G1, G7, and G10) (Table 3).

A previous study also obtained the high number of nodes, smaller seed size, and many pods as the characteristic properties in the dry land [30]. The good adaptability to the wetland condition was shown by most of the genotypes in cluster IV, as shown by their high yield. In addition, the combination of high yield with large seed size or with a high number of branches can be served as yield supporting characters [31].

The G9 and G10 were suggested as adaptive genotypes in the acidic, dry land, and wetland based on their yield. Those genotypes have agronomic similarities with G6 and G7 in the acidic dryland. Meanwhile, in the wetland, those genotypes showed comparable similarity with the G8, G1, and G7. The similarity assessment of the F5 soybean population by Kuswantoro *et al.* [32] succeeded in identifying several soybean genotypes as a gene source for plant age, seed size, and high yield. A study showed that the number of branches and pods affects traits for high yield in soybean [33]. Borah *et al*. [34] revealed the candidate genes for plant height and the number of primary branches in soybean using genome-wide association studies (GWAS). Meanwhile, the approach through the seed quality, Adsul *et al.* [35] studied the inheritance of seed longevity as the yield determinant in soybean.

In this study, identifying clustering patterns (Fig. 4 and Fig. 5) can help recognize the adaptive genotypes for specific environments and thus support soybean yield improvement. In addition, this study also enables breeders to improve quantitative traits in the soybean varieties through hybridization in the breeding program.

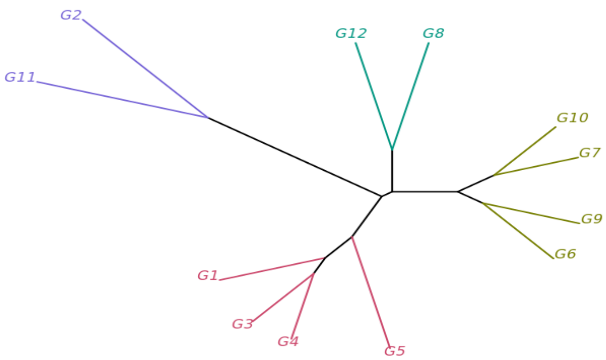

Fig. 4 Unrooted dendrogram based on the agronomic characteristics of soybeans in the acidic dryland.

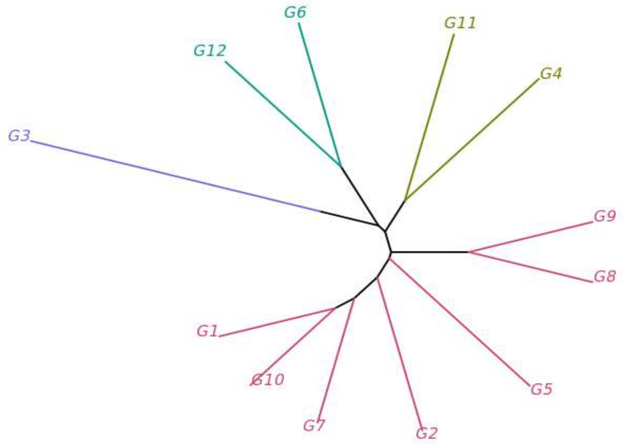

Fig. 5 Unrooted dendrogram based on the agronomic characteristics of soybeans in the wetland

IV. Conclusion

Soybean genotypes G9 (SPL-182) and G10 (SPL-181) maintained their high potential yield both in the acidic dryland and wetland, implying adaptable genotypes. Therefore, those genotypes were recommenced to be developed in acidic dryland as well as the wetland.

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References

[1] Z. Tadele, “Raising crop productivity in Africa through intensification,” *Agronomy*, vol. 7, no. 1, Mar. 2017, doi: 10.3390/agronomy7010022.

[2] G. Agegnehu, C. Yirha, and T. Erkossa, *Soil Acidity Management*. Addis Ababa, Ethiopia: Ethiopian Institute of Agricultural Research (EIAR), 2019.

[3] T. . Blumenschein, K. A. Nelson, and P. P. Motavalli, “Impact of a new deep vertical lime placement practice on corn and soybean production in conservation tillage systems,” *Agronomy*, vol. 8, no. 7, 2018, doi: 10.3390/agronomy8070104.

[4] D. Muleta, M. H. Ryder, and M. D. Denton, “The potential for rhizobial inoculation to increase soybean grain yields on acid soils in Ethiopia,” *Soil Sci. Plant Nutr.*, vol. 63, no. 5, pp. 441–451, Sep. 2017, doi: 10.1080/00380768.2017.1370961.

[5] M. M. Adie, A. Krisnawati, and R. Iswanto, “Agronomic performance of soybean genotypes in lowland paddy fields under zero-tillage condition,” *Biosaintifika J. Biol. Biol. Educ.*, vol. 12, no. 2, pp. 140–146, Aug. 2020, doi: 10.15294/biosaintifika.v12i2.23263.

[6] D. A. A. Elisabeth, S. Mutmaidah, and A. Harsono, “Adoption determinants of biofertilizer technology for soybean in rainfed area,” in *IOP Conference Series: Earth and Environmental Science*, Nov. 2019, vol. 347, no. 1, doi: 10.1088/1755-1315/347/1/012114.

[7] D. Gawęda, A. Nowak, M. Haliniarz, and A. Woźniak, “Yield and economic effectiveness of soybean grown under different cropping systems,” *Int. J. Plant Prod.*, vol. 14, no. 3, pp. 475–485, Sep. 2020, doi: 10.1007/s42106-020-00098-1.

[8] O. Sobko, S. Zikeli, W. Claupein, and S. Gruber, “Seed yield, seed protein, oil content, and agronomic characteristics of soybean (Glycine max L. Merrill) depending on different seeding systems and cultivars in Germany,” *Agronomy*, vol. 10, no. 7, Jul. 2020, doi: 10.3390/agronomy10071020.

[9] M. M. Adie and A. Krisnawati, “Identification of soybean genotypes adaptive and productive to acid soil agro-ecosystem,” *Biodiversitas*, vol. 17, no. 2, 2016, doi: 10.13057/biodiv/d170225.

[10] H. Kuswantoro, “Genetic variability and heritability of acid-adaptive soybean promising lines,” *Biodiversitas*, vol. 18, no. 1, pp. 378–382, Jan. 2017, doi: 10.13057/biodiv/d180149.

[11] N. Matsuo, T. Yamada, Y. Takada, K. Fukami, and M. Hajika, “Effect of plant density on growth and yield of new soybean genotypes grown under early planting condition in southwestern Japan,” *Plant Prod. Sci.*, vol. 21, no. 1, pp. 16–25, Jan. 2018, doi: 10.1080/1343943X.2018.1432981.

[12] B. Q. V. Machado *et al.*, “Phenotypic and genotypic correlations between soybean agronomic traits and path analysis,” *Genet. Mol. Res.*, vol. 16, no. 2, Jun. 2017, doi: 10.4238/gmr16029696.

[13] I. M. Pérez-Ramos, L. Matías, L. Gómez-Aparicio, and Ó. Godoy, “Functional traits and phenotypic plasticity modulate species coexistence across contrasting climatic conditions,” *Nat. Commun.*, vol. 10, no. 1, Dec. 2019, doi: 10.1038/s41467-019-10453-0.

[14] P. E. R. Marchiori *et al.*, “Physiological plasticity is important for maintaining sugarcane growth under water deficit,” *Front. Plant Sci.*, vol. 8, Dec. 2017, doi: 10.3389/fpls.2017.02148.

[15] Minitab, “Getting Started with Minitab Statistical Software.” Minitab, LLC, 2020.

[16] W. B. Suwarno, Sobir, and T. Sitaresmi, “Analisis keragaman genetik untuk pemuliaan tanaman dengan PBSTAT-CL,” Bogor, 2019.

[17] R. Tabassum, A. F. M. S. Islam, M. Rahman, and F. I. Monshi, “Morpho-physiological features and yield attributes of soybean genotypes in acid soil,” *Res. J. Agric. Biol. Sci.*, vol. 1, no. 11, pp. 11–20, 2015, [Online]. Available: http://www.aensiweb.com/RJABS/.

[18] M. I. Uguru, Benedict, C. Oyiga, and E. A. Jandong, “Responses of Some Soybean Genotypes to Different Soil pH Regimes in two Planting Seasons,” *African J. Plant Sci. Biotechnol.*, vol. 6, no. 1, pp. 26–37, 2012.

[19] A. Singla and R. Singh, “Estimation of avoidable yield losses in chickpea caused by Helicoverpa armigera (Hübner) (Lepidoptera: Noctuidae),” *Phytoparasitica*, vol. 48, no. 5, pp. 755–765, Nov. 2020, doi: 10.1007/s12600-020-00833-4.

[20] M. Sarjan, “Influence of attack intensity of sucking pod (Riptorus linearis), to the yield of superior soybean varieties in drought stress condition,” in *IOP Conference Series: Earth and Environmental Science*, Jul. 2020, vol. 519, no. 1, doi: 10.1088/1755-1315/519/1/012037.

[21] A. Bhartiya, J. P. Aditya, K. Singh, Pushpendra, J. P. Purwar, and A. Agarwal, “AMMI & GGE biplot analysis of multi environment yield trial of soybean in North Western Himalayan state Uttarakhand of India,” *Legum. Res.*, vol. 40, no. 2, pp. 306–312, Apr. 2017, doi: 10.18805/lr.v0iOF.3548.

[22] A. S. Milioli *et al.*, “Yield stability and relationships among stability parameters in soybean genotypes across years,” *Chil. J. Agric. Res.*, vol. 78, no. 2, pp. 299–309, Jun. 2018, doi: 10.4067/S0718-58392018000200299.

[23] A. Xavier *et al.*, “Genome-wide analysis of grain yield stability and environmental interactions in a multiparental soybean population,” *G3 Genes, Genomes, Genet.*, vol. 8, no. 2, pp. 519–529, Feb. 2018, doi: 10.1534/g3.117.300300.

[24] R. Ghimire, S. Machado, and P. Bista, “Soil ph, soil organic matter, and crop yields in winter wheat-summer fallow systems,” *Agron. J.*, vol. 109, no. 2, pp. 706–717, 2017, doi: 10.2134/agronj2016.08.0462.

[25] B. Tóth, C. Juhász, M. Labuschagne, and M. J. Moloi, “The influence of soil acidity on the physiological responses of two bread wheat cultivars,” *Plants*, vol. 9, no. 11, pp. 1–13, 2020, doi: 10.3390/plants9111472.

[26] X. Zhang, Y. Long, J. Huang, and J. Xia, “Molecular mechanisms for coping with Al toxicity in plants,” *Int. J. Mol. Sci.*, vol. 20, no. 7, Apr. 2019, doi: 10.3390/ijms20071551.

[27] S. J. Zheng, “Crop production on acidic soils: Overcoming aluminium toxicity and phosphorus deficiency,” *Ann. Bot.*, vol. 106, no. 1, pp. 183–184, Jul. 2010, doi: 10.1093/aob/mcq134.

[28] C. Liang *et al.*, “Low pH, aluminum, and phosphorus coordinately regulate malate exudation through GmALMT1 to improve soybean adaptation to acid soils,” *Plant Physiol.*, vol. 161, no. 3, pp. 1347–1361, 2013, doi: 10.1104/pp.112.208934.

[29] H. Kuswantoro, “Increasing grain size improves grain yield of acid-adaptive soybean lines in optimal soil condition,” *J. Plant Sci.*, vol. 10, no. 3, pp. 79–89, 2015, doi: 10.3923/jps.2015.79.89.

[30] M. M. Adie and A. Krisnawati, “Characterization and clustering of agronomic characters of several soybean genotypes,” *Nusant. Biosci.*, vol. 9, no. 3, pp. 237–242, 2017, doi: 10.13057/nusbiosci/n090301.

[31] H. Kuswantoro, R. Artari, W. Rahajeng, E. Ginting, and A. Supeno, “Genetic Variability, Heritability, and Correlation of Some Agronomical Characters of Soybean Varieties,” *Biosaintifika J. Biol. Biol. Educ.*, vol. 10, no. 1, pp. 1–8, 2018, doi: 10.15294/biosaintifika.v10i1.9939.

[32] H. Kuswantoro, R. Artari, R. Iswanto, and H. Imani, “Family structure of F5 soybeans lines derived from soybean varieties with the main differences on seed size and maturity traits,” *Biodiversitas*, vol. 21, no. 6, pp. 2576–2585, Jun. 2020, doi: 10.13057/biodiv/d210630.

[33] W. de S. Leite, S. H. Unêda-Trevisoli, F. M. da Silva, A. J. da Silva, and A. O. Di Mauro, “Identification of superior genotypes and soybean traits by multivariate analysis and selection index,” *Rev. Cienc. Agron.*, vol. 49, no. 3, pp. 491–500, Jul. 2018, doi: 10.5935/1806-6690.20180056.

[34] J. Borah, A. Singode, A. Talukdar, R. R. Yadav, and R. N. Sarma, “Genome-wide association studies (GWAS) reveal candidate genes for plant height and number of primary branches in soybean [Glycine max (L.) Merrill],” *Indian J. Genet. Plant Breed.*, vol. 78, no. 4, pp. 460–469, Nov. 2018, doi: 10.31742/IJGPB.78.4.8.

[35] A. T. Adsul, V. P. Chimote, and M. P. Deshmukh, “Inheritance of seed longevity and its association with other seed-related traits in soybean (Glycine max),” *Agric. Res.*, vol. 7, no. 2, pp. 105–111, Jun. 2018, doi: 10.1007/s40003-018-0297-7.