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Morpho-physiological seed diversity and viability of Indonesian cowpea (*Vigna unguiculata*)

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Abstract. *Widajati E, Syukur M, Diaguna R, Permatasari OSI, Ritonga AW, Sahid ZD, Pratiwi GR, Hatta ANNL. 2023. Morpho-physiological seed diversity and viability of Indonesian cowpea* (Vigna unguiculata). *Biodiversitas 24: 5319-5327.* Cowpea is a legume with a potential nutritional content almost equivalent to soybeans; it can be developed as a substitute agent for raw materials for food processing. One of the factors in obtaining high cowpea production is to use of quality seeds. Our study aimed to evaluate the performance and morpho-physiological correlations and viability of cowpea seed collections from IPB University Bogor and the Indonesian Research Institute of Legume. We used ten genotypes of cowpea, which had superior seed information. The results showed that the ten cowpea genotypes had superior morpho-physiological and seed viability. The seed germination percentage was categorized as medium-high (>60%). Eight cowpea genotypes were grouped into one major group based on morpho-physiological characteristics and viability. Furthermore, positive correlations were found between the observed variables of seed viability (seed germination, seed growth speed, and seed vigor index). Our research results are useful as a source of genetic diversity for plant breeders in developing new superior varieties in the future. In addition, agronomists can use this information to plant cowpeas based on planting location.

Keywords: Correlation, cowpea, seed diversity, viability

INTRODUCTION

Indonesia is a biodiversity country with various legumes, such as soybeans, green beans, peanuts, and cowpeas. One of the well-known, highly nutritious processed food products that utilize legumes (soybeans) is called "*tempe*" (Rahmawati et al. 2021). In addition, innovation in the food industry processes soybeans and green beans into vegetable drinks in milk, which can be equivalent to animal protein (Mu et al. 2022). This certainly affects the market chain, so a strategy is needed to fulfill the market demand. In 2019, soybean production in Indonesia reached 424,189 Tons with a harvested area of 285,265 hectares (Indonesian Ministry of Agriculture 2020). Domestic production that cannot meet market demand causes inflation; one way that has been taken is to import. The process of importing raw materials, which is continuous, causes dependence and impacts the price volatility of this raw material (Ren et al. 2021).

Tropical countries where the equator passes have a geographical advantage in overcoming this problem; the other legumes can be used as food substitutes. One type of bean that has been reported to have nutrition close to soybeans is cowpea (N'goran et al. 2023). Cowpea (*Vigna unguiculata* L.) can produce energy for the human body of 1,420 Kj per 100 g (Momanyi et al. 2020). It was reported in a previous study that 100 g of cowpea seeds contained 10 g of water, 22 g of protein (Gerrano et al. 2019), 1.4 g of fat (Ciurescu et al. 2022), 51 g of carbohydrates (Abebe et al. 2022), 3.7 g of vitamins (Mekonnen et al. 2022), 104 mg of calcium (Peyrano et al. 2017), and various other functional compounds (Jayathilake et al. 2018; Owade et al. 2020). In addition, the advantages of cowpeas include being easy to cultivate, containing quite high protein, and relatively cheap price compared to soybeans. Cowpea also has high adaptability to grow in marginal land environments (i.e., acid soil, dry soil, and attack by pests and diseases) (da Cruz et al. 2020; da Cruz et al. 2021).

Therefore, quality seeds are needed for plants to grow and produce optimal productivity. In seed terminology, cowpea belongs to the orthodox seed class (Sreedevi et al. 2023). Orthodox seeds can be stored for a long time because the moisture content can be reduced to below 10% and stored at low temperatures and humidity (Ebone et al. 2019). The dry weight gain of orthodox seeds stopped before physiological ripening, and the moisture content decreased to 6-10% at maturity with small variations among individual seeds (Costa et al. 2017). Cowpea seeds are generally not replanted directly after harvest. Therefore, proper seed storage techniques are important to maintain seed supply, viability, and quality.

Principally, seed storage is influenced by environmental and genetic factors. Environmental influences that could cause seed damage during pre-treatment in the field are closely related to seed moisture content (Kibar and Kibar 2019); properly handling seeds during harvest can prevent seed damage. During physiological maturity, orthodox seed metabolism is inactive (Matilla 2021). Generally, in cultivating cowpea plants practice, the seeds are stored long enough before being planted in the next growing season, causing the seeds' quality to decrease. During storage, the viability and vigor of the seeds will decrease if the moisture content in the seeds is high with low humidity, which can cause evaporation of moisture from the seeds and increase the humidity of the air around the seeds (de Vitis et al. 2020); these seeds are hygroscopic (Rongsangchaicharean et al. 2022). Orthodox seed viability can be extended by controlling humidity and storage temperature. Meanwhile, the cowpea genotype is another genetic factor that influences seed quality.

Plant variety is also a genetic key factor that influences the appearance of a plant character, including seed character and viability. Inadequate choice of cowpea variety causes farmers to use local varieties in the area; local varieties whose unknown origins and used repeatedly cause the quality of the seeds to degrade, leading to unsatisfactory productivity. Mh Syukur's Breeder Team has several cowpea varieties with good growth, viability, and productivity. In addition, the Indonesian Research Center of Legumes also has cowpea genotypes to be tested. Therefore, in this study, we aimed to evaluate the morphological diversity and seed viability of cowpea seeds collected by the IPB plant breeding laboratory. These were stored for four months to provide scientific information on seed diversity and viability.

MATERIALS AND METHODS

Genetic material

The study uses genetic material genotypes from the collection of the Plant Breeding Laboratory of IPB and the Indonesian Research Institute for Legumes. Ten genotypes were used in this study, and the selections were based on superiority information reported in previous studies (Wahyudi and Syukur 2021). The cowpea genotypes used are shown in Table 1.

Field experimental

Cowpea planting was carried out at the Lewikopo Experimental Garden of IPB University (altitude 218 masl with field temperature 23-31°C and humidity 80-85%). Meanwhile, observations of cowpea yields were carried out at the Seed Laboratory, IPB University. The procedure for plant cultivation refers to the standard operational procedure for cowpeas. The activity begins with preparing the land for planting, including loosening the soil, applying organic fertilizer (20 Ton Ha^{-1}) and dolomite (2 Ton Ha^{-1}), and leaving for two weeks. After that, beds with a size of 1.25 x 21 meters were made with a distance between beds of 50 cm, and Nitrogen (45 kg Ha^{-1}), P_2O_5 (75 kg Ha^{-1}), and K_2O (75 kg Ha^{-1}) fertilizers were applied in two fertilization grooves. Furthermore, the beds are covered with silver-black plastic mulch and perforated with a 50 x 40 cm spacing. Two seeds were planted per hole and given Furadan 3G (3% Carbofuran). Watering is done five times a week, while additional fertilizing is carried out in the fourth week by watering a solution of 250 mL of NPK fertilizer (1.5 g L^{-1}) per plant. The pest and plant disease controls are carried out regularly, and insect traps are installed in each planting bed.

Harvesting was done when the fruit pods showed physiological maturity by cutting the pods along with the stalks at 4 cm long. The pods were cut and stored in harvesting boxes covered with cotton to prevent pod damage. The harvested pods were immediately taken to the Seed Laboratory for seed extraction and observation. Seed extraction was done by cutting the pods and slowly removing the seeds. The extracted seeds were then air-dried for 24 hours, and seed morphology and preparation were observed to observe seed viability.

Seed morphology observation

Observation of seed morphology was observed after the seeds were extracted and air-dried. Morphological observations were made on seed length (mm), seed width (mm), seed color, and seed weight (g). Seed length and width were observed using a digital caliper measuring the longest and widest seeds. Seed weight was done by counting the number of seeds, as many as one hundred, and weighing them using a digital scale. Observation of seed color is done by taking pictures and comparing them qualitatively by the standard.

Seed viability observation

Seed viability observation was conducted for four months; the perfect seed shape sorts the harvested and air-dried seeds, separation and storage into seed bags that have been differentiated based on month storage time at room temperature. Observation of viability was carried out based on the seed storage bag every first day of the month. Seed viability observation variables include Seed Moisture Content (SMC), Seed Germination (SG), Seed Growth Speed (SGS), and Seed Vigor Index (SVI). SMC was observed using 103 + 2°C for 17 hours and calculated based on seed wet weight. Seed germination using between paper method, 100 seeds per replicate carried out three replicates. The first count was five Days After Sowing (DAS), and the final was seven DAS. SGS was carried out by observing normal seedlings every day for seven days, while SIV was the percentage of normal seedlings observed at five DAS. The raw observational data was inputted into Microsoft Excel and followed by data normalization.

Table 1. Ten cowpea genotypes used in this research

Genotypes	Owner agency
Tampi IPB	Plant Breeding Laboratory, IPB University
Albina IPB	Plant Breeding Laboratory, IPB University
KT-1	Indonesian Research Institute of Legumes
KM-6	Indonesian Research Institute of Legumes
Arghavan IPB	Plant Breeding Laboratory, IPB University
KT-5	Indonesian Research Institute of Legumes
KTH-25	Indonesian Research Institute of Legumes
Uno IPB	Plant Breeding Laboratory, IPB University
KM-1	Indonesian Research Institute of Legumes
KM-2	Indonesian Research Institute of Legumes

Data analysis

This study carried out a Randomized Complete Block Design (RCBD) with three replications; the collected data was arranged based on templates in auxiliary applications. Visualization and PostHoc analysis of data using the PKBT Stat Clustering (http://pbstat.com/pkbt-stat/) and R Studio v. 4.3.1. Post hoc analysis was carried out, including 5% HSD test, Hierarchical Cluster Analysis, Genotype cluster analysis, and Pearson correlation which was carried out while the ANOVA showed significant results. HCA visualization using the "heatmaply_package" and R Color Brewer (coul: PuRd) using R Studio (Syukur et al. 2022). Pearson correlation analysis visualization also uses the same program as the ggplot_package (Syukur et al. 2023).

RESULTS AND DISCUSSION

Analysis of variance was carried out to see the coefficient of variance and determine whether a post hoc test could carry out the data. ANOVA in this study was divided into two tables: ANOVA on seed morphology (Table 2) and ANOVA on seed viability (Table 3). Table 2 shows that all mean square source genotypes were significant (P<1%). The same results are shown in Table 3, where the source genotype was very significant (P<1%); the significance was found in the interaction between genotype and month of storage. The coefficient of variance produced in both ANOVA tables ranged from 1.33 to 15.43%. Sources of replicates showed no significant effect on the observational characters of seed length, seed width, moisture content, and vigor index. Significant mean squares for all observational characters can be used to conduct post hoc tests (Suhi et al. 2022). The data that is further tested have good conclusion validity due to the coefficient of variation being less than 20%, so the validity of the conclusions was getting better (Aliyu et al. 2022).

The means for seed morphology are shown in Table 4. The KTH-25 genotype had the highest weight and seed length morphology; KTH-25 seed weight differed significantly from all other genotypes. Meanwhile, the length of KTH-25 seeds was not significantly different compared to Tampi IPB, Arghavan IPB, KM-1, and KM-2 genotypes. KT-1 and Albina IPB genotypes had the lowest seed weight and length; the seed weight of the two genotypes was not statistically significantly different. Meanwhile, the length of the Albina IPB seeds was significantly different, higher than KT-1. The highest seed width was shown by the KM-1 genotype, which was statistically significantly different from the other genotypes except for KM-2 and Uno IPB. The smallest seed width is shown by KTH-25, where this genotype has the highest seed weight and length; it indicates that seed width was unaffected. Seed weight is influenced by several factors, including moisture content, seed length, seed width, and seed coat diameter (Stanisavljevic et al. 2020) and supported by Lian et al. (2020), who informed that long seeds also have high seed weight.

The moisture content of ten genotypes of cowpea stored for four months of storage is shown in Table 5; the storage period did not show a significant difference in moisture content. The highest average moisture content for the ten observed genotypes was shown by Albina IPB, which was statistically not significantly different from all other genotypes except KM-4. The fourth month of storage in this study showed that the moisture content of all genotypes did not differ significantly between genotypes. The highest significant variation indicated by the second month of storage was divided into three letters of significance. The cowpea's moisture content in this study follows the theory that storage of orthodox seeds can be carried out under conditions below 15% (Plitta-Michalak et al. 2021). Moisture content can affect the viability of other seeds, especially germination (Arteaga et al. 2020). Therefore, a four-month germination test was conducted using the same ten genotypes.

Seed quality can be seen from the percentage of seed germination shown in Table 6. The greater the percentage value of seed germination, the better the seed quality (de Marcos Lapaz et al. 2019). The longer month storage and use of different genotypes significantly affected this study's results. The third month of storage is the month of storage that has the best average germination rate and is significantly different from the other months of storage. While the mean germination observed in ten genotypes showed results above 60%. De Vitis et al. (2020) state that a germination rate above 80% is categorized as high, and 60-80% is categorized as medium. As much as 50% of the germination power of the genotypes tested was classified as high, while the other five were classified as medium (KTH-25, KM-1, KT-5, Albina IPB, and Uno IPB). The highest germination power significantly different from the other genotypes was shown by KT-1, followed by KM-2 and Tampi IPB, respectively.

In addition to the best average percentage of germination, the average growth speed of KT-1 was also the fastest and most significant compared to other genotypes except Albina IPB and KM-2. Albina IPB has a moderate germination capacity, but the speed at which Albina IPB grows into new individuals is relatively fast. The speed at which plants germinate becomes essential in the planting cycle. Thus, the faster it grows, the faster the plants can produce seeds (de Lima Nunes et al. 2020) so that raw materials for processing are quickly available. The results of this study indicated that the highest growth speed was shown by the third month of storage, which was not significantly different from the second month of storage. The second month of storage was also not significantly different from the first, while the month of storage that shows the lowest growth rate is the fourth month. The ability of high seed speed in the third month can be caused by the seed dormancy phenomenon (Haq et al. 2023). Seed dormancy occurs when seeds experience a pause after being harvested to grow.

The old theory states that vigor seeds can grow in various environmental conditions (Sadjad 1994). Seed vigor can be seen from the vigor index value, which compares the number of normal sprouts at the start of the calculation and the total number of seeds planted (Rego et al. 2021). The highest average vigor index for ten genotypes was shown by KM-2, which was not significantly different from Albina IPB and KT-1. The vigor index observed in this study decreased significantly in the fourth month of storage. This decrease occurs due to membrane damage in seeds that have passed the shelf life (Prażak et al. 2020).

Seed viability graphs (SG, SGS, SVI) are shown in Figure 1. The pattern that occurs for the three observation parameters shows the same trend. There was an increase in the second and third months of storage, then a decrease in the fourth month of storage. This pattern shows that the cowpea commodity's high viability occurs in the second and third months of storage after fresh harvest. Similar results were shown in another study (Michalak et al. 2021) that seed viability in orthodox seeds was found to be dormancy for one month after fresh harvest and then experiencing a break in dormancy in the second month of storage.

The relationship between observed variables (Figure 2) and the relationship between genotypes (Figure 3) can be obtained from hierarchical cluster analysis. The analysis results separated them into three major groups. Seed vigor index, seed growth speed, seed germination, and seed width are grouped in the first group. At the same time, the second group is indicated by the observation variables seed weight and seed length. Moisture content separates itself into a third group. The close relationship between moisture content, seed weight, and seed length is closer than that of the first group of observations.

Table 2. ANOVA for seed morphology characters

Sources	df	Mean square		
		Seed weight	**Seed length**	**Seed width**
Repetition	2	0.09^{*}	0.001^{ns}	0.009^{ns}
Genotype	9	7.59^{**}	1.71^{**}	0.832^{**}
Error	18	0.036	0.067	0.008
Coefficient of variance (%)		1.33	3.81	2.79

Notes: **: Very significant at level α 1%, *: Significant at level α 5%, ns: Non-significant

Table 3. ANOVA for seed viability characters

Sources	df	Mean square			
		SMC	**SG**	**SGS**	**SVI**
Month (M)	3	1.40^{ns}	1053.70^{**}	201.77^{**}	5967.34^{**}
Repetition	3	0.55^{ns}	47.02^{*}	11.15^{**}	50.59^{ns}
Genotype (G)	9	3.32^{**}	660.95^{**}	107.16^{**}	2789.89^{**}
G * M	27	2.51^{**}	252.29^{**}	27.09^{**}	516.80^{**}
Error	72	0.77	22.56	3.73	41.19
Coefficient of variance (%)		6.50	5.89	8.49	15.43

Notes: **: Very significantly at level α 1%, *: Significantly at level α 5%, ns: Non-significant, SMC: Seed Moisture Content, SG: Seed Germination, SGS: Seed Germination Speed, SVI: Seed Vigour Index

Table 4. Seed morphology of ten cowpea genotypes

Genotype	**Seed weight (g)**	**Seed length (mm)**	**Seed width (mm)**
Tampi IPB	14.81 d	7.30 a	3.43 cd
Albina IPB	12.18 g	6.23 d	3.53 bc
KT-1	12.19 g	5.20 e	3.33 cd
KM-4	15.38 bc	6.43 bcd	3.03 e
Arghavan IPB	14.24 e	7.17 ab	3.20 de
KT-5	13.09 f	6.37 cd	3.00 e
KTH-25	16.61 a	7.67 a	2.17 f
Uno IPB	12.76 f	7.07 abc	3.77 ab
KM-1	15.10 cd	7.40 a	4.03 a
KM-2	15.92 b	7.40 a	3.77 ab

Note: Means followed by the same letter in the same column show non-significant difference based on the HSD test at 5%

Table 5. Cowpea moisture content for four months of storage

Genotypes	Moisture content (%)				**Genotype average**
	Month-1	**Month-2**	**Month-3**	**Month-4**	
Tampi IPB	13.45^{ab}	15.05^{ab}	13.63^{ab}	13.94^{a}	14.02^{a}
Albina IPB	13.32^{ab}	13.81^{abc}	14.38^{a}	15.03^{a}	14.13^{a}
KT-1	13.27^{ab}	13.13^{bc}	11.83^{b}	13.59^{a}	12.95^{ab}
KM-4	13.32^{ab}	11.52^{c}	11.87^{b}	13.59^{a}	12.58^{b}
Arghavan IPB	11.99^{b}	13.30^{abc}	13.12^{ab}	13.35^{a}	12.94^{ab}
KT-5	13.13^{ab}	13.22^{abc}	14.14^{ab}	13.44^{a}	13.48^{ab}
KTH-25	11.83^{b}	15.59^{a}	13.17^{ab}	13.38^{a}	13.50^{ab}
Uno IPB	15.38^{a}	12.83^{bc}	14.62^{a}	13.01^{a}	13.96^{a}
KM-1	12.27^{b}	12.94^{bc}	13.53^{ab}	14.03^{a}	13.19^{ab}
KM-2	13.79^{ab}	13.46^{abc}	14.15^{ab}	13.65^{a}	13.76^{ab}
HSD 5%	2.38	2.38	2.38	2.38	1.19
Month average	13.18	13.49	13.44	13.70	

Note: Means followed by the same letter in the same column show non-significant difference based on the HSD test at 5%

Table 6. Cowpea seed germination for four months of storage

Genotypes	Seed germination (%)				Genotype average
	Month-1	Month-2	Month-3	Month-4	
Tampi IPB	86.67^{abc}	71.33^{cd}	87.00^{abc}	89.33^{ab}	83.58^{bc}
Albina IPB	63.00^{d}	92.33^{a}	90.67^{abc}	68.00^{de}	78.50^{cde}
KT-1	96.67^{a}	93.67^{a}	94.00^{ab}	92.33^{a}	94.17^{a}
KM-4	95.00^{ab}	61.67^{de}	87.67^{abc}	89.33^{ab}	83.42^{bc}
Arghavan IPB	69.00^{d}	79.00^{bc}	95.00^{a}	86.67^{ab}	82.42^{bcd}
KT-5	74.67^{cd}	63.33^{de}	93.67^{ab}	73.00^{cde}	76.17^{de}
KTH-25	65.00^{d}	59.67^{de}	80.33^{c}	63.00^{e}	67.00^{f}
Uno IPB	82.33^{bc}	76.67^{c}	86.33^{abc}	69.33^{de}	78.67^{cde}
KM-1	83.67^{bc}	57.00^{e}	82.00^{bc}	77.00^{bcd}	74.92^{e}
KM-2	83.00^{bc}	90.33^{ab}	90.67^{abc}	85.67^{abc}	87.42^{b}
HSD 5%	12.94	12.94	12.94	12.94	6.47
Month Average	79.90^{b}	74.50^{b}	88.73^{a}	79.37^{b}	

Note: Means followed by the same letter in the same column show non-significant difference based on the HSD test at 5%

Table 7. Cowpea seed growth speed for four months of storage

Genotypes	Seed growth speed (%)				Genotype average
	Month-1	Month-2	Month-3	Month-4	
Tampi IPB	22.89^{ab}	22.53^{cd}	27.39^{ab}	23.11^{ab}	23.98^{bc}
Albina IPB	21.56^{b}	30.38^{a}	27.56^{ab}	19.28^{abcd}	24.69^{abc}
KT-1	25.17^{ab}	31.56^{a}	28.22^{ab}	24.27^{a}	27.30^{a}
KM-4	27.72^{a}	21.28^{cde}	26.78^{ab}	21.76^{abc}	24.38^{bc}
Arghavan IPB	15.82^{c}	24.64^{bc}	23.54^{bc}	19.93^{abc}	20.99^{de}
KT-5	20.50^{bc}	16.89^{ef}	29.00^{a}	18.46^{bcd}	21.21^{de}
KTH-25	15.60^{c}	18.97^{def}	20.61^{c}	14.12^{d}	17.33^{f}
Uno IPB	23.59^{ab}	24.84^{bc}	24.06^{abc}	17.17^{cd}	22.41^{cd}
KM-1	22.21^{b}	15.33^{f}	23.44^{bc}	17.90^{bcd}	19.72^{ef}
KM-2	25.39^{ab}	28.83^{ab}	27.44^{ab}	20.29^{abc}	25.49^{ab}
HSD 5%	5.26	5.26	5.26	5.26	2.63
Month Average	22.04^{bc}	23.53^{ab}	25.80^{a}	19.63^{c}	

Note: Means followed by the same letter in the same column show non-significant difference based on the HSD test at 5%

Table 8. Cowpea seed vigor index for four months of storage

Genotypes	Seed vigor index (%)				Genotype average
	Month-1	Month-2	Month-3	Month-4	
Tampi IPB	38.33^{bc}	50.00^{b}	70.33^{a}	44.67^{a}	50.83^{bc}
Albina IPB	47.00^{ab}	83.33^{a}	70.33^{a}	17.33^{bcd}	54.50^{ab}
KT-1	38.33^{bc}	78.00^{a}	65.33^{ab}	39.67^{a}	55.33^{ab}
KM-4	59.33^{a}	37.33^{bc}	69.00^{a}	34.00^{ab}	49.92^{bc}
Arghavan IPB	16.67^{de}	27.33^{cd}	23.00^{e}	27.67^{abc}	23.67^{e}
KT-5	27.33^{cd}	50.67^{b}	76.33^{a}	18.33^{bcd}	43.17^{c}
KTH-25	9.33^{e}	32.00^{cd}	29.33^{de}	1.33^{d}	18.00^{e}
Uno IPB	49.33^{ab}	19.33^{d}	48.33^{bc}	20.33^{bc}	34.33^{d}
KM-1	7.67^{e}	36.00^{bcd}	45.33^{cd}	11.33^{cd}	25.08^{e}
KM-2	54.33^{ab}	78.00^{a}	71.33^{a}	40.33^{a}	61.00^{a}
HSD 5%	17.49	17.49	17.49	17.49	8.74
Month Average	34.77^{c}	49.20^{b}	56.87^{a}	25.50^{d}	

Note: Means followed by the same letter in the same column show non-significant difference based on the HSD test at 5%

The ten genotypes used in this study were divided into three major groups based on seed morphology and seed viability (Figure 3). KT-1 genotype occupies the first group. The second group consisted of eight genotypes: KT-5, Albina IPB, Uno IPB, Tampi IPB, KM-2, KM-4, Arghavan IPB, and KM-1. Meanwhile, the third group was shown by the KTH-25 genotype. The intensity of the color indicates the mean value of observed characters and genotypes based on the legend. The darker the box's color, the higher the resulting character and genotype mean values (Erdoğan and Özdestan 2022). KT-1 genotype is the genotype with the highest mean value for seed germination characters, and this genotype also has the highest mean value for this observation compared to other characters. The seed length of this genotype has the shortest value compared to other genotypes.

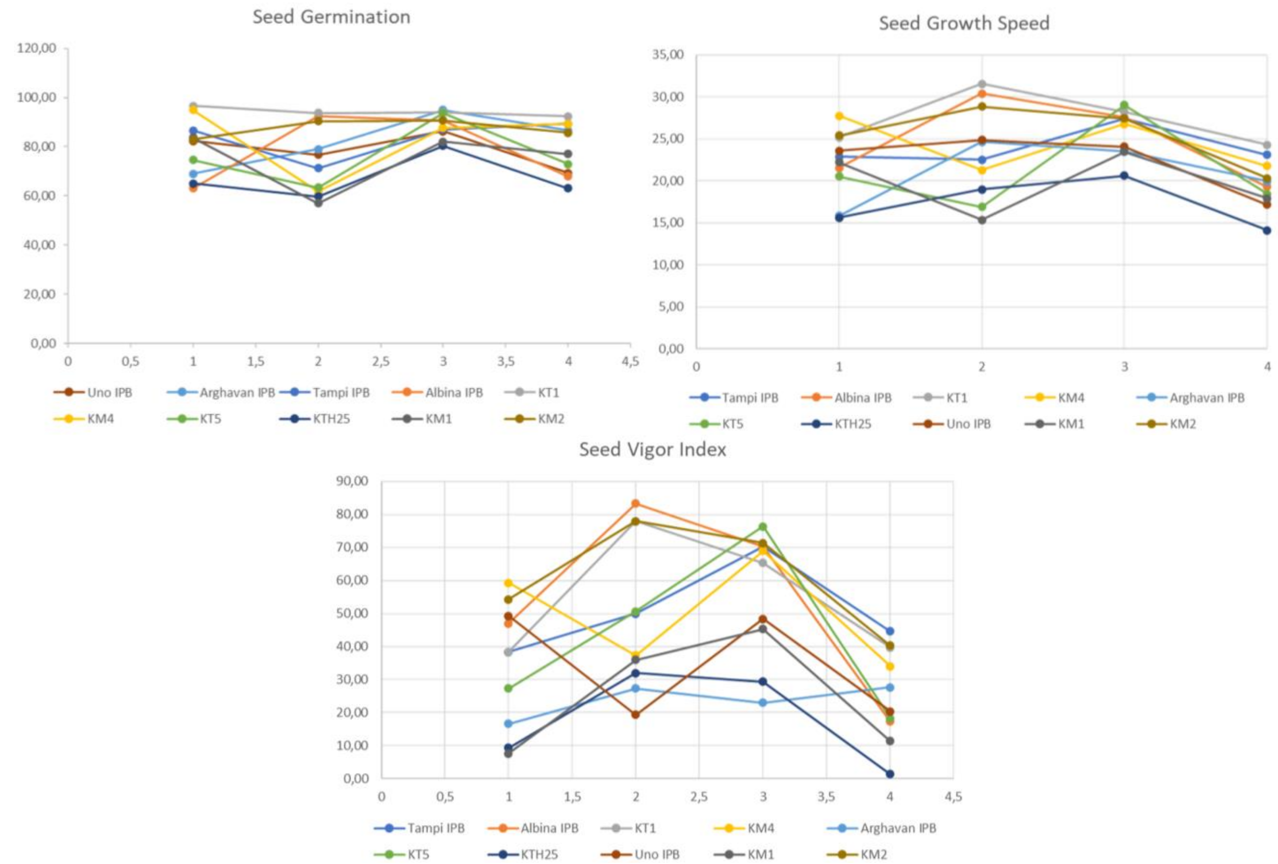

Figure 1. Cowpea's seed viability graph

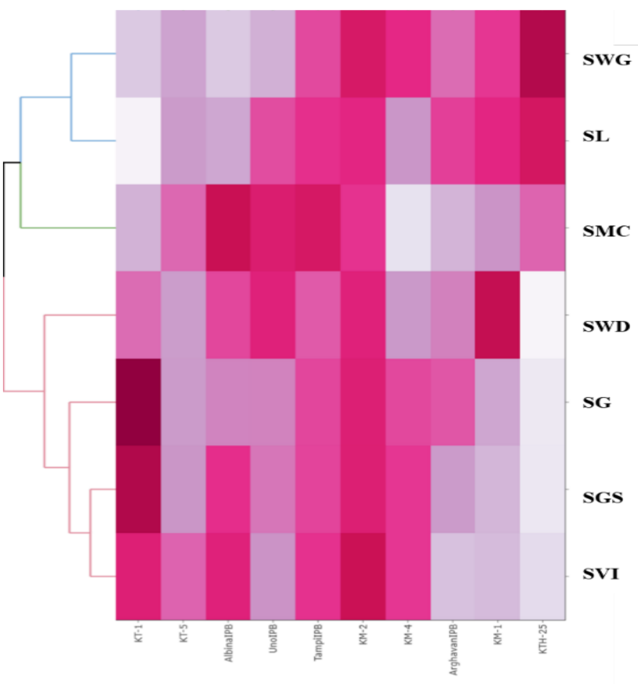

Figure 2. Hierarchical cluster analysis of cowpea seed observation

Figure 4 shows the result from the Pearson correlation analysis between seed morphology variables and observed seed viability (SW, SL, SW, SMC, SG, SGS, and SVI). A significant positive correlation at 5% ($p<0.05$) was found in the combination of SW-SL characters (r^2 value 0.74) and SG-SVI (r^2 value 0.72). At the same time, a significant positive correlation at 1% ($p<0.01$) was indicated by the combination of SG-SGS characters (r^2 value 0.90) and SGS-SVI (r^2 value 0.92). A significant negative correlation at 5% was only found in the combination of SL-SG characters (r^2 value 0.58) and SL-SGS (r^2 value 0.66).

A positive correlation indicates a mutually supportive relationship between the combinations of observational variables (Fattahi et al. 2019; Rehman et al. 2020). It means that seed width and seed length characters positively influence each other. The three seed viability characteristics (seed germination, seed growth speed, and seed vigor index) also positively affect each other. The seed length with seed germination and seed growth speed showed the opposite character. It shows that the greater the measurement value of the seed length, the smaller the seed germination and seed growth speed. Supported by research results (Patel et al. 2023) that a negative correlation means the opposite between the observed variables.

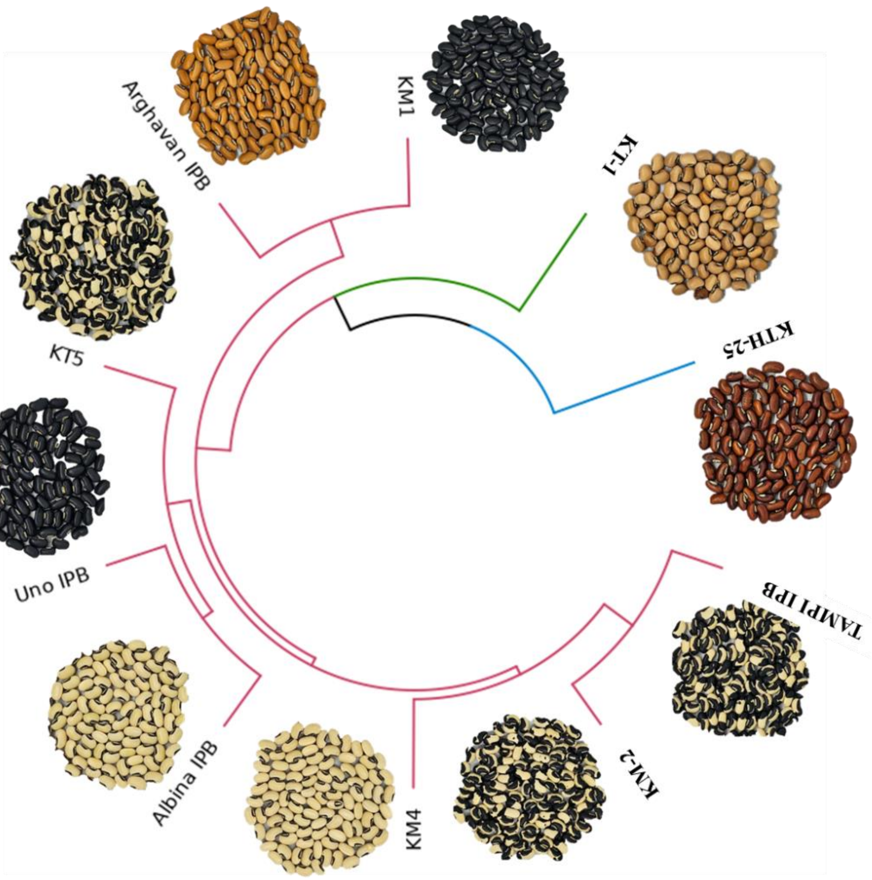

Figure 3. Genotype cluster analysis of cowpea seed

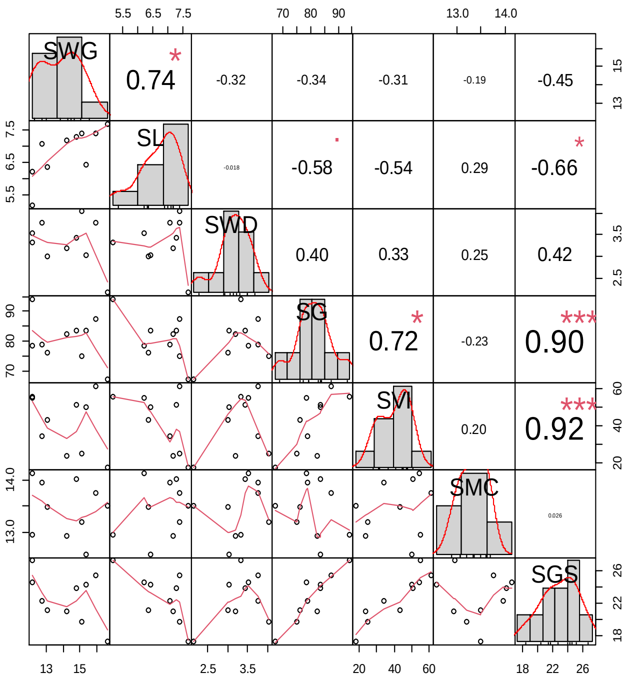

Figure 4. Pearson correlation of cowpea seed morphology and viability

This study concluded that cowpea seeds have morpho-physiology and viability variations due to different genetic influences on each genotype of cowpea used. Relationships based on morpho-physiological characters and seed viability grouped the ten genotypes into three major groups. Storage of cowpea seeds caused a decrease in seed viability in the fourth month. Thus, the three seed viability characteristics (seed germination, seed growth speed, and seed vigor index) were positively correlated. According to HCA analysis, moisture content with seed weight and length were more closely related. The graph of the three observational characteristics of seed viability in this study showed a similarity: an increase in two months of storage and a decrease in the fourth month.

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