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Variability of agronomic characters and seed quality of 12 sorghum (*Sorghum bicolor*) genotypes

ADITYA KUSUMAWARDANA[1], SATRIYAS ILYAS[2,♥], ABDUL QADIR[2], TRIKOESOEMANINGTYAS[2], SOERANTO HUMAN[3]

[1]Agronomy and Horticulture Study Program, Graduate School, Institut Pertanian Bogor. Jl. Meranti, Kampus IPB Darmaga, Bogor 16680, West Java, Indonesia

[2]Department of Agronomy and Horticulture, Faculty of Agriculture, Institut Pertanian Bogor. Jl. Meranti, Kampus IPB Darmaga, Bogor 16680, West Java, Indonesia. Tel./fax.: +62-251-8629352, ♥email: satriyas_ilyas@apps.ipb.ac.id

[3]Research Center for Food Crops, National Research and Innovation Agency. Jl. Raya Jakarta-Bogor Km 46, Cibinong 16911, West Java, Indonesia

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Abstract. *Kusumawardana A, Ilyas S, Qadir A, Trikoesoemaningtyas, Human S. 2025. Variability of agronomic characters and seed quality of 12 sorghum (*Sorghum bicolor*) genotypes. Biodiversitas 26: 628-635.* Sorghum is a nutrient-rich food crop, an alternative commodity to substitute rice and other cereal crops, and can be grown on dry land; thus, it is important for food diversification to support food security and sustainable agriculture development in Indonesia. Utilization of high-quality seeds of superior varieties will improve sorghum productivity and quality. This study aimed to characterize the performance of 12 sorghum genotypes and identify potential lines for developing superior varieties. The planting materials used were nine BRIN sorghum lines (GHP-2, GHP-16, CTY-43, GH-1, GH-7, GH-9, G-5, G-7, G-8) and three national varieties (Bioguma 1, Pahat, Samurai 2). This research was conducted from June to October 2024 at the Institut Pertanian Bogor Leuwikopo Experimental Farm, Bogor, and Seed Quality Testing Development Center for Food Crops and Horticulture, Depok, West Java, Indonesia. The experimental design was a single-factor (genotypes) randomized complete block design with four replications. Seeds were planted in plots of 1x2.8 m with a spacing of 70x20 cm. Observations were made on agronomic characters and seed quality. The characters of plant height, 1000-seed weight, flowering age, and seed weight per plot significantly differed among genotypes. GH-9 line showed the highest productivity (2467.61 g seeds per plot) and 1000-seed weight (33.7 g). Of the 12 genotypes tested, the flowering ages ranged from 57 to 65 days after planting, with the fastest flowering age (57 days) on the CTY-43 line. Plant height measurements showed the lowest plant height (123.4 cm) on GHP-16, while the highest was GH-7 (228.9 cm).

Keywords: 1000-seed weight, flowering age, plant height, productivity, superior varieties

INTRODUCTION

Sorghum (*Sorghum bicolor* [L.] Moench) is a cereal crop with great potential for development in Indonesia because it has a wide adaptation area. Sorghum can be used as a food, feed, and bioenergy source because of its high sugar content in stems (Regassa and Wortmann 2014; Batog et al. 2020). Sorghum can adapt to various environments, especially under water deficiency conditions. Due to this characteristic, the crop is of great utility in regions with irregular rainfall distribution and high air temperature (Griebel et al. 2019). Sorghum can adapt to marginal lands and requires less water because it is more drought-tolerant than other food crops (Praptiningsih et al. 2020). The water use efficiency of sorghum is higher than that of other C4 crops, such as corn (Amaducci et al. 2016). Sorghum demands fewer agricultural resources than other crops, making it an ideal option for farmers with limited means. While it is primarily consumed as a basic food source, sorghum's adaptability allows it to be utilized in various ways. These include its use as an energy crop for renewable biofuel production, animal feed for livestock, and as a component in industrial processes (Habyarimana et al. 2020).

According to Xiong et al. (2019), starch is the dominant carbohydrate in sorghum and is stored as granules in the endosperm. The starch content varies significantly among varieties, from 32.1 to 72.5 g per 100 g, which is higher than cassava, corn, and soybeans. Likewise, the protein content of sorghum is 11 g per 100 g, which is higher than that of rice, cassava, and corn but lower than soybeans at 30.2 g per 100 g. Its grain contains calories, amino acids, vitamins, and minerals. Significantly, sorghum contains higher levels of vitamin B and iron than rice, making it a crucial tool in the fight against nutritional deficiencies and an alternative solution to food insecurity (Human et al. 2023).

The productivity and yield of sorghum can be increased by using superior varieties. One sorghum breeding activity was used to obtain superior varieties. The limitations of genetic diversity prompted us to improve our search for new sources of genetic resources. Efforts should be made to identify the genetic sources of these plants, including their genetic mutations. Indonesian National Research and Innovation Agency (BRIN) has conducted mutation-breeding of sorghum using gamma radiation at 300 Gy to obtain new sweet sorghum varieties (Sihono et al. 2022). With the changes in sorghum characteristics resulting from this mutation breeding, research activities are expected to yield useful mutant strains of sorghum according to the objectives of plant breeding. Enhancing sorghum's potential as a food crop requires concurrent efforts in breeding superior cultivars. These improved varieties should possess multiple advantages, including high yield potential, robust defense mechanisms against pests and pathogens, the ability to thrive in suboptimal environments, substantial biomass production, and exceptional grain attributes. According to Bailey-Serres (2019), greater and more consistent crop production must be achieved against a backdrop of climatic stress that limits yields owing to shifts in pests and pathogens, precipitation, heat waves, and other weather extremes.

Characterization is an effort to identify important traits. It is crucial to cultivate improved varieties that exhibit multiple desirable characteristics to advance sorghum as a viable food option. These include high productivity, resilience against pests and diseases, adaptability to less favorable soil conditions, substantial biomass production, and superior grain quality. Genetically characterizing germplasm lines is to identify economically valuable or specific traits that need to be conserved and targeted. These characterization and evaluation processes are essential to obtain genetic lines with superior characteristics (Rini et al. 2017).

Various sorghum genotypes with economically superior characters can be used to develop new superior varieties. Agronomic characterization can enrich information regarding genetic diversity, which can be used as the main capital for assembling new varieties that can adapt to local environmental conditions (Slamet et al. 2020; Zapico et al. 2020). It is crucial to test the potential of these agronomic characteristics (Ahimsya et al. 2018) to ensure the progress of sorghum research. This study aimed to characterize the performance of 12 sorghum genotypes and to identify potential lines for developing superior varieties.

MATERIALS AND METHODS

Study area

The experiment was conducted at the Institut Pertanian Bogor Leuwikopo Experimental Farm, Ciampea Sub-district, Bogor, West Java, Indonesia, at 6°33'S and 106°43'E, 190 m asl. Seed quality testing was conducted at the Seed Quality Testing Development Center for Food Crops and Horticulture (BBPPMBTPH), Indonesian Ministry of Agriculture. This study was conducted from June to October 2024.

Plant materials

The sorghum seeds used in this study were obtained from the Food Crop Research Center (PRTP), the Organization of Agricultural and Food Research (ORPP), National Research and Innovation Agency (BRIN). A total of 12 genotypes were used, namely nine BRIN sorghum strains (GHP-2, GHP-16, CTY-43, GH-1, GH-7, GH-9, G-5, G-7, and G-8) and three national varieties (Bioguma 1, Pahat, and Samurai 2).

Procedures

Cultivation

Land preparation consisted of tillage activities for planting to loosen the soil, clean the land from weeds or remnants of previous crops, and liming and applying manure. Seed planting was performed after creating planting holes in plots that were prepared at the land preparation stage. Sorghum seeds were planted at no more than 5 cm in depth, and each hole was filled with three seeds. Replanting was done one Week After Planting (WAP) to replace plants that died or did not grow. Thinning was performed when the plants were at 2 WAP leaving two plants per hole. Fertilizer application to sorghum was carried out in two stages: the first stage was carried out when the plants were 10 days after planting, and the second stage at 4 WAP with a fertilizer dose of urea 200 kg ha^{-1}, KCl 100 kg ha^{-1}, and SP-36 100 kg ha^{-1} (Ardiyanti et al. 2019).

Weeding and fertilization were performed regularly. Pest and disease control were carried out when the plant was attacked by pests by spraying to reduce the attack. Panicle hooding was performed when pollen breakage reached 70% to avoid bird attacks, which otherwise would result in crop yield loss. Sorghum seeds were harvested when plants reached physiological maturity. Characteristics of the plants that were ready to harvest seeds, i.e. the leaves turned yellow, and the panicles with fully matured seeds, characterized by the presence of a black layer on the surface of sorghum seeds.

Research design

The experiment was arranged in a randomized complete block design with one factor, i.e. 12 genotypes and four replications (blocks). Seeds were planted in plots of 1x2.8 m with a spacing of 70x20 cm.

Agronomic character observation and seed quality testing

Observations of agronomic characteristics were performed by the guidelines of Wirnas et al. (2021). Observations were made on ten sample plants in each experimental unit, which included plant height, number of leaves, stem diameter, flowering age, biomass dry weight, harvesting age, panicle length, seed weight per plot, 1000-seed weight, and harvest index. Plant height, number of leaves, and stem diameter were measured at 9 WAP. Quality testing of harvested seeds included seed moisture content, germination percentage and speed, vigor index, maximum growth potential, seedling growth rate, tetrazolium test, and electrical conductivity test. Normal seedlings were counted on the 4^{th} (first count) and 10^{th} day after sowing (final count) (ISTA 2022). Tetrazolium test was performed by moisturizing the seeds at 7°C for 18 h, cutting them longitudinally through the embryo and 1/4 of the endosperm. They were immersed in a 1% tetrazolium solution at 30±2°C for 3 h. The maximum part of the unstained embryo considered viable was 1/3 of the radicle measured from the tip of the radicle. A temperature of 7°C was required to prevent germination during humidification (ISTA 2022). An Electrical Conductivity (EC) test was performed with 75 seeds soaked in 150 mL aquabidest in a glass jar and covered with aluminum foil incubated at 20°C for 24 h. EC measurements were taken using a conductivity meter, and the conductivity per gram of seed weight was calculated (µS cm^{-1} g^{-1}) (Fatonah et al. 2017).

Data analysis

Data was analyzed using analysis of variance at the 5% level with SAS software. If the test results showed a real effect, further tests were carried out with the Duncan Multiple Range Test (DMRT) at α: 5%.

RESULTS AND DISCUSSION

Agronomic characteristics

The agronomic characteristics of the 12 sorghum genotypes (Table 1) showed that line GH-7 was the tallest (228.90 cm) among the mutant lines observed. The GHP-16 line had the shortest plant height (123.43 cm). The difference in plant height in each strain proves that genotype factors significantly affect sorghum plant height. However, Bioguma-1 was the tallest sorghum variant (234.08 cm).

Genotypes had a significant effect on the number of leaves. The average number of leaves for each genotype is shown in Table 1. The highest growth in the number of leaves on sorghum was in the Pahat variety, while the lowest number of leaves was observed in the G-8 line. Among the lines, GH-9 had the highest number of leaves.

This study observed significant variation among genotypes in stem diameter, which indicates differences in the interactions between each genotype and the environment. The GHP-16 line had the largest stem diameter of 27.51 mm, whereas the two genotypes had the smallest stem diameters of 18.71 mm (Samurai-2) and 18.89 mm (GH-1). The mutant line GHP-2 had a large stem diameter of 24.25 mm. Table 1 shows that the average flowering age of the 12 sorghum genotypes was 61.76 days. The CTY-43 line (56.97 days) flowered faster than the other genotypes. The flowering age of Samurai-2 as a comparison variety was 63.02 days and was not significantly different from that of GHP-16, GH-1, GH-7, GH-9, G-5, and G-7.

The Bioguma-1 variety had the highest biomass dry weight (121.45 g) compared to other genotypes (Table 1). Bioguma-1 also had the greatest plant height (234.08 cm), thus contributing to the biomass dry weight. The GH-9 line had the highest biomass dry weight among the other lines (82.66 g), while the lowest was observed in GH-7 (67.65 g), higher than the mutant Pahat variety (60.16 g). This study showed that the biomass dry weight differed between genotypes, indicating that it is more influenced by plant genetics.

The average harvest age of the 12 sorghum genotypes (Table 2) was 104 days, ranging from 96.97 to 114.55 days. Pahat variety, GHP-2, and CTY-43 lines had harvest ages of less than 100 days. The lines that had the fastest harvest age were found in the CTY-43 line (96.97 days) and GHP-2 line (97 days), whereas the fastest was observed in the mutant Pahat variety (89.02 days).

Sorghum genotypes showed significant variation in panicle length (Table 2). Samurai 2 variety and GH-1 line produced the highest panicle length, 31.82 cm, and 31.25 cm, respectively, while the Gh-8 line produced the lowest (20.12 cm). The panicle performance of the 12 sorghum genotypes is shown in Figure 1.

Table 2 shows that genotypes had significantly different effects on seed weight per plot. Bioguma-1 had the highest seed weight (2,455.30 g) per plot. As for all lines tested, the GH-9 line showed the highest yield (1,861.75 g per plot), while the lowest was the CTY-43 line (2,467.61 g per plot). The differences in each genotype were due to the genetic response of each genotype to the environment. The 1000-seed weight of the 12 sorghum genotypes ranged from 22.06 to 33.7 g. The highest 1000-seed weight was found in the GH-9 line (33.7 g), followed by Bioguma-1 (32.32 g).

The harvest index was obtained as the percentage of seed weight to the dry weight of the plant stover. The harvest index represents the distribution of dry matter in the plant, indicating the balance between the weight of economically valuable dry matter and the total dry matter weight of the plant at harvest. A high harvest index indicates the genotype can distribute more assimilates into seeds. The harvest indices of the tested genotypes ranged from 0.44-0.53. Genotypes GH-7, G7, and GHP-2 had the lowest harvest indices, and they have the same harvest index (0.44), and genotype GH-9 had the highest (0.53).

Table 1. Plant height, number of leaves, stem diameter, flowering age, and biomass dry weight

Genotype	Plant height (cm)	Number of leaves	Stem diameter (mm)	Flowering age (days)	Biomass dry weight (g)
Bioguma-1	234.08a	11.25b	23.11c	65.12a	121.45a
Pahat	144.55h	12.13a	23.29c	59.15d	60.16b
Samurai-2	186.55d	9.05g	18.71g	63.02b	80.85b
GHP-2	140.09i	10.37d	24.25b	57.00e	80.98b
GHP-16	123.43j	10.07e	27.51a	63.55b	79.50bc
CTY-43	145.27h	9.02g	23.42c	56.97e	74.97bc
GH-1	228.16bc	10.05e	18.89g	63.22b	72.25bc
GH-7	228.90b	9.87ef	20.55d	63.55b	67.65ab
GH-9	226.85c	10.70c	19.86ef	63.17b	82.66b
G-5	158.96f	9.75f	20.11de	62.95b	76.14bc
G-7	152.39g	9.67f	20.18de	63.10b	78.90bc
G-8	161.47e	9.07g	19.42f	60.35c	73.92bc
Average	177.56	10.08	21.61	61.76	79.12

Note: Numbers followed by the same letters in the same columns are not significantly different at the level of 5% LS

Seed quality testing

All genotypes did not show significantly different germination percentages and speed, vigor index, maximum growth potential, seedling growth rate, and tetrazolium test (Table 3). All genotypes germinated well above 95%. The average growth speed was 27.13 %/d. The vigor index value was above 86% for all genotypes, indicating that the seeds harvested from the 12 sorghum genotypes had high vigor. The average maximum growth potential was 96%. The seedling growth rate ranged from 6.27-7.14 mg/normal seedling. The tetrazolium test results were above 96%, indicating that the 12 sorghum seed genotypes had high viability.

Table 3 shows that genotype had a very significant effect on the dry weight of normal seedlings. The dry weight of normal seedlings was the lowest (0.60 g) in lines GHP-2, CTY-43, and G-7, while the Bioguma-1 variety and GH-9 line were the highest 0.69 g and 0.68 g, respectively. The electrical conductivity of the sorghum seeds was in the range of 10.34-12.64 µS cm^{-1} g^{-1}; the lowest was shown by the Bioguma-1 variety (10.34 µS cm^{-1} g^{-1}), while the highest was the G-7 line (12.64 µS cm^{-1} g^{-1}).

Discussion

Sorghum lines with plant heights between 123.43-228.90 cm open up opportunities to direct and select sorghum according to the required criteria, including sorghum for livestock fodder, sweet stalk and sweet sorghum, and food sorghum. Plant breeding activities for food sorghum, in addition to having high seed production, another selection criterion is to have short plant stem characteristics. The reason for short plants is to facilitate harvesting and to resist falling if there is wind accompanied by rain. Plant height was evaluated in the selected mutant lines to determine the visual characteristics of sorghum. Some farmers prefer short sorghum to make harvesting panicles and seeds easier. The Pahat variety is an example of a sorghum variety that follows farmers' tastes. Pahat is a semi-dwarf sorghum type with 102.04-131.69 cm in height; semi-dwarf small plants grow 100-130 cm tall (Choe et al. 2023). In Table 1, the sorghum genotype classified as semi-dwarf with a height of less than 130 cm is the GHP-16 line, which has a height of 123.43 cm. All mutant lines had lower plant heights than the Bioguma-1 variety, known for its tall and robust growth.

Table 2. Harvesting age, panicle length, seed weight per plot, 1000-seed weight, and harvest index

Genotype	Harvesting age (days)	Panicle length (cm)	Seed weight per plot (g)	1000-seed weight (g)	Harvest index
Bioguma-1	101.75bc	21.95e	2,455.30a	32.32b	0.47
Pahat	89.02e	29.62b	2,131.33cd	28.45e	0.48
Samurai-2	113.05a	31.82a	1,989.25de	27.10f	0.45
GHP-2	97.00d	30.12b	2,085.62cde	26.74f	0.44
GHP-16	113.92a	26.62d	2,378.18ab	22.06i	0.46
CTY-43	96.97d	21.82e	1,861.75e	31.54c	0.45
GH-1	114.55a	31.25a	2,260.92abc	29.60d	0.46
GH-7	102.25b	21.10e	1,871.45e	30.27d	0.44
GH-9	113.17a	29.80b	2,467.61a	33.70a	0.53
G-5	102.95b	28.12c	2,085.59cde	25.76g	0.45
G-7	103.10b	27.95c	2,090.67cde	24.42h	0.44
G-8	100.25c	20.12f	2,181.78bcd	30.14d	0.46
Average	104.00	26.69	2,154.95	28.51	0.46

Note: Numbers followed by the same letters in the same columns are not significantly different at the level of 5% LSD

Table 3. Seed testing of 12 sorghum genotypes

Genotype	MC (%)	GP (%)	GS (% /d)	VI (%)	MGP (%)	DWNS (g)	SGR (mg/normal seedling)	TZ (%)	EC (µS cm^{-1} g^{-1})
Bioguma-1	12.00	96.75	27.08	88.25	97.00	0.69a	7.14	97.00	10.34c
Pahat	12.07	96.50	27.09	87.75	96.75	0.62ab	6.44	96.50	12.21a
Samurai-2	12.00	95.75	27.25	87.50	96.25	0.67ab	7.06	96.25	12.38a
GHP-2	12.02	96.00	27.01	87.00	96.50	0.60b	6.33	96.25	11.95a
GHP-16	12.00	95.75	27.07	87.25	96.25	0.62ab	6.53	96.25	12.63a
CTY-43	12.07	95.75	27.07	87.50	96.25	0.60b	6.27	96.00	11.31abc
GH-1	12.02	96.75	27.23	87.75	96.75	0.63ab	6.55	96.75	12.02a
GH-7	12.15	96.25	26.68	87.75	96.50	0.62ab	6.43	96.50	11.72ab
GH-9	12.12	96.75	27.69	88.25	96.75	0.68a	7.11	97.25	10.48bc
G-5	12.02	95.75	26.95	86.75	95.75	0.63ab	6.63	96.00	12.44a
G-7	12.00	95.25	27.30	87.50	95.25	0.60b	6.33	95.75	12.64a
G-8	12.10	96.00	27.13	87.75	96.00	0.62ab	6.49	96.50	11.94a
Average	12.05	96.10	27.13	87.58	96.33	0.63	6.61	96.42	11.84

Note: MC: Moisture Content; GP: Germination Percentage; GS: Germination Speed; IV: Vigor Index; MGP: Maximum Growth Potential; DWNS: Dry Weight of Normal Seedlings; SGR: Seedling Growth Rate; TZ: Tetrazolium Test; DHL: Electrical conductivity. Numbers followed by the same letters in the same columns are not significantly different at the level of 5% LSD

Figure 1. Panicle performance of the 12 sorghum genotypes. A. Bioguma-1, B. Pahat, C. Samurai-2, D. GHP-2, E. GHP-16, F. CTY-43, G. GH-1, H. GH-7, I. GH-9, J. G-5, K. G-7, L. G-8. Bar = 2cm

The number of leaves is an indicator of sorghum production as animal feed. According to Harmini (2021), 90-day-old sorghum with 10 to 14 leaves positively correlated with fresh biomass production. In this study, the GH-9 line was also developed for animal feed with a height of 226.85 cm and a leaf number of 10.70. The number of leaves is closely related to the amount of light captured and the CO_2 absorbed by the plants for photosynthesis. The more light received, the more photosynthates are produced to support plant growth. This agrees with Long et al. (2015), photosynthesis is considered one of the most important approaches to increasing crop yield. The more leaves there are, the higher the photosynthesis. The result of photosynthesis is then translocated to other plant parts to produce high biomass.

According to Elangovan et al. (2014), sorghum stem diameter characteristics are divided into three categories: small (<2 cm), medium (2-4 cm), and large (>4 cm). In Table 1, the sorghum genotypes included in the small category were Samurai-2 (18.71 mm), GH-1 (18.89 mm), GH-9 (19.86 mm), and G-8 (19.42 mm). The other genotypes fell into the medium category. The results showed that all sorghum genotypes had stem diameters >18 mm. This size is bigger than reported previously (Li et al. 2015), which stated that the diameter of sorghum plants of various types was 1.66-1.74 cm. The role of environmental factors in affecting sorghum stem diameter is significant, as differences in sorghum response to the environment will cause differences in diameter and some agronomic parameters. Sensitive sorghum genotypes show stronger changes in physiological traits and yield components (Dewi et al. 2023). Interactions between genetic and environmental characteristics cause the diverse agronomic observations of sorghum (Maftuchah et al. 2021).

Flowering, a crucial indicator of plant age, is more than just a biological event. It's a key adaptive trait that enables plants to synchronize reproduction with the most favorable environmental conditions (Vicentini et al. 2023). The age at which a plant flower is determined by the length of its vegetative phase, a process influenced by genetic factors and environmental conditions; this means that while all sorghum plants are of the same type, they do not flower at the same age. Environmental factors, such as nutrient absorption, can also influence the flowering age of sorghum plants. The differences in flowering and harvesting age under the same conditions and environment, according to Ozdogan et al. (2019), come from the individual's genes. In this study, the flowering age of each genotype sorghum plant was different and influenced more by genetic factors. Genotypes are included in the category that determines plant growth and development. Differences in growth characteristics among genotypes are due to differences in the genetic structure, concentrations of mineral elements, and partitioning of photosynthetic products in each part of the plant. Genetic factors play an important role in controlling a trait compared to environmental factors. Genetic factors controlled the appearance of phenotypes of several agronomic characters (Kartahadimaja et al. 2021).

Plant dry weight is influenced by nutrient absorption. Plant growth is related to the availability of nutrients and water in the soil and absorbed by the roots, which can affect the plant's weight. In this study, the GH-9 line effectively absorbed nutrients, as evidenced by its high biomass dry weight.

According to Subagio and Aqil (2014), the harvest age of sorghum plants can be grouped into three categories: early (less than 80 days), medium (80-100 days), and deep (>100 days). The CTY 43 and GHP-2 lines were 96.97 days and 97 days, respectively, included in the medium harvest age, whereas the other lines were included in the deep harvest age because the harvest time was above 100 days. Meanwhile, the observation result reveals that the flowering age and harvest age of the CTY-43 genotype is the fastest among the other sorghum genotypes; factors of nutrition and the environment influence this condition. The appropriate environment for growth will stimulate plants to flower and harvest faster (Sulistyowati et al. 2015).

The 1000-seed weight was used to assess seed quality: the larger the food reserves, the heavier the seeds. Bečka (2024) found that the number of seedlings per row increased under field conditions as seed size increased. Seedlings from small seeds had the poorest establishment compared to large seeds. Likewise, regressed seeds will have a lower weight than high-vigor seeds. The 1000-seed weight is the ratio of the weight of 1000 seeds produced by a variety. The 1000-seed weight is necessary to determine the need for seeds per hectare; the GH-9 line had the highest 1000-seed weight. Wahyuningrum et al. (2022) stated that high-weight seeds can grow into strong seedlings and accelerate the seedbed period of the three rice varieties tested. High- and medium-weight seeds had better vegetative growth than low-weight seeds.

Hütsch and Schubert (2017) reported that the harvest index can be used to measure reproductive efficiency. For many crop plants, an increase in the harvest index was achieved by breeding shorter cultivars, shortening the vegetative phase in favor of a longer grain-filling period, and delaying sowing, which also reduces the vegetative growth phase. Therefore, the harvest index is related to genetics. Genotypes with high harvest indices provided high seed yields. Harvest index is an important characteristic that determines seed yield. The correlation between the harvest index and seed yield was more consistent than that between the other characteristics because the influence of the environment on the harvest index was relatively small. This indicates that the harvest index can be used as a selection criterion to obtain high-yielding genotypes in breeding programs (Asefa 2019).

The results of seed quality testing showed that the seed production of the 12 sorghum genotypes tested in this study was of high quality. All genotypes produced values for seed moisture content, germination, germination speed, vigor index, maximum growth potential, seedling growth rate, and tetrazolium test, which were not significantly different. The average moisture content was 12.1% (Table 3). The seed moisture content, a crucial factor in seed storage, was optimal for these genotypes. The problem with seed supply is the decline in seed quality during storage, and the role of moisture content in this decline cannot be overstated. During the storage period, the seeds experience a reduction in viability and vigor depending on the type of seed, especially concerning moisture content. Sorghum seeds with a high moisture content above 14% can increase the rate of seed deterioration during storage. This is in line with a previous study (Timotiwu et al. 2017), which showed that sorghum seeds stored for 10 months at 18°C with a moisture content of less than 12% had a germination rate of 78%. Wawo et al. (2020) stated that corn seeds with moisture content below 12% can be free from microbial infection, and high seed moisture content above 14% can accelerate the process of seed damage.

All genotypes germinated well above 90% (Table 3). Germination is the most widely used measure of seed viability for seed quality testing. According to Ilyas (2012), seed viability is the seed's vitality, metabolically active, and contains enzymes that can catalyze metabolic reactions needed for the germination and growth of the seedlings. The availability of food reserves in seeds also supports the process of seed germination. Seeds with high viability indicate that the seeds have sufficient food reserves in the endosperm, which is used as an energy source by the seeds during the germination process.

The dry weight of normal seedlings, describing the amount of available food reserves, is one of the main benchmarks for seed viability testing. Under appropriate environmental conditions, seeds can grow into strong and structurally complete normal seedlings (Ilyas 2012). The high seedling dry weight illustrates the efficient utilization of food reserves in seeds. Highly vigorous seeds can quickly transfer raw materials to the embryonic axis, resulting in increased dry matter accumulation. The substantial dry weight indicates efficient utilization of seed food reserves (Bahri et al. 2018). Seed size has a significant effect on dry weight (Table 3). The large seeds of the Bioguma-1 variety and GH-9 line had the highest seedling dry weight of 0.69 g and 0.68 g, while the small seeds of CTY-43, G-7, and GHP-2 lines had a low seedling dry weight of 0.60 g.

The difference in the electrical conductivity values of the 12 genotypes might be due to seed deterioration. Seed deterioration is related to biochemical changes in seeds. Changes in cell membrane integrity are the first symptom of seed deterioration and the decrease in cell membrane integrity results in the release of compounds from seeds. According to Ujjainkar et al. (2021), as seeds lose vigor nutrients exude from their membranes, and low-quality seeds leak electrolytes such as amino and organic acids. In contrast, high-quality seeds contain their nutrients within well-structured membranes. Therefore, seeds with higher conductivity are indications of low-quality seeds and vice versa. The electrical conductivity test showed a positive correlation with potassium leakage. The electrical conductivity test is based on the resistance to the flow of an electric current imposed upon the seed's steep water. The resistance is a function of the number of electrolytes in the solution. Pure water has great electrical resistance, but solutions of electrolytes, which are ionic substances, allow electric currents to flow. Many cellular constituents are acids, bases, or their salts, that is, electrolytes. Electrolyte efflux from seeds during imbibition presumably indicates the seed cell membrane condition. Weak seeds generally possess a poor membrane structure, which results in greater electrolyte loss and higher conductivity (Fatonah et al. 2017).

Bioguma-1 (10.34 µS cm^{-1} g^{-1}) and GH-9 (10.48 µS cm^{-1} g^{-1}) seeds have large seeds but have the lowest electrical conductivity values compared to other sizes. In comparison, the small seeds of GHP-16 had a high electrical conductivity value of 12.63 µS cm^{-1} g^{-1}. The Electrical Conductivity (EC) value increased from large seeds to small seeds. Silva et al. (2023) studied soybean seeds, stating that the higher the EC, that is, the higher the leaching of exudates of the seeds, the lower the integrity level of the membranes is, which may indicate the occurrence of deterioration, consequently, lower seed vigor. High EC may justify the worst performance of the seeds in storage. According to Noviana et al. (2016), the increasing EC in soybean seeds indicated that the seeds were damaged and the seed vigor decreased. Large seeds have high vigor with low membrane leakage, and small seeds have high membrane leakage and low vigor. Fatonah et al. (2017) predicted the standard germination and field emergence values in sorghum seeds with an electrical conductivity test. The electrical conductivity value with a range of 10.1-12.5 µS cm^{-1} g^{-1} predicted a germination value of 74.03-80.45 and an emergence value of 75.33-80.77%. In this study, the electrical conductivity value was 10.34-12.64 µS cm^{-1} g^{-1} with germination above 95%, which indicates that the harvested seeds were high quality and had not deteriorated.

This study concluded that the lines used in this study have genetic diversity, which can be seen from their agronomic characteristics. The lines selected were adjusted for plant height, seed production, and early maturation. GH-9 line showed the highest productivity (2467.61 g per plot) and 1000-seed weight (33.7 g). The fastest flowering age (57 days) was on the CTY-43 line, and the lowest plant height (123.4 cm) was on GHP-16.

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REFERENCES

Ahimsya MB, Basunanda, Supriyanta P. 2018. Morphological characterization and photoperiodism of local rice (*Oryza sativa* L.) Indonesia. Vegetalika 7: 52-65. DOI: 10.22146/veg.33557.

Amaducci S, Colauzzi M, Battini F, Fracasso, Perego A. 2016. Effect of irrigation and nitrogen fertilization on the production of biogas from maize and sorghum in a water-limited environment. Eur J Agron 76: 54-56. DOI: 10.1016/j.eja.2016.01.019.

Ardiyanti SE, Sopandie D, Wirnas D, Trikoesoemaningtyas. 2019. Ratoon productivity of sorghum breeding lines (*Sorghum bicolor* (L.) Moench). IOP Conf Ser Earth Environ Sci 399: 012030. DOI: 10.1088/1755-1315/399/1/012030.

Asefa G. 2019. The role of harvest index in improving crop productivity: A review. J Nat Sci Res 9 (6): 24-28. DOI: 10.7176/JNSR.

Bahri S, Syamsuddin, Syafruddin. 2018. Viability and vigor of cocoa seed (*Theobroma cacao* L.) to some levels of water content and old period of save. Intl J Agron Agric Res 13 (2): 144-154.

Bailey-Serres J, Parker JE, Ainsworth EA, Oldroyd GED, Schroeder JI. 2019. Genetic strategies for improving crop yields. Nature 575 (7781): 109-118. DOI: 10.1038/s41586-019-1679-0.

Batog J, Frankowski J, Wawro A, Lacka A. 2020. Bioethanol production from biomass of selected sorghum varieties cultivated as the main and second crop. Energies 13 (23): 6291. DOI: 10.3390/en13236291.

Bečka D, Bečková L, Satranský M, Pazderů K. 2024. Effect of seed weight and biostimulant seed treatment on establishment, growth, and yield parameters of winter oilseed rape. Plant Soil Environ 70 (5): 296-304. DOI: 10.17221/98/2024-PSE.

Choe M, Han S, Song S. 2023. The semi-dwarf grain sorghum (*Sorghum bicolor* L. Moench) variety 'Noeulchal', with increased digestibility. Korean J Breed Sci 55 (1): 70-76. DOI: 10.9787/KJBS.2023.55.1.70.

Dewi ES, Abdulai I, Bracho-Mujica G, Appiah M, Rötter RP. 2023. Agronomic and physiological traits response of three tropical sorghum (*Sorghum bicolor* L.) cultivars to drought and salinity. Agronomy 13 (11): 2788. DOI: 10.3390/agronomy13112788.

Elangovan M, Reddy GC, Babu PK, Rani MJ. 2014. Preliminary Evaluation of A Mini-Core Collection of Sorghum for Utilization. Directorate of Sorghum Research, Hyderabad, India.

Fatonah K, Suliansyah I, Rozen N. 2017. Electrical conductivity for seed vigor test in sorghum (*Sorghum bicolor*). Cell Biol Dev 1 (1): 6-12. DOI: 10.13057/cellbioldev/v010102.

Griebel D, Webb MM, Campanella OH, Craig BA, Weil CF, Tuinstra MR. 2019. The alkali spreading phenotype in *Sorghum bicolor* and its relationship to starch gelatinization. J Cereal Sci 86: 41-47. DOI: 10.1016/j.jcs.2019.01.002.

Habyarimana E, Franceschi PD, Ercisli S, Baloch FS, Dall'Agata M. 2020. Genome-wide association study for biomass-related traits in a panel of *Sorghum bicolor* and *S. bicolor* × *S. halepense* populations. Front Plant Sci 11: 551305. DOI: 10.3389/fpls.2020.551305.

Harmini. 2021. Pemanfaatan tanaman sorgum sebagai pakan ternak ruminansia di lahan kering. Livest Anim Res 19 (2): 159-170. DOI: 10.20961/lar.v19i2.42359. [Indonesian]

Human S, Indritama WM, Sihono. 2023. Success of mutation breeding of sorghum to support food security in Indonesia. In: Penna S, Jain SM (eds). Mutation Breeding for Sustainable Food Production and Climate Resilience. Springer, Singapore. DOI: 10.1007/978-981-16-9720-3_14.

Hütsch BW, Schubert S. 2017. Chapter two - harvest index of maize (*Zea mays* L.): Are there possibilities for improvement? Adv Agron 146: 37-82. DOI: 10.1016/bs.agron.2017.07.004.

Ilyas S. 2012. Ilmu dan Teknologi Benih: Teori dan Hasil-hasil Penelitian. Institut Pertanian Bogor Press, Bogor. [Indonesian]

International Seed Testing Association (ISTA). 2022. International Rules for Seed Testing. ISTA, Swiss.

Kartahadimaja J, Utomo SD, Yuliadi E, Salam AK, Warsono, Wahyudi A. 2021. Agronomic characters, genetic and phenotypic diversity coefficients, and heritability of 12 genotypes of rice. Biodiversitas 22 (3): 1091-1097. DOI: 10.13057/biodiv/d220302.

Li Y, Mao P, Zhang W, Wang X, You Y, Zhao H, Zhai L, Liu G. 2015. Dynamic expression of the nutritive values in forage sorghum populations associated with white, green, and brown midrib genotypes. Field Crops Res 184: 112-122. DOI: 10.1016/j.fcr.2015.09.008.

Long SP, Marshall-Colon A, Zhu XG. 2015. Meeting the global food demand of the future by engineering crop photosynthesis and yield potential. Cell 161: 56-66. DOI: 10.1016/j.cell.2015.03.019.
Maftuchah, Febriana L, Sulistyawati, Reswari HA, Septia ED. 2021. Morphological diversity and heritability of nine local sorghum (*Sorghum bicolor*) genotypes in East Java, Indonesia. Biodiversitas 22 (3): 1310-1316. DOI: 10.13057/biodiv/d220330.
Noviana I, Qadir A, Suwarno FC. 2016. Perilaku biokimia benih kedelai selama penyimpanan dalam kondisi terkontrol. Jurnal Agronomi Indonesia 44 (3): 255-260. DOI: 10.24831/jai.v44i3.12931. [Indonesian]
Ozdogan E, Zaitchik B, Ademe D, Foltz J, Simane B. 2019. Vulnerability of sorghum production to extreme, sub-seasonal weather under climate change. Environ Res Lett 14: 045005. DOI: 10.1088/1748-9326/aafe19.
Praptiningsih GA, Sri R, Luluk SB, Setyobudi RH. 2020. Adaptation and phenotype varieties of sweet sorghum (*Sorghum bicolor* L. Moench) at different altitudes. Intl J Adv Sci Eng Inf Technol 10 (6): 2429. DOI: 10.18517/ijaseit.10.6.8695.
Regassa TH, Wortmann CS. 2014. Sweet sorghum as a bioenergy crop: Literature review. Biomass Bioenergy 64: 348-355. DOI: 10.1016/j.biombioe.2014.03.052.
Rini EP, Wirnas D, Trikoesoemaningtyas, Sopandie D. 2017. Genetic analysis on agronomic and quality traits of sorghum hybrids in Indonesia. Sabrao 49 (2): 192-200.
Sihono, Human S, Indriatama WM, Marina YM, Puspitasari W. 2022. Yield and performance test of sweet sorghum hope mutants in Citayam, Bogor. In: Wardana R, Harlianingtyas I, Darah PRR, Taufika R, Nuraisyah A, Rohman HF (eds). Prosiding: Seminar Nasional Semanis Tani Polije 2022. Jember, 19 October 2022. [Indonesian]
Silva MF, Soares JM, Xavier WA, Silva FCS, SIlva FL, Silva LJ. 2023. The role of the biochemical composition of soybean seeds in the tolerance to deterioration under natural and artificial aging. Heliyon 9: e21628. DOI: 10.1016/j.heliyon.2023.e21628.
Slamet A, Hisrab, Rajab. 2020. The characteristics of the morphological genotypes of local sorghum (*Sorghum bicolor* L. Moench) from Buton Selatan. Sci Educ 9 (1): 87-95. DOI: 10.24235/sc.educatia.v9i1.6120.
Subagio H, Aqil M. 2014. Development of improved sorghum variety for food, feed, and bioenergy. IPTEK Tanaman Pangan 9 (1): 39-50. [Indonesian]
Sulistyowati Y, Trikoesoemaningtyas, Sopandie D, Ardie SW, Nugroho S. 2015. Estimation of genetic parameters and gene actions of sorghum (*Sorghum bicolor* (L.) Moench) tolerance to low P condition. Intl J Agron Agric Res 7 (3): 38-46.
Timotiwu PB, Eko P, Agustiansyah, Asih NWAS. 2017. Effect of storage periods on physical quality and seed vigor of four varieties of sorghum (*Sorghum bicolor* [L.] Moench). Res Agric 2 (2): 29. DOI: 10.22158/ra.v2n2p29.
Ujjainkar VV, Vidyapeeth PDK, Marawar MW. 2021. Seed vigor testing in cotton: A review. Intl J Adv Res Ideas Innov Technol 7 (4): 675-679.
Vicentini G, Biancucci M, Mineri L, Chirivì D, Giaume F, Miao Y, Kyozuka J, Brambilla V, Betti C, Fornara F. 2023. Environmental control of rice flowering time. Plant Commun 4 (5): 100610. DOI: 10.1016/j.xplc.2023.100610.
Wahyuningrum A, Zamzami A, Agusta H. 2022. Effect of 1000-seed weight on field emergence, growth, and production of several rice varieties (*Oryza sativa* L.). Bull Agrohortic 10 (3): 321-330. DOI: 10.29244/agrob.v8i3.46485.
Wawo AH, Sumbogo VG, Lestari P. 2020. Comparison of seed germination and seedling growth between Indonesian local corn cultivars for deciding the quality of seed. Biodiversitas 21 (7): 3189-3199. DOI: 10.13057/biodiv/d210741.
Wirnas D, Oktanti N, Rahmi HN, Andriani D, Rini EP, Marwiyah S, Sopandie D. 2021. Genetic analysis for designing an ideotype of high-yielding sorghum based on existing lines performance. Biodiversitas 22 (12): 286-5292. DOI: 10.13057/biodiv/d221208.
Xiong Y, Zhang P, Warner RD, Fang Z. 2019. Sorghum grain: From genotype, nutrition, and phenolic profile to its health benefits and food applications. Compr Rev Food Sci Food Saf 18: 2025-2046. DOI: 10.1111/1541-4337.12506.
Zapico FL, Dizon JT, Borromeo TH, McNally KL, Fernando ES, Hernandez JE. 2020. Genetic erosion in traditional rice agroecosystems in Southern Philippines: Drivers and consequences. Plant Gen Res 18: 1-10. DOI: 10.1017/S1479262119000406.