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# Yield-related traits and proximate content of winged bean for seed production purpose

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**Abstract.** *Ishthifaiyyah SA, Syukur M, Trikoesoemaningtyas, Maharijaya A, Marwiyah S. 2023. Yield-related traits and proximate content of winged bean for seed production purpose. Biodiversitas 24: 3609-3615.* The winged bean is an underutilized plant that can produce valuable seeds with great nutrient content. Meanwhile, the lack of improved genotypes limits its large-scale cultivation. This study aimed to evaluate the flowering and maturity time of winged bean lines and elaborate on various traits correlated with the seed yield. We also performed the seeds' proximate analysis to unravel each line's nutrient content. This study was conducted in Bogor, Indonesia, between April and October 2020. Hybridization between two distinct parents had successfully developed early flowering winged bean genotypes in its progeny. The H4P and L3 had the highest seed yield (1.40 t $ha^{-1}$) with brown and purple seed colors, respectively. The dried pod weight (0.56), young pod weight (0.36), and the number of dried pods (0.39) had a positive direct effect yet were still smaller than their correlation coefficient. Thus, the selection process to obtain high-yielding winged bean genotypes can be conducted simultaneously through those traits. The evaluated winged bean genotypes had various fat and protein content ranging from 11.10% to 16.48% and 28.81% to 33.45%, respectively. This information can be used as future selection criteria for the winged bean breeding program.

**Keywords:** Early flowering, indirect selection, path analysis, plant-based protein source, seed yield

## INTRODUCTION

The winged bean (*Psophocarpus tetragonolobus* L.) is a diploid (2n = 2x = 18) species that belongs to the Fabaceae family and Papilionoideae subfamily. It is a self-pollinated plant that can live both as an annual and perennial (Hymowitz and Boyd 1977). It is widely distributed in hot and humid tropical regions, including South East Asia and some African countries. The winged bean is commonly known as a horticultural plant grown in the yard to consume its flowers, leaves, and young pods as vegetables. This twining legume has ovate to deltoid-shaped trifoliate leaves with various colors of flowers ranging from white, blue, and red to purple (Yulianah et al. 2020). The part differentiating winged beans from other legume species is the longitudinal pods with four corners bearing a wing.

Some winged bean accessions have produced edible tuberous roots with high protein content and significant fiber, energy, and minerals (Sriwichai et al. 2021). Another valuable part of the plant is the seed, which is still underexploited. It is expected to be a "possible soybean for the tropics" since both have similar seed morphology and equivalent nutritional value (Rif'atunidaudina 2018). Winged bean seeds contain 33% protein, 39% carbohydrate, and 19% fat, with various vitamins and adequate minerals recommended for the human diet (Amoo et al. 2006; Lepcha et al. 2017; Adegboyega et al. 2019). Compared to soybean, winged bean seeds have incredible essential amino acids such as valine, leucine, histidine, and lysine (Mohanty et al. 2020). Winged bean oil is also more suitable for frying food due to its high thermal conductivity, oxidative strength, and solid fat content (Makeri et al. 2016). Its abundant bioactive compounds with therapeutic activities make the winged bean a promising plant for medicinal purposes as well (Bassal et al. 2020). As a cereal complement, winged bean is one of the best possible solutions for protein-calorie malnutrition, especially in developing countries.

Indonesia is known to be one of the centers of diversity of winged beans. There are several local names for winged bean such as *cipir* (Javanese), *jaat* (Sundanese), and *kelongkang* (Balinese). Nevertheless, the lack of improved genotypes limits its large-scale cultivation, making this crop underutilized. The government has released no winged bean varieties, especially for seed production. Late flowering and maturity times have become barriers in winged bean development and caused little interest among farmers to plant this commodity. Local winged beans start flowering 122 days after planting (DAP) and producing mature seeds in 190 DAP (Eagleton 2019), later than soybean that can produce mature seeds in 73-84 DAP (Adie and Krisnawati 2018). Genetic improvement could expand winged bean production from a purely horticultural crop to a crop grown for its seed protein. It could also help reduce many countries' dependence on soybean imports and the environmental impacts of expanded soybean production.

Yield is one of the most critical traits that always becomes the main target in plant breeding programs. Direct selection to obtain high-yielding genotypes is challenging because the trait is complex and controlled by several minor genes. If the heritability is low, direct selection to yield character will be ineffective (Acquaah 2007). Therefore, secondary traits related to seed yield need to be explored to be used as selection criteria in plant breeding programs. In this case, correlation and path analysis must be studied to elaborate on secondary traits related to seed yield. Here we evaluated the flowering and maturity time of winged bean pure lines generated from hybridization between early- and late-flowering genotypes. Path analysis was conducted to elaborate on various traits correlated with the seed yield. We also performed the seeds' proximate analysis to unravel each line's nutrient content.

## MATERIALS AND METHODS

### Study area and plant materials

The study was conducted at IPB University, Bogor, Indonesia, between April and October 2020. Twenty genotypes of winged beans were planted in Leuwikopo teaching farm at an altitude of 250 m, latitude -6.563800S, and longitude 106.726083E. Those genotypes consisted of 15 F8 generations which were generated from a bi-parental cross between purple and green-winged bean, two parents, and three controls (Table 1). The female parent was a purple-seeded genotype introduced from Thailand with early flowering time, long pod, big seed size, and high protein content. Also, the male parent was a brown-seeded local winged bean from Cilacap, Central Java, Indonesia. It has a late-flowering time, a short pod with small seed size and low protein content. The F1 plants were allowed to self-pollinate to produce an F2 population. The pedigree selection was conducted from F2 until the F8 population based on phenotypic performance and yield components. Proximate content was analyzed by technical staff in the university center laboratory, IPB University.

### Procedure

The experiment was arranged as described by Ishthifaiyyah et al. (2021). Twenty-winged bean genotypes were evaluated in a Randomized Complete Block Design with three replications. The winged beans were planted in a 4 $m^2$ ridge with a 40 cm x 50 cm plant spacing. The seeds were harvested when they were completely dried under field drying conditions. Several qualitative and quantitative traits were recorded, including (i) seed color, (ii) seed shape, (iii) seed surface, (iv) days to flowering, (v) days to first maturity, (vi) stem diameter, (vii) number of young pods, (viii) number of dried pods, (ix) young pods weight, (x) dried pod weight, (xi) number of seeds per pod, (xii) 100-seed weight, (xiii) seed weight, (xiv) seed yield. Seed yield was calculated as below.

$$\text{Seed yield (ton ha}^{-1}) = \frac{10{,}000\ m^2}{\text{plot length (m)}} x \frac{\text{plot width (m)}}{\text{plot width+plot spacing (m)}} x \frac{\text{seed weight per plot (g m}^{-2})}{1{,}000{,}000}$$

Proximate analysis was also carried out using the standard method (AOAC 2005) to measure moisture content, ash, fat, protein, and fiber percentage in winged bean seeds. The sample used for this analysis was 100 g seeds.

**Table 1.** Winged bean genotypes were used for this study

| Genotypes code | Origin |
|---|---|
| L1 | Selected (F8) |
| L2 | Selected (F8) |
| L3 | Selected (F8) |
| L4 | Selected (F8) |
| H1U | Selected (F8) |
| H1P-19(3) | Selected (F8) |
| H1P-20(3) | Selected (F8) |
| H2 | Selected (F8) |
| H3U | Selected (F8) |
| H4P | Selected (F8) |
| L1-2 | Selected (F8) |
| L2-2 | Selected (F8) |
| HIP-2 | Selected (F8) |
| HIU-2 | Selected (F8) |
| H4P-2 | Selected (F8) |
| P1 | Female parent (introduced purple winged bean from Thailand) |
| P2 | Male parent (local green winged bean from Cilacap, Indonesia) |
| KH1 | Local green winged bean |
| KH2 | Local green winged bean |
| KH3 | Local green winged bean |

### Data analysis

The quantitative data were analyzed using an F test performed using SAS 9.0 software, followed by Duncan Multiple Range Test (DMRT). Pearson correlation and path analysis was performed using R Studio 4.1.0.

## RESULTS AND DISCUSSION

The variability of winged bean seeds is shown in Figure 1. All winged bean genotypes had oval seeds with smooth surfaces. This study showed that hybridization between purple and brown seed winged beans generated a diverse seed color in their progeny. Some genotypes showed similar seed color to female parent (P1), such as L3, L4, H1U, H1P-20(3), H3U, H1P-2, and H4P-2, while L1 and L2 had darker colors than that of P1. In the other hand, H1P-19(3), H2, H4P, L1-2, L2-2, and H1U-2 had light to dark brown color, similar to P2. Winged bean genotypes with purple seeds mostly had purple coloration in other parts of the plant, such as the stem, calyx, corolla, pod, and wings. However, the phenomenon was not found in H1U and KH2. Although both genotypes had purple seeds, there is no purple coloration in other parts of the plant. Chankaew et al. (2022) reported that winged bean seed color was correlated with pod (0.547) and calyx color (0.595). Pod color was also significantly correlated with flower color. The significant correlation between flower, pod, and seed color indicated that those characters were controlled by the same or closely linked gene(s). Purple coloration in those organs showed a high anthocyanin content (Calvindi et al. 2020).

Analysis of variance showed that all recorded quantitative traits differed significantly among genotypes except days to flowering and days to first maturity, with a coefficient of variation between 5.06%-24.20% (Table 2). In this study, the days to flowering (DF) of 20 winged bean genotypes range from 58.67-67.33 DAP. Although there was no significant difference between days to flowering among genotypes, the female parent of the crossing (P1) had the lowest mean of DF (58.67 DAP). Initially, P2 was a late flowering genotype when it was used as the male parent of the crossing. Rakhmad (2021) reported that days to flowering of P2 in three different locations ranged between 93.00-197.00 DAP. However, in this study, P2 had an earlier flowering time with a mean value of 62.67 DAP. P2 was a landrace population that had not been purified. Syukur et al. (2015) explained that the landrace population for self-pollinating plants is genetically homozygote in a single plant and heterogeneous among the plant in the population. The P2 genotype in this study was likely to have been accidentally selected from the original population and thus had an earlier flowering time. Nevertheless, this study showed that hybridization between two distinct parents had successfully developed early flowering winged bean genotypes in their progeny.

**Table 2.** Analysis of variance of several quantitative traits in winged bean

| Traits | CV (%) | MS | Range | Mean |
|---|---|---|---|---|
| Stem diameter (mm) | 7.66 | 0.17$^{*}$ | 3.07-3.95 | 3.60 |
| Days to flowering (DAP) | 5.06 | 10.73$^{ns}$ | 58.67-67.33 | 62.67 |
| Days to first maturity (DAP) | 15.47 | 410.84$^{ns}$ | 97.33-137.50 | 143.03 |
| Number of young pods (pods per plot) | 21.87 | 15.77$^{**}$ | 16.00-160.00 | 80.55 |
| Number of dried pods (pods per plot) | 22.32 | 17.70$^{**}$ | 5.00-146.33 | 61.48 |
| Young pod weight (g per plot) | 23.45 | 222.98$^{**}$ | 172.40-2192.10 | 1047.78 |
| Dried pod weight (g per plot) | 23.69 | 129.34$^{**}$ | 35.20-890.00 | 416.66 |
| Number of seeds (seeds per pod) | 9.26 | 5.34$^{**}$ | 9.19-13.67 | 11.48 |
| 100-seed weight (g) | 7.89 | 25.27$^{**}$ | 28.22-40.51 | 33.72 |
| Seed weight (g per plot) | 24.20 | 65.27$^{**}$ | 14.24-421.20 | 201.46 |
| Seed yield (t ha$^{-1}$) | 8.51 | 0.07$^{**}$ | 0.05-1.40 | 0.67 |

Note: CV: coefficient of variance, MS: mean of the square, DAP: days after planting, $^{*}$: significant α = 0.05, $^{**}$: significant α = 0.01, $^{ns}$: not significant

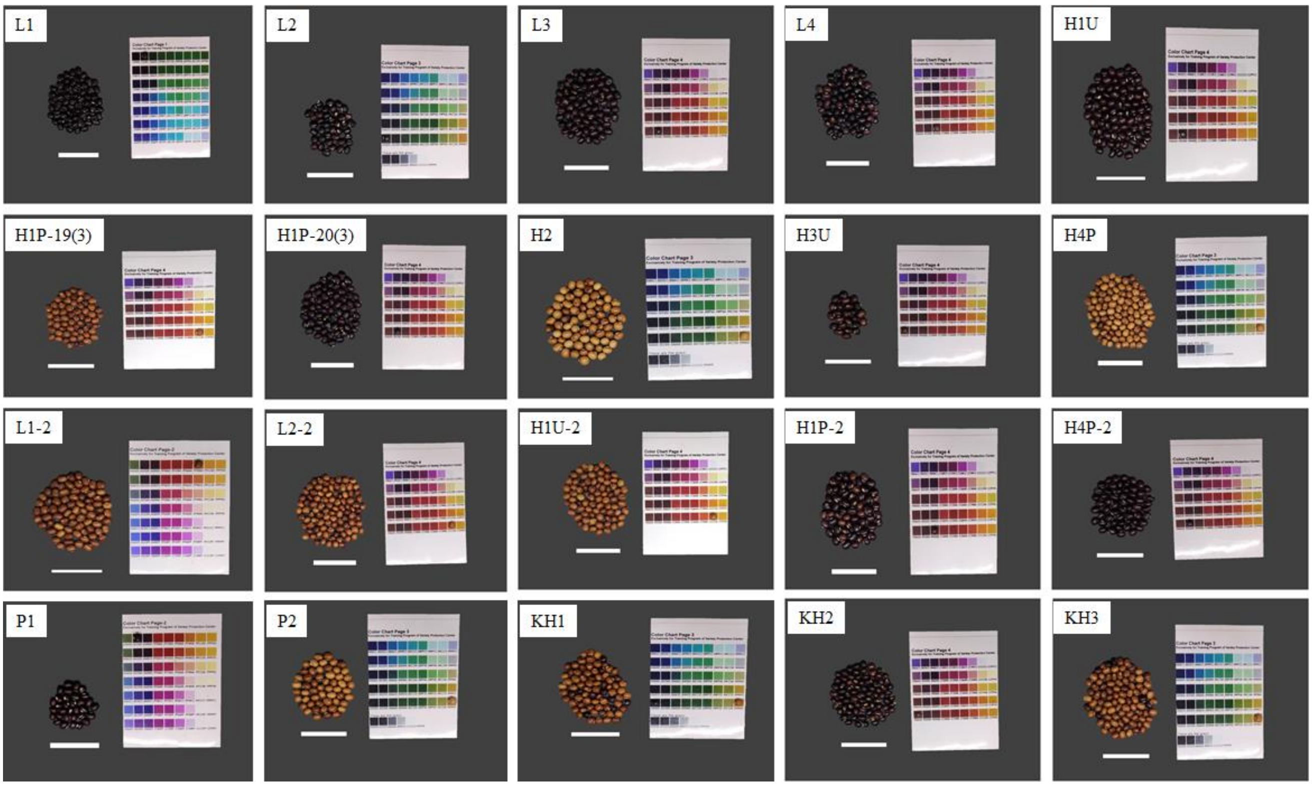


**Figure 1.** Variability of winged bean seed's color

Winged bean seeds were first harvested between 97.33-137.50 DAP with a mean of 143.03 DAP. Although there was no significant difference between days to maturity (DM) among genotypes, some showed earlier maturity time than others. Those genotypes were H4P, L1, and H1P-20(3) with DM before 100 DAP. Maturity time in this study is known to be correlated significantly with flowering time (r = 0.59). Tanzi et al. (2019) also reported that days to flowering in winged beans positively correlated with days to maturity. In contrast, it was negatively correlated with stem length and number of branches per plant. Compared to soybean, winged bean seed had longer days to maturity. Soybean lines in Indonesia could be harvested between 73-84 DAP (Adie and Krisnawati 2018). Liu et al. (2017) evaluated more soybean genotypes from around the world, and the result showed that its maturity time ranged between 75-201 DAP with an average of 124.20 DAP. This maturity time would be longer if soybean were planted in the highland because of its low temperature.

The winged bean genotypes had the number of dried pods per plot ranging between 5.00-146.33 with an average of 61.48 pods, while the dried pod weight was about 35.20-890.00 g with a mean of 416.66 g. H4P had the highest mean on both traits, although it did not differ significantly from L3 and H2. Those genotypes had a higher mean value than the parents and controls. Pearson's correlation showed a significant correlation between the number of pods and pod weight, which means the increase in the number of pods would increase the dried pod weight per plot.

The winged bean pod contained approximately 9.19-13.67 seeds. A hundred seeds weighed between 28.22-40.51 g, averaging 33.72 g. Rakhmad (2021) elucidated that 100 winged bean seeds could weigh up to 48.30 g, which was more significant than soybean with 100 seeds weighing 15.29-16.69 g (Eagleton 2019). It showed that winged beans had a bigger seed size than soybean. A larger seed size is preferable for the tempeh industry because it will produce a larger volume of tempeh (Krisnawati and Adie 2015).

Winged bean genotypes in this study produced approximately 14.24-421.20 g seeds per plot. H4P and L3 had the highest mean seed weight. It was higher than controls but did not differ significantly from other genotypes, including P2 as the male parent. From Table 3, H2 had a lower seed weight than H4P and L3, although it had a higher mean on some yield-related traits, such as the number of seeds per pod and 100 seed weight. It was because H2 had fewer pods per plot than H4P and L3. Parallel to seed weight, H4P and L3 also had the highest seed productivity (1.40 t $ha^{-1}$), higher than controls but did not differ significantly from P2. According to Rakhmad (2021), seed productivity was directly affected by seed weight per plot, with a coefficient of 0.81. It supported this result where H4P and L3 with the highest seed weight also had the highest seed yield. Nevertheless, the seed yield in this study was lower than that of Rakhmad (2021), which could reach 3.36 t $ha^{-1}$. This gap might happen due to the differences in growing conditions since the environment influences yield.

**Table 3.** Mean value of quantitative traits in winged bean genotypes

| Genotypes | SD (mm) | DF (DAP) | DM (DAP) | NYP (pod) | NDP (pod) | YPW (g) | DPW (g) | NS (seed) | W100 (g) | SW (g) | YS (t $ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L1 | 3.40$^{a-d}$ | 61.33$^{a-d}$ | 98.33$^{b}$ | 16.00$^{f}$ | 33.00$^{e-g}$ | 172.40$^{e}$ | 203.40$^{e-g}$ | 9.93$^{d-f}$ | 30.20$^{e-g}$ | 88.14$^{e-h}$ | 0.29$^{e-h}$ |
| L2 | 3.74$^{a-c}$ | 61.33$^{a-d}$ | 105.00$^{ab}$ | 108.67$^{a-d}$ | 30.33$^{e-g}$ | 1569.60$^{a-c}$ | 229.80$^{e-g}$ | 11.70$^{a-e}$ | 32.54$^{b-g}$ | 109.62$^{d-h}$ | 0.37$^{d-h}$ |
| L3 | 3.94$^{a}$ | 63.33$^{a-d}$ | 117.33$^{ab}$ | 90.67$^{b-d}$ | 119.00$^{ab}$ | 1253.40$^{a-c}$ | 886.50$^{a}$ | 12.73$^{a-c}$ | 33.94$^{b-f}$ | 421.20$^{a}$ | 1.40$^{a}$ |
| L4 | 3.44$^{a-d}$ | 63.67$^{a-d}$ | 109.67$^{ab}$ | 55.00$^{c-f}$ | 28.00$^{e-g}$ | 777.50$^{c-e}$ | 198.80$^{e-g}$ | 11.43$^{b-e}$ | 35.65$^{a-d}$ | 91.25$^{e-h}$ | 0.30$^{e-h}$ |
| H1P-19(3) | 3.64$^{a-c}$ | 60.00$^{cd}$ | 127.00$^{ab}$ | 89.00$^{bcd}$ | 26.50$^{e-g}$ | 1219.40$^{b-d}$ | 160.30$^{fg}$ | 9.60$^{ef}$ | 30.48$^{d-g}$ | 57.56$^{f-h}$ | 0.19$^{f-h}$ |
| H1P-20(3) | 3.91$^{a}$ | 61.33$^{a-d}$ | 99.33$^{b}$ | 42.00$^{def}$ | 63.67$^{c-f}$ | 633.00$^{c-e}$ | 447.30$^{c-f}$ | 10.00$^{d-f}$ | 37.79$^{ab}$ | 194.55$^{c-g}$ | 0.65$^{c-g}$ |
| H1U | 3.72$^{a-c}$ | 60.67$^{b-d}$ | 104.00$^{ab}$ | 51.67$^{c-f}$ | 67.00$^{c-e}$ | 693.40$^{c-e}$ | 482.00$^{b-f}$ | 11.63$^{a-e}$ | 32.58$^{b-g}$ | 234.11$^{b-e}$ | 0.78$^{b-e}$ |
| H2 | 3.60$^{a-d}$ | 60.67$^{b-d}$ | 120.00$^{ab}$ | 160.00$^{a}$ | 113.33$^{a-c}$ | 2007.50$^{ab}$ | 794.40$^{ab}$ | 13.23$^{ab}$ | 36.06$^{a-c}$ | 398.41$^{ab}$ | 1.33$^{ab}$ |
| H3U | 3.20$^{cd}$ | 67.00$^{ab}$ | 130.33$^{ab}$ | 20.33$^{ef}$ | 5.00$^{g}$ | 315.40$^{de}$ | 35.20$^{g}$ | 9.19$^{f}$ | 36.33$^{a-c}$ | 14.24$^{h}$ | 0.05$^{h}$ |
| H4P | 3.53$^{a-d}$ | 62.00$^{a-d}$ | 97.33$^{b}$ | 105.00$^{a-d}$ | 146.33$^{a}$ | 1362.00$^{a-c}$ | 890.00$^{a}$ | 12.53$^{a-c}$ | 30.49$^{d-g}$ | 420.29$^{a}$ | 1.40$^{a}$ |
| L1-2 | 3.60$^{a-d}$ | 62.33$^{a-d}$ | 111.67$^{ab}$ | 102.67$^{a-d}$ | 80.00$^{b-e}$ | 1337.10$^{a-c}$ | 549.40$^{a-e}$ | 10.90$^{c-f}$ | 33.37$^{b-g}$ | 276.22$^{a-d}$ | 0.92$^{a-d}$ |
| L2-2 | 3.95$^{a}$ | 62.00$^{a-d}$ | 107.67$^{ab}$ | 96.67$^{a-d}$ | 63.00$^{c-f}$ | 1216.80$^{b-d}$ | 409.50$^{c-f}$ | 11.87$^{a-d}$ | 29.78$^{fg}$ | 188.91$^{c-g}$ | 0.63$^{c-g}$ |
| H1P-2 | 3.51$^{a-d}$ | 65.33$^{a-c}$ | 122.00$^{ab}$ | 72.33$^{c-f}$ | 37.00$^{d-g}$ | 932.00$^{c-e}$ | 305.70$^{c-g}$ | 11.37$^{b-e}$ | 40.51$^{a}$ | 139.61$^{c-h}$ | 0.47$^{c-h}$ |
| H1U-2 | 3.81$^{ab}$ | 61.00$^{a-d}$ | 111.67$^{ab}$ | 85.67$^{c-e}$ | 46.00$^{d-g}$ | 1179.80$^{b-d}$ | 393.00$^{c-g}$ | 12.40$^{a-c}$ | 33.82$^{b-f}$ | 193.71$^{c-g}$ | 0.65$^{c-g}$ |
| H4P-2 | 3.67$^{a-c}$ | 61.67$^{a-d}$ | 105.00$^{ab}$ | 86.33$^{c-e}$ | 89.33$^{b-d}$ | 1068.60$^{c-e}$ | 594.50$^{a-d}$ | 11.50$^{b-e}$ | 35.48$^{a-e}$ | 263.60$^{a-e}$ | 0.88$^{a-e}$ |
| P1 | 3.07$^{d}$ | 58.67$^{d}$ | 137.50$^{a}$ | 16.00$^{f}$ | 11.00$^{fg}$ | 193.50$^{e}$ | 48.80$^{g}$ | 12.87$^{a-c}$ | 28.21$^{g}$ | 20.86$^{gh}$ | 0.07$^{gh}$ |
| P2 | 3.85$^{a}$ | 62.67$^{a-d}$ | 136.67$^{a}$ | 154.67$^{ab}$ | 78.33$^{b-e}$ | 2192.10$^{a}$ | 611.60$^{a-c}$ | 13.17$^{ab}$ | 35.71$^{a-d}$ | 311.18$^{a-c}$ | 1.04$^{a-c}$ |
| KH1 | 3.30$^{b-d}$ | 67.33$^{a}$ | 128.33$^{ab}$ | 112.67$^{a-c}$ | 37.67$^{d-g}$ | 1384.80$^{a-c}$ | 245.70$^{d-g}$ | 13.67$^{a}$ | 32.59$^{b-g}$ | 140.46$^{c-h}$ | 0.47$^{c-h}$ |
| KH2 | 3.45$^{a-d}$ | 61.00$^{a-d}$ | 110.67$^{ab}$ | 69.67$^{c-f}$ | 79.67$^{b-e}$ | 671.80$^{c-e}$ | 388.50$^{c-g}$ | 9.83$^{d-f}$ | 31.56$^{c-g}$ | 215.44$^{c-f}$ | 0.72$^{c-f}$ |
| KH3 | 3.75$^{a-c}$ | 62.67$^{a-d}$ | 113.33$^{ab}$ | 76.00$^{c-f}$ | 47.00$^{d-g}$ | 775.40$^{c-e}$ | 250.90$^{d-g}$ | 9.87$^{d-f}$ | 34.44$^{c-f}$ | 141.76$^{c-h}$ | 0.47$^{c-h}$ |

Note: SD: stem diameter, DF: days to flowering, DM: days to first maturity, NYP: number of young pods, NDP: number of dry pods, YPW: young pod weight, DPW: dry pod weight, NS: number of seeds, W100: 100-seed weight, SW: seed weight, YS: seed yield, DAP: days after planting. Values in each column followed by the same letters do not differ significantly ($P<0.05$)

**Table 4.** Percentage of seed proximate content in winged bean genotypes

| Genotypes | Moisture content | Ash | Fat | Protein | Fiber |
|---|---|---|---|---|---|
| | (%) | | | | |
| 1 | $10.70^{fg}$ | $4.68^{b-d}$ | $14.16^{e}$ | $33.45^{a}$ | $7.38^{c-f}$ |
| L2 | $11.14^{de}$ | $4.82^{a-d}$ | $12.59^{hi}$ | $33.01^{ab}$ | $6.86^{ef}$ |
| L3 | $11.39^{cd}$ | $4.88^{a-d}$ | $13.19^{g}$ | $30.69^{f}$ | $7.04^{d-f}$ |
| L4 | $11.04^{e}$ | $4.91^{a-d}$ | $14.41^{e}$ | $31.50^{e}$ | $8.60^{ab}$ |
| H1P-19(3) | $10.95^{e-g}$ | $4.54^{d}$ | $11.78^{k}$ | $33.21^{ab}$ | $8.30^{a-c}$ |
| H1P-20(3) | $11.04^{e}$ | $3.96^{e}$ | $13.51^{fg}$ | $29.83^{gh}$ | $7.53^{b-f}$ |
| H1U | $11.05^{e}$ | $4.47^{d}$ | $15.17^{d}$ | $30.54^{f}$ | $6.68^{f}$ |
| H2 | $10.65^{g}$ | $4.77^{a-d}$ | $14.00^{ef}$ | $29.47^{hi}$ | $6.66^{f}$ |
| H3U | $10.7^{fg}$ | $4.63^{cd}$ | $15.04^{d}$ | $31.20^{e}$ | $7.80^{a-e}$ |
| H4P | $11.09^{de}$ | $4.78^{a-d}$ | $13.03^{gh}$ | $32.06^{d}$ | $8.18^{a-c}$ |
| L1-2 | $11.00^{ef}$ | $4.71^{a-d}$ | $12.47^{ij}$ | $31.50^{e}$ | $8.11^{a-d}$ |
| L2-2 | $11.11^{de}$ | $4.74^{a-d}$ | $15.44^{cd}$ | $27.61^{k}$ | $8.55^{ab}$ |
| H1P-2 | $10.84^{e-g}$ | $4.55^{d}$ | $16.48^{a}$ | $31.25^{e}$ | $8.60^{ab}$ |
| H1U-2 | $11.46^{c}$ | $4.75^{a-d}$ | $15.36^{cd}$ | $32.87^{bc}$ | $8.63^{ab}$ |
| H4P-2 | $10.89^{e-g}$ | $5.15^{a}$ | $16.15^{ab}$ | $29.02^{ij}$ | $8.53^{ab}$ |
| P1 | $10.95^{e-g}$ | $4.8^{a-d}$ | $15.87^{bc}$ | $32.46^{cd}$ | $7.30^{c-f}$ |
| P2 | $11.44^{c}$ | $4.75^{a-d}$ | $13.92^{ef}$ | $29.22^{ij}$ | $7.85^{a-e}$ |
| KH1 | $11.94^{b}$ | $5.02^{a-c}$ | $11.94^{jk}$ | $30.29^{fg}$ | $8.80^{a}$ |
| KH2 | $11.54^{c}$ | $4.58^{cd}$ | $11.10^{l}$ | $28.81^{j}$ | $8.72^{a}$ |
| KH3 | $12.22^{a}$ | $5.09^{ab}$ | $12.32^{i-k}$ | $31.37^{e}$ | $8.34^{a-c}$ |

Note: Values in each column followed by the same letters do not differ significantly (P<0.05)

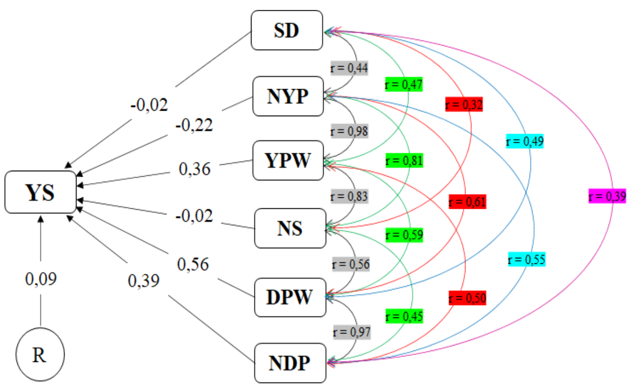


**Figure 2**. Diagram of the direct and indirect effect for seed yield. Note: YS: seed yield, SD: stem diameter, NYP: number of young pods, YPW: young pods weight, NS: number of seeds per pod, DPW: dried pod weight, NDP: number of dried pods

Yield has become one of the main targets in plant breeding programs. This trait represents many factors and the results of their interaction. Since this trait is controlled by a complex mechanism, secondary traits related to seed yield should be used in breeding to improve selection effectiveness. The relationship between two or more quantitative variables can be learned through correlation analysis. Pearson correlation is one of the most popular methods for studying the relationship between variables with interval or ratio measurement scales. A linear relation between the two variables is represented by the correlation coefficient (*r*) between -1 and 1 (Wright 1921). However, correlation analysis cannot explain how much a secondary trait affects the main trait. Path analysis is performed to elucidate the relationship between these causal and effect factors by partitioning the coefficient correlation to study a trait's direct and indirect effects on a more complex main trait (Singh and Chaudary 2007). The variables included in the model can be selected biologically or statistically. Stepwise selection is a statistical procedure used to determine the variables to be included in the model to get the best model to explain the main trait (Mattjik and Sumertajaya 2011).

Seed weight in this study was not included in path analysis because seed yield was an estimated value obtained from converting seed weight per plot to hectares. If this value were included, it would tremendously affect seed yield so that it could cover the effect of other traits. Stem diameter (SD), number of young pods (NYP), young pods weight (YPW), number of seeds per pod (NS), dried pod weight (DPW), and number of dried pods (NDP) were known to be positively correlated with seed yield based on Pearson's correlation analysis. Those traits were able to elucidate 90.70% variability in seed yield. DPW had the highest direct effect (p = 0.56) but was still lower than its correlation coefficient (r = 0.99). It showed that DPW had a relatively significant indirect effect on seed yield, in this case, through YPW and NDP. YPW and NDP also had a smaller direct effect than their correlation coefficient (Figure 2). Thus, the selection process to obtain high-yielding winged bean genotypes can be conducted simultaneously through DPW, YPW, and NDP.

Winged bean seed contained 10.65%-12.22% water, 3.96%-5.15% ash, and 11.10%-16.48% fat (Table 4). The composition of fatty oil in winged bean seed oil primarily consists of unsaturated fatty acid, which is good for health because it can prevent cardiovascular disease and increase insulin stability and glucose metabolism (Budai et al. 2019; Mohanty et al. 2021). Winged bean oil is also an excellent material for frying food and producing zero-trans-fat margarine due to its high oxidative stability, solid fat concentration, and thermal conductivity (Makeri et al. 2016). Therefore, by blending it with palm oil, the physicochemical properties of the final oil blends were enhanced, leading to increased unsaturation levels and improved cloudiness resistance (Hishamuddin and Saw 2022).

Winged bean seed had a high protein content between 28.81%-33.45%, with L1 being the highest, similar to H1P-19(3) and L2. Rif'atunidaudina (2018) reported that winged bean seed had the most similar primary metabolites, especially protein content, to soybean, compared to other underutilized legumes in Indonesia. Several winged bean genotypes also had seed morphology similar to soybean, such as seed color and shape. With better adaptability in the tropical climate, winged bean is projected as an alternative to soybean to fulfill the protein needs in tropical regions, including Indonesia.

The crude fiber content of the evaluated winged bean genotypes ranged from 6.66%-8.80%. Ningombam et al. (2012) also stated that winged bean seeds had a fiber content of about 8.57% and would increase with increasing harvest age. Adegboyega et al. (2019) added that winged bean seeds had a higher fiber content after processing, about 10.40%-13.82%. Finally, the information from this study can be used as consideration in developing winged bean varieties for seed production purposes. Indirect selection through some yield-related traits would help the selection process to get a high-yielding winged bean, while index selection using multi-traits, including proximate content, would generate winged bean varieties with a high seed yield and nutritional content. Further research must be done to explore the relationships between seed yield and other plant components, mainly vegetative traits, to accelerate the selection process.

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## REFERENCES

Acquaah G. 2007. Principles of Plant Genetics and Breeding. Blackwell Publishing, Oxford.

Adie MM, Krisnawati A. 2018. Identification of soybean genotypes adaptive to tropical area and suitable for industry. IOP Conf Ser Earth Environ Sci 102: 012045. DOI: 10.1088/1755-1315/102/1/012045.

Adegboyega TT, Abberton MT, AbdelGadir AH, Dianda M, Maziya-Dixon B, Oyatomi OA, Ofodile S, Babalola OO. 2019. Nutrient and antinutrient composition of winged bean (*Psophocarpus tetragonolobus* (L.) DC.) seeds and tubers. J Food Qual 2019: 3439620. DOI: 10.1155/2020/3439620.

Amoo IA, Adebayo OT, Oyeleye AO. 2006. Chemical evaluation of winged beans (*Psophocarpus tetragonolobus*), pitanga cherries (*Eugenia uniflora*) and orchid fruit (orchid fruit Myristica). African J Food Agric Nutr Dev 6 (2): 1-12. DOI: 10.4314/ajfand.v6i2.71734.

AOAC [Association of Official Analytical Chemists]. 2005. Official Methods of Analysis of AOAC International 18th Edition. AOAC Inc, Maryland.

Bassal H, Merah O, Ali AM, Hijazi A, Omar F El. 2020. *Psophocarpus tetragonolobus*: An underused species with multiple potential uses. Plants 9 (12): 1730. DOI: 10.3390/plants9121730.

Budai Z, Balogh L, Sarang Z. 2019. Short-term high-fat meal intake alters the expression of circadian clock-, inflammation-, and oxidative stress-related genes in human skeletal muscle. Intl J Food Sci Nutr 70 (6): 749-758. DOI: 10.1080/09637486.2018.1557607.

Calvindi J, Syukur M, Nurcholis W. 2020. Investigation of biochemical characters and antioxidant properties of different winged bean (*Psophocarpus tetragonolobus*) genotypes grown in Indonesia. Biodiversitas 21 (6): 2420-2424. DOI: 10.13057/biodiv/d210612.

Chankaew S, Sriwichai S, Rakvong T, Monkham T, Sanitchon J, Tangphatsornruang S, Kongkachana W, Sonthirod C, Pootakham W, Amkul K, Kaewwongwal A, Laosatit K, Somta P. 2022. The first genetic linkage map of winged bean (*Psophocarpus tetragonolobus* (L.) DC.) and QTL mapping for flower-, pod-, and seed-related traits. Plants 11: 500. DOI: 10.3390/plants11040500.

Eagleton GE. 2019. Prospects for developing an early maturing variety of winged bean (*Psophocarpus tetragonolobus*) in Bogor, Indonesia. Biodiversitas 20 (11): 3142-3152. DOI: 10.13057/biodiv/d201106.

Hishamuddin E, Saw MH. 2022. Enhancement of physicochemical characteristics of palm olein and winged bean (*Psophocarpus tetragonolobus*) seed oil blends. OCL - Oilseeds fats, Crop Lipids 29: 1-7. DOI: 10.1051/ocl/2021049.

Hymowitz AT, Boyd J. 1977. Origin, ethnobotany and agricultural potential of the winged bean: *Psophocarpus tetragonolobus*. Econ Bot 31 (2): 180-188.

Ishthifaiyyah SA, Syukur M, Trikoesoemaningtyas, Maharijaya A. 2021. Agro-morphological traits and harvest period assessment of winged bean (*Psophocarpus tetragonolobus*) genotypes for pods production. Biodiversitas 22 (2): 1069-1075. DOI: 10.13057/biodiv/d220264.

Krisnawati A, Adie MM. 2015. Selection of soybean genotypes by seed size and its prospects for industrial raw material in Indonesia. Procedia Food Sci 3: 355-363. DOI: 10.1016/j.profoo.2015.01.039.

Lepcha P, Egan AN, Doyle JJ, Sathyanarayana N. 2017. A review on current status and future prospects of winged bean (*Psophocarpus tetragonolobus*) in tropical agriculture. Plant Foods Hum Nutr 72 (3): 225-235. DOI: 10.1007/s11130-017-0627-0.

Liu X, Wu JA, Ren H, Qi Y, Li C, Cao J, Zhang X, Zhang Z, Cai Z, Gai J. 2017. Genetic variation of world soybean maturity date and geographic distribution of maturity groups. Breed Sci 67 (3): 221-232. DOI: 10.1270/jsbbs.16167.

Makeri MU, Karim R, Abdulkarim MS, Ghazali HM, Miskandar MS, Muhammad K. 2016. Comparative analysis of the physico-chemical, thermal, and oxidative properties of winged bean and soybean oils. Intl J Food Prop 19: 2769-2787. DOI: 10.1080/10942912.2015.1031246.

Mattjik AA, Sumertajaya IM. 2011. Multivariate Analysis Using SAS. IPB University, Bogor.

Mohanty CS, Singh V, Chapman MA. 2020. Winged bean: An underutilized tropical legume on the path of improvement, to help mitigate food and nutrition security. Sci Hortic 260: 108789. DOI: 10.1016/j.scienta.2019.108789.

Mohanty CS, Syed N, Kumar D, Khare S, Nayak SP, Sarvendra K, Pattanayak R, Pal A, Chanotiya CS, Rout PK. 2021. Chemical characterization of winged bean (*Psophocarpus tetragonolobus* (L.) DC.) seeds and safety evaluation of its fatty oil. J Food Meas Charact 15 (1): 807-816. DOI: 10.1007/s11694-020-00680-1.

Ningombam RD, Singh PK, Salam JS. 2012. Proximate composition and nutritional evaluation of underutilized legume *Psophocarpus tetragonolobus* (L.) DC. grown in Manipur, Northeast India. Am J Food Technol 7: 487-493. DOI: 10.3923/ajft.2012.487.493.

Rakhmad D. 2021. Yield Stability and Agronomic Performance of Several Winged Bean Inbred Lines (*Psophocarpus tetragonolobus* L.) in Three Environments. [Thesis]. IPB University, Bogor. [Indonesian]

Rif'atunidaudina R. 2018. Studies on Morphological, Primary Metabolites Content and Molecular Diversity Among Underutilized Pulse Genetic Resources of Indonesia. [Thesis]. IPB University, Bogor. [Indonesian]

Singh RK, Chaudary BD. 2007. Biometrical Methods in Quantitative Genetic Analysis. Kalyani Publisher, New Delhi.

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: 1746-1758. DOI: 10.3390/plants10081746.

Syukur M, Sujiprihati S, Yunianti R. 2015. Teknik Pemuliaan Tanaman. Penebar Swadaya, Jakarta. [Indonesian]

Tanzi AS, Ho WK, Massawe F, Mayes S. 2019. Development and interaction between plant architecture and yield-related traits in winged bean (*Psophocarpus tetragonolobus* (L.) DC.). Euphytica 215: 36. DOI: 10.1007/s10681-019-2359-8.

Wright S. 1921. Correlation and causation. J Agric Res 20 (7): 557-585. DOI: 10.1016/s0161-6420(13)30987-7.

Yulianah I, Waluyo B, Ashari S, Kuswanto. 2020. Variation in morphological traits of a selection of Indonesian winged bean accessions (*Psophocarpus tetragonolobus*) and its analysis to assess genetic diversity among accessions. Biodiversitas 21 (7): 2991-3000. DOI: 10.13057/biodiv/d210716.