Research Article

Stability analysis on yield of several winged bean lines (*Psophocarpus tetragonolobus* L.) in three environments

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ABSTRACT

Winged bean is a plant with a high seed protein content equivalent to soybeans. Indonesia is one of the central origins in southern Asia. However, there are still only a few superior varieties that can be widely cultivated. One effort to increase productivity is by growing improved varieties. This study aimed to identify promising winged bean lines with high and stable yield potential. The experiment was conducted in three environments, i.e., two planting seasons in Bogor and one in Palembang from January 2019 to June 2020. A total of 11 winged bean genotypes were tested and observed for grain yield characters. Parametric analysis methods were used to obtain information on the stability of 11 winged bean genotypes across the three environments. Grain yield was significantly affected by G x E interaction and, therefore, was subjected to stability analyses. Genotypes H1(P), L2, and H4(P) were classified as stable. This genotype had similar characteristics with stable grain yield in three test environments.

Keywords: G x E interaction; seed yield; parametric stability, underutilized legume

INTRODUCTION

The winged bean (*Psophocarpus tetragonolobus* (L.) DC) belongs to the Fabaceae family, which is an underutilized legume plant (Akinyosoye et al., 2023; Ng, Samsuri, et al., 2020). It grows well on various types of soil, including marginal land. The underuse of this plant is primarily due to insufficient awareness of its potential. In line with the food diversification initiative, winged beans should be recognized as a viable alternative source of nutrition (Kuswanto et al., 2024). Winged bean plants have good prospects as a significant multipurpose food crop in tropical areas, including Asia, Africa, and Latin America, providing human nutrition, animal feed, and environmental protection (Alalade et al., 2016). Even though dozens of species are consumed globally, only 20 crops comprising cereals, legumes, roots, and other food crops provide most of the world's calories (Mohanty et al., 2020). Every component of the winged bean plant, such as flowers, leaves, young pods, seeds, and tubers, can be consumed (Mohanty et al., 2015; Eagleton, 2020).

Several winged bean accessions have produced edible tubers with high protein content and significant fiber, energy, and minerals (Sriwichai et al., 2021). Winged bean seeds contain 33% protein, 39% carbohydrates, 19% fat, and various vitamins and minerals recommended for humans (Adegboyega et al., 2019; Lepcha et al., 2017; Ishthifaiyyah et al., 2023). Winged beans are known for their potent antioxidant content,

antihypertensive, and antifungal, in addition to their excellent nutritional value (Singh et al., 2019; Koley et al., 2019; Chay et al., 2018; Zakuan et al., 2018). Winged beans have also been utilized as a component in several earlier trials to treat conditions like diabetes, cancer, infections, migraines, eye disorders, muscle weakness, and asthma (Singh et al., 2019; Ng, Yong,   et al., 2020). With this potential, winged beans can be one way to increase vegetable protein consumption in developing countries.

Indonesia is one of the centres of winged bean plant diversity worldwide. However, the lack of superior genotypes is a significant obstacle in the widespread use of winged beans (Popoola et al., 2019). The yield and productivity of winged beans could be increased by breeding and introducing superior cultivars. Data on production shows that winged bean produces 2000 kg ha^{-1} of dry seeds and up to 10,000 kg ha^{-1} of young green pods (Tanzi et al., 2019). A thorough survey was carried out at several cultivation centers across several provinces. This investigation identified 69 different local lines that exhibit a high degree of variation in seed color (Kuswanto, et al., 2024). Local crop accessions have been successfully collected, and genetic diversity has been enhanced through crossbreeding. To obtain genotypes with high and stable yields, genotype studies must be conducted through environmental interactions (G x E). Interactions (G × E) are important for the development of enhanced genotypes in various contexts. When G × E interaction effects are non-significant, the means of assessed varieties across environments serve as sufficient indications of genotypic performance across those environments (Mafouasson et al., 2018).

Developing varieties that can adapt to various environments (broad adaptation) is the ultimate goal of plant breeders in crop improvement programs (Khalili & Pour-Aboughadareh, 2016). Therefore, genotype evaluation in a multi-environment is crucial for accurate candidate genotype ranking and discrimination and for identifying stable and high-yielding genotypes. The interaction between genotype and environment provides an effective assessment of genotypes regarding stability, and a stable genotype may be utilized for broader cultivation (Tiwari et al., 2022). Stability has been widely studied by biometrics and genetics. Genetic × environment interactions (G × E) are crucial to developing better genotypes in various contexts. The means of examined variety across environments are sufficient markers of genotypic performance across environments when the effects of the G × E interaction are not considerable (Mafouasson et al., 2018; Mebratu et al., 2019). Finding significant crossover rank changes of the genotypes in various settings is critical when G × E exists such that distinct winners are selected in various contexts. The most common method is the parametric method. This method relies on a series of assumptions, including the hypothesis of a normal distribution with a zero mean and homogeneous variance.

The stability of the results of new candidate varieties can be analyzed using several methods, namely the parametric method based on Wricke (1962), Shukla (1972), and Francis and Kannenberg (1978). This study aimed to identify promising winged bean lines with high and stable yield potential that can adapt widely to diverse environments.

MATERIALS AND METHODS

The research was conducted in three environments, Bogor1, Bogor2, and Palembang, from January 2019 to June 2020. The description of the three environments is presented in Table 1. The genetic material used was 9 selected progeny of the 7th generation (F$_7$) from pedigree selection and 2 parent genotypes in Table 2.

Table 1.   Description of the three research environments.

Location	Geographic location			Mean annual rainfall (mm)	Temperature (°C)	
	Longitude	Latitude	Altitude		Min	Max
Bogor 1	106°43 E	6°33 S	201 m	285	26	35
Bogor 2	106°43 E	6°33 S	201 m	351	28	36
Palembang	104°48 E	2°57 S	8 m	187	28	37

Table 2.   The list of winged bean genotypes evaluated.

No	Genotype code	Origin	Grain color
1	L1	Selected F_7 progeny	Dark purple
2	L2	Selected F_7 progeny	Dark purple
3	L3	Selected F_7 progeny	Dark purple
4	L4	Selected F_7 progeny	Dark purple
5	H1(P)	Selected F_7 progeny	Brown
6	H1(U)	Selected F_7 progeny	Dark purple
7	H2	Selected F_7 progeny	Brown
8	H3(U)	Selected F_7 progeny	Dark purple
9	H4(P)	Selected F_7 progeny	Brown
10	P2	Male parent (local green-winged bean from Cilacap, Indonesia	Brown
11	P1	Female parent (purple winged bean, introduced from Thailand)	Dark purple

The combined variance analysis of each environment refers to the fixed model (Table 3). Analysis of yield stability was carried out using parametric methods: Wricke (1962), Shukla (1972), and Francis and Kannenberg (1978).

Wricke (1962)

Wricke's method uses ecovalence ($W_i{}^2$) as a stability parameter. Ecovalence is a measurement of the contribution of each genotype to the total square of interaction with the environment. The calculation used is :

$$W_i{}^2 = \sum_{j=1}^{q} (\bar{X}_{ij} - \bar{X}_{i.} - \bar{X}_{.j} - \bar{X}_{..})$$

Shukla (1972)

(Shukla, 1972) method uses stability variance ($\sigma^2{}_i$) as the stability parameter. The stability variance is the difference between two sums of squares so that the value can be negative. The calculation used is :

$$\sigma_i^2 = \frac{p}{(p-2)-(q-1)} \sum_{j=1}^{q} (\bar{X}_{ij} - \bar{X}_{i.} - \bar{X}_{.j} - \bar{X}_{..}) + \frac{SS(GE)}{(p-1)(p-2)(q-1)}$$

Francis and Kannenberg (1978)

Francis and Kannenberg (1978) stated that the stability of a genotype is determined by the value of environmental variation and the coefficient of variation (CV_i). The value of the coefficient of variation (CV_i) is determined from the value of the average standard deviation of the results of a genotype based on the general average.

$$CVi = \left(\frac{\sqrt{s_i^2}}{\bar{Y}_{i.}} \right) x \ 100\% = \left(\frac{\sqrt{\dfrac{\sum_i (\bar{Y}_{ij} - \bar{Y}_{.j})^2}{q-1}}}{\bar{Y}_{i.}} \right) x \ 100\%$$

Where CVi is the coefficient of diversity, $S_i{}^2$ is the environmental variance, $\bar{Y}_{i.}$ is the mean of the ith genotype across all j^{th} locations, $\bar{Y}_{ij}$ is the mean of the ith genotype and the jth environment, $\bar{Y}_{.j}$ is the mean of the jth environment for all genotypes, q is the number of the ith environment. The outline of the mixed model analysis of variance is shown in Table 2. Analysis of variance and stability analyses used PBSTAT-GE on www.pbstat.com.

Table 3. Model of combined analysis of variance across environments.

Source	df	Mean square	F-value
Environments (E)	(l-1)	M5	M5/M4
Replications/E	l(r-1)	M4	-
Genotype (G)	(g-1)	M3	M3/M1
G x E	(g-1)(l-1)	M2	M2/M1
Error	l(g-1)(r-1)	M1	-

Note: l, r, and g are the numbers of location, replication, and genotype, respectively; Genotype and environment were regarded as fixed effects, while replication within the environment was regarded as a random effect.

RESULTS AND DISCUSSION

Analysis of variance (Table 4) showed that environmental factors and their interactions (G x E) significantly affected grain yield in the genotypes tested. Analysis of variance also indicated that the sum of the squares of the environment contributed 43.76% to the character of grain yield variance. The interaction of genotype x environment contributed 33.65% to grain yield variance, while the genotype contributed 22.59% to grain yield variance. The large and significant sum of the mean squares of the environment indicates that environmental conditions cause diversity in response between environments (Chimonyo et al., 2019).

Table 4. Combined analysis of variance for grain yield.

Source	df	SS	MS	F-value	Contribution (%)
Environment (E)	2	35.03	17.52	18.25**	43.76
Replication/E	6	5.75	0.96	3.03*	
Genotype (G)	10	18.09	1.81	5.71**	22.59
G x E	20	26.94	1.35	4.25**	33.65
Error	59	18.70	0.32		
Total	97	104.513			

Note: * = significant at α = 0.05; ** = significant effect at α = 0.01; ns = not significant.

The interaction between genotype and environment causes differences in response in each genotype. The effects of both factors, both genotype and environment, determine the phenotype of an individual, but they are not always additive because of the interaction between the two. The analysis of highly significant genotype and environment interactions indicates that character performance and environmental changes fluctuate (Lodhi et al., 2015).

Figure 1 shows the grain yield of 11 genotypes tested in three environments and the interaction between genotype x environment. This interaction was caused by changes in the response of each genotype tested in different locations and seasons. This showed that the genotypes tested provided different productivity responses to the three growing environments. The values of young pod productivity and grain yield that differed between genotypes in three environments and had a significant G x E interaction met the requirements for stability analysis. This was done to explain the effect of interaction.
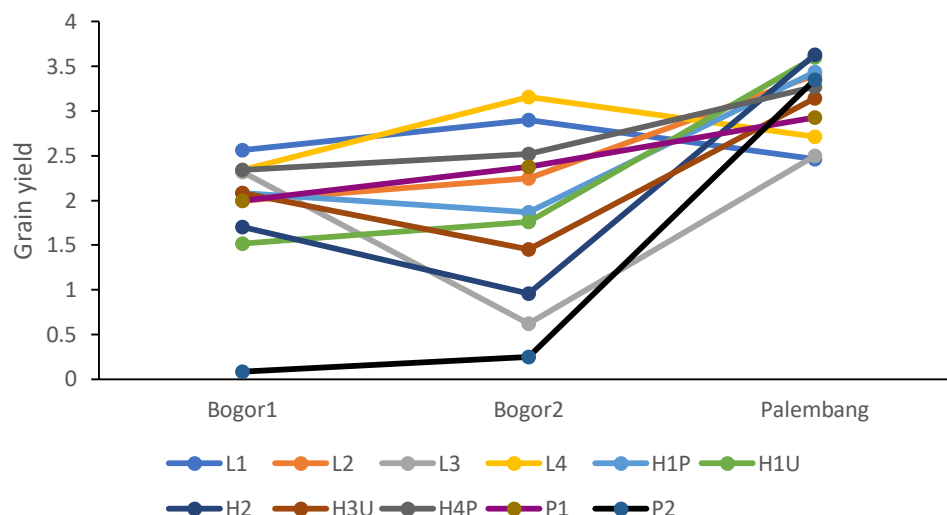
Figure 1.   Genotype x environment interaction on grain yield.

The number of seeds per pod of winged bean (Table 5) tested in three environments ranged from 10.46 to 17.37. The purple elder genotype P1 showed the highest average number of seeds per pod, with 18.86 seeds, which was significantly different from all genotypes. The environment showed no significant difference in the number of seeds per pod. The average seed weight per plant tested in the three environments ranged from 1.39 to 79.55 g. Genotype H3(U) had the highest average seed weight per plant with 58.23 g and was not significantly different from genotypes L4, L1, L2, H4(P), and P1 (purple parents). The test environment showed a significant difference, whereas the Palembang environment had the heaviest seed weight per plant, with 60.59 g.

Table 5.   Yield component of winged bean grain yields.

Lines	Number of seeds per pod	Weight of seeds per plant (g)	100 seed weight (g)	Weight of young pod (g)
L1	10.60c	47.94ab	34.05e	10.60e
L2	11.38bc	48.59ab	36.99cd	10.40e
L3	11.44bc	35.54c	36.61cd	10.94de
L4	11.08c	53.73ab	35.25de	10.81de
H1(P)	11.62bc	42.31b	38.35bc	10.81de
H1(U)	11.72bc	42.46b	40.41a	11.10de
H2	11.62bc	36.45c	35.67de	11.65cd
H3(U)	14.62b	58.23a	39.83ab	12.40bc
H4(P)	12.11bc	47.36ab	35.18de	11.62cd
P1	18.86a	53.65ab	40.14a	12.69b
P2	11.47bc	22.77d	34.08e	13.96a

Note: Numbers in the same column followed by the same letter are not significantly different based on the DMRT test at α = 0.05.

The weight of 100 seeds tested in three environments ranged from 32.80 to 46.43 g. According to Eagleton (2019), the average weight of 100 seeds of local accessions of winged beans was 48.30 g. In comparison, soybeans' weight of 100 seeds ranged from 15.29 to 16.69 g. Genotype H1(U) had an average weight of 100 in the three test environments and was not significantly different from genotype P1 (purple parents) and genotype H3U. The environment with a real effect was due to high temperature and rainfall in the Bogor 2 environment, resulting in flowering age in the Bogor 2 environment appearing later than the other two environments.

Wricke (1962)

Ecovalence was a stability parameter employed by Wricke (1962). The contribution of each genotype to the overall interaction of all genotypes with the environment is measured by ecovalence. It is, therefore, a technique for analyzing dynamic stability. According to (Mulusew et al., 2014), genotypes with low ecovalence scores exhibit less variability in yield across all settings, hence being categorized as stable genotypes. Wricke stability analysis is presented in Table 5. The most stable genotypes were H1(P), L2, and H4(P), in that order. Conversely, the least stable genotypes were L1, L4, and L3.

Shukla (1972)

Shukla's (1972) method uses stability variance (σ^2_i) as a parameter, where genotypes with small variance values indicate stable genotypes. Based on Table 5, genotypes H1(P), L2, and H4(P) were classified as stable genotypes, while genotype P2 was unstable. The same results were obtained using the Wricke method analysis. This is in line with the statement of (Goksoy et al., 2019), which states that the Shukla method is a dynamic stability concept whose results resemble the Wricke method.

Table 6.   Average grain yield, Wricke ecovalence, Shukla stability variance, and Francis and Kannenberg coefficient of variation.

Genotype	Y (tons ha^{-1})	W^2_i	σ^2_i	CV_i
L1	2.64	1.64	0.95	8.75
L2	2.55	0.06	-0.02	29.33
L3	1.81	1.36	0.78	57.36
L4	2.74	1.54	0.89	15.12
H1(U)	2.46	0.38	0.18	34.69
H1(P)	2.29	0.04	-0.03	49.77
H2	2.09	0.94	0.52	65.91
H3(U)	2.22	0.16	0.05	38.31
H4(P)	2.71	0.15	0.04	18.10
(P1)	2.44	0.29	0.13	19.21
(P2)	1.23	2.49	1.47	150.06
Mean	2.29			

Note: Y= average grain yield; W^2_i = Wricke's ecovalence; σ^2_i = stability variance; CV_i = coefficient of variability.

Francis and Kannenberg (1978)

This method uses the coefficient of diversity (CV_i) value. The coefficient of diversity (CV_i) value is determined from the standard deviation value of the average yield of a genotype based on the general average. The smaller the coefficient of diversity value, the higher the level of stability of a genotype.

The relationship between the coefficient of diversity (CV_i) and the average productivity of each genotype is presented in Figure 2. The average production results against the coefficient of diversity (CV) are divided into four groups. Group I is genotypes that have high production with low diversity. Group II is genotypes that have high yields with high diversity. Meanwhile, groups III and IV are genotypes that have low production with low and high diversity, respectively.
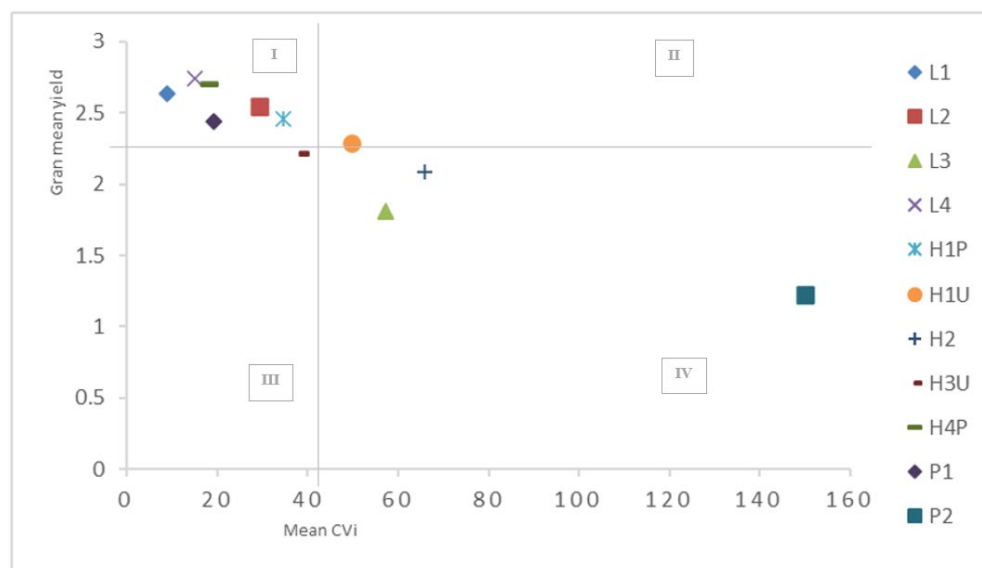
Figure 2.   Relationship between the coefficient of variance (CVi) and mean of grain yield.

Genotypes in group I are genotypes with high and stable production. According to the Francis and Kanennberg method, only group I is considered stable. So, although group III is classified as stable, it shows low results in other environments. Figure 2 shows that genotypes L1, L2, L4, H1(P), H4(P), and P1 were stable and had relatively high results compared to the average of all genotypes in the three environments. Genotypes that showed instability were L3, H2, and P2, and they had low seed yields compared to the average of all genotypes in the three environments.

CONCLUSIONS

The effect of environment, genotype, and genotype by environment interaction was significant on grain yield were highly significant ($p < 0.01$). Genotypes L4, H4(P), L1 and L2 showed higher grain yield per hectare. According to parametric methods, genotypes H1(P), L2, and H4(P) were classified as stable. Therefore, those genotypes may be deployed in those specific locations.

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REFERENCES

Adegboyega, T. T., Abberton, M. T., Abdelgadir, A. H., Dianda, M., Maziya-Dixon, B., Oyatomi, O. A., Ofodile, S., & Babalola, O. O. (2019). Nutrient and antinutrient composition of winged bean (*Psophocarpus tetragonolobus* (L.) DC.) seeds and tubers. *Journal of Food Quality*, *2019*(1), 3075208. https://doi.org/10.1155/2019/3075208

Akinyosoye, S. T., Agbeleye, O. A., Adetumbi, J. A., Ukachukwu, P. C., & Amusa, O. D. (2023). Genotype – genotype × environment (GGE) biplot analysis of winged bean for grain yield. *Acta Horticulturae et Regiotecturae*, *26*(1), 53–63. https://doi.org/10.2478/ahr-2023-0009

Alalade, J. A., Akinlade, J. A., Aderinola, O. A., Fajemisin, A. N., Muraina, T. O., & Amoo, T. A. (2016). Proximate, Mineral and Anti-nutrient Contents in *Psophocarpus tetragonolobus* (L) DC. (Winged Bean) Leaves. *British Journal of Pharmaceutical Research*, *10*(2), 1–7. https://doi.org/10.9734/bjpr/2016/22087

Chay, S. Y., Salleh, A., Sulaiman, N. F., Abidin, N. Z., Hanafi, M. A., Zarei, M., & Saari, N. (2018). Blood-pressure lowering efficacy of winged bean seed hydrolysate in spontaneously hypertensive rats, peptide characterization and a toxicity study in Sprague-Dawley rats. *Food and Function*, *9*(3), 1657–1671. https://doi.org/10.1039/c7fo01769c

Chimonyo, V. G. P., Snapp, S. S., & Chikowo, R. (2019). Grain legumes increase yield stability in maize-based cropping systems. *Crop Science*, *59*(3), 1222–1235. https://doi.org/10.2135/cropsci2018.09.0532

Eagleton, G. E. (2019). Prospects for developing an early maturing variety of winged bean (*Psophocarpus tetragonolobus*) in Bogor, Indonesia. *Biodiversitas*, *20*(11), 3142–3152. https://doi.org/10.13057/biodiv/d201106

Eagleton, G. E. (2020). Review: Winged bean (*Psophocarpus tetragonolobus*) cropping systems. *Biodiversitas*, *21*(12), 5927–5946. https://doi.org/10.13057/biodiv/d211258

Francis, T. R., & Kannenberg, L. W. (1978). Yield stability studies in short-season maize. I. A descriptive method for grouping genotypes. *Canadian Journal of Plant Science*, *58*, 1029–1034. https://doi.org/10.4141/cjps78-157

Goksoy, A. T., Sincik, M., Erdogmus, M., Ergin, M., Aytac, S., Gumuscu, G., Gunduz, O., Keles, R., Bayram, G., & Senyigit, E. (2019). The parametric and non-parametric stability analyses for interpreting genotype by environment interaction of some soybean genotypes. *Turkish Journal of Field Crops*, *24*(1), 28–38. https://doi.org/10.17557/tjfc.562637

Ishthifaiyyah, S. A., Syukur, M., Trikoesoemaningtyas, T., Maharijaya, A., & Marwiyah, S. (2023). Yield-related traits and proximate content of winged bean for seed production purpose. *Biodiversitas*, *24*(6), 3609–3615. https://doi.org/10.13057/biodiv/d240661

Khalili, M., & Pour-Aboughadareh, A. (2016). Parametric and non-parametric measures for evaluating yield stability and adaptability in barley doubled haploid lines. *Journal of Agricultural Science and Technology, 18,* 789-803.

Koley, T. K., Maurya, A., Tripathi, A., Singh, B. K., Singh, M., Bhutia, T. L., Tripathi, P. C., & Singh, B. (2019). Antioxidant potential of commonly consumed underutilized leguminous vegetables. *International Journal of Vegetable Science*, *25*(4), 362–372. https://doi.org/10.1080/19315260.2018.1519866

Kuswanto, K., Yulianah, I., Saptadi, D., & Andayani R. D. (2024). Determining the ideal type of superior variety as a target for breeding of winged bean. *Agrivita: Journal of Agricultural Science*, *46*(2), 330–338. https://doi.org/10.17503/agrivita.v46i2.4433

Lepcha, P., Egan, A. N., Doyle, J. J., & Sathyanarayana, N. (2017). A review on current status and future prospects of winged bean (*Psophocarpus tetragonolobus*) in tropical agriculture. *Plant Foods for Human Nutrition 72,* 225-235. https://doi.org/10.1007/s11130-017-0627-0

Lodhi, R. D., Prasad, L. C., Bornare, S. S., Madakemohekar, A. H., & Prasad, R. (2015). Stability analysis of yield and its component traits of barley (*Hordeum vulgare* L.) genotype in multi-environment trials in the north eastern plains of India. *SABRAO Journal of Breeding and Genetics, 47*(2), 143-159.

Mafouasson, H. N. A., Gracen, V., Yeboah, M. A., Ntsomboh-Ntsefong, G., Tandzi, L. N., & Mutengwa, C. S. (2018). Genotype-by-environment interaction and yield stability of maize single cross hybrids developed from tropical inbred lines. *Agronomy*, *8*(5), 62. https://doi.org/10.3390/agronomy8050062

Mebratu, A., Wegary, D., Mohammed, W., Teklewold, A., & Tarekegne, A. (2019). Genotype × environment interaction of quality protein maize hybrids under contrasting management conditions in eastern and Southern Africa. *Crop Science*, *59*(4), 1576–1589. https://doi.org/10.2135/cropsci2018.12.0722

Mohanty, C. S., Pradhan, R. C., Singh, V., Singh, N., Pattanayak, R., Prakash, O., Chanotiya, C. S., & Rout, P. K. (2015). Physicochemical analysis of *Psophocarpus tetragonolobus* (L.) DC seeds with fatty acids and total lipids compositions. *Journal of Food Science and Technology*, *52*, 3660–3670. https://doi.org/10.1007/s13197-014-1436-1

Mohanty, C. S., Singh, V., & Chapman, M. A. (2020). Winged bean: an underutilized tropical legume on the path of improvement to help mitigate food and nutrition security. *Scientia Horticulturae, 260*, 108789. https://doi.org/10.1016/j.scienta.2019.108789

Mulusew, F., Bing, D. J., Tadele, T., & Amsalu, A. (2014). Comparison of biometrical methods to describe yield stability in field pea (*Pisum sativum* L.) under southeastern Ethiopian conditions. *African Journal of Agricultural Research*, *9*(33), 2574–2583. https://doi.org/10.5897/ajar09.602

Ng, Z. X., Samsuri S. N., & Yong, P. H. (2020). The antioxidant index and chemometric analysis of tannin, flavonoid, and total phenolic extracted from medicinal plant foods with solvents of different polarities. *Journal of Food Processing and Preservation*, *44*(9), e14680. https://doi.org/10.1111/jfpp.14680

Ng, Z. X., Yong, P. H., & Lim, S. Y. (2020). Customized drying treatments increased the extraction of phytochemicals and antioxidant activity from economically viable medicinal plants. *Industrial Crops and Products*, *155,* 112815. https://doi.org/10.1016/j.indcrop.2020.112815

Popoola, J., Ojuederie, O., Omonhinmin, C., & Adegbite, A. (2019). Neglected and underutilized legume crops: improvement and future prospects. In F. Shah et al. (Eds.). *Recent Advances in Grain Crops Research* (pp. 120-141). IntechOpen. https://doi.org/10.5772/intechopen.87069

Shukla, G. K. (1972). Some Statistical Aspect of Partitioning Genotype-Environmental Components of Variability. *Heredity*, *29*, 237–245. https://doi.org/10.1038/hdy.1972.87

Singh, M., Dubey, R. K., Koley, T. K., Maurya, A., Singh, P. M., & Singh, B. (2019). Valorization of winged bean (*Psophocarpus tetragonolobus* (L) DC) by evaluation of its antioxidant activity through chemometric analysis. *South African Journal of Botany*, *121*, 114–120. https://doi.org/10.1016/j.sajb.2018.10.026

Sriwichai, S., Monkham, T., Sanitchon, J., Jogloy, S., & Chankaew, S. (2021). Dual-purpose of the winged bean (*Psophocarpus tetragonolobus* (L.) DC.), the neglected tropical legume, based on pod and tuber yields. *Plants*, *10*(8), 1746. https://doi.org/10.3390/plants10081746

Tanzi, A. S., Eagleton, G. E., Ho, W. K., Wong, Q. N., Mayes, S., & Massawe, F. (2019). Winged bean (*Psophocarpus tetragonolobus* (L.) DC.) for food and nutritional security: synthesis of past research and future direction. *Planta, 250,* 911–931. https://doi.org/10.1007/s00425-019-03141-2

Tiwari, J. K., Kanwar, R. R., Yadav, R. K., & Singh, A. K. (2022). Yield stability analysis in an underutilized legume 'winged bean' (*Psophocarpus tetragonolobus* L.). *Legume Research*, *45*(2), 209–214. https://doi.org/10.18805/LR-4333

Wricke, G. (1962). Evaluation method for recording ecological differences in field trials. *Z Pflanzenzücht, 47,* 92-96.

Zakuan, Z., Mustapa, S. A., Sukor, R., & Rukayadi, Y. (2018). Antifungal activity of *Boesenbergia rotunda* (temukunci) extracts against filamentous spoilage fungi from vegetables. *International Food Research Journal 25*(1), 433-438.