SORGHUM F2 POPULATION DERIVED FROM CROSS-POLLINATION OF "BIOGUMA 1 AGRITAN" AND "GANDO KETA": A GENETIC VARIABILITY AND HERITABILITY

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Abstract. Sorghum has been known as a raw material for food, but it is not widely accepted to consume as a whole grain because its rice taste hard and coarse, especially due to the high amylose or low amylopectin content in the grain. The research aimed to study genetic variability, heritability, and genetic gain of F2 from cross-pollination and select superior genotypes for breeding high yield and good eating quality of sorghum for food. This research was carried out at the ICABIOGRAD "Cikeumeuh Experimental Station" in Bogor-Indonesia. The genetic material used was sorghum varieties "Bioguma 1 Agritan" and "Gando Keta," and 14 F2 populations derived from cross-pollination of those two parents. The results showed a significant difference in the mean value of all observed variables between populations compared to their parents. The population of "F2-3" has a similarity of 88.2% with "Bioguma 1 Agritan" and 26.3% with "Gando Keta". Unweighted simultaneous selection revealed an increase in panicle dry weight (30.77 g or 55.94%) between the parent genotype (mid-parent) and the "F2-3" genotype. Unweighted simultaneous selection on the F2-3 population also showed that selected individual genotypes (G2, G3, G4, G6, G8, and G11) had an average seed weight of 11.08% higher than "Bioguma 1 Agritan" and 188.25% higher than "Gando Keta". Due to the seed weight and panicle dry weight characteristics and a high amylopectin or low amylose content, the "F2-3" population was selected to be used in the breeding of high-yielding and better eating quality in sorghum rice.
Keywords: *agronomic characters, amylose and amylopectin content, sorghum rice*

Introduction

The genetic variability of sorghum (*Sorghum bicolor* (L.) Moench) is low because this plant is a self-pollinating plant with cross-pollination opportunities ranging from 2%-10% (Sihono, 2013). Genetic variability is essential in plant-breeding activities (Syukur et al., 2010). The availability of vast genetic variation within the population will determine the success of the new variety breeding program because the chances of obtaining the desired character are greater (Sushma et al., 2020; Syukur et al., 2010). The effectiveness of selection in plant breeding activities is determined by the availability of vast genetic variability and high heritability (Sushma et al., 2020). High heritability can be seen from the phenotypic appearance, which is more influenced by genetic factors than environmental factors (Hakim, 2010; Hermanto et al., 2017).

The genetic variability of plant populations can be increased through several methods, including the exploration of genetic resources, mutation, and hybridization by artificial cross-pollination (Hermanto, 2017). Artificial cross-pollination can be done to combine

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the desired characters from two or more plant parents so that a population can be used as material for selection (Qadri, 2020). The success of breeding new varieties is determined by the availability of genetic resources, wide genetic diversity, and the understanding of the genetic control of the target characters to be improved (Syukur et al., 2010).

In the development of superior plant varieties, information on the heritability of the target characters of the population resulting from cross-pollinated is needed, as well as the genetic variability and genetic gain of the results of the selection activities (Kristamtini et al., 2016). Homogeneous and heterogeneous populations can be seen from the value of heritability. Homogeneous populations can be seen in the form of parental or hybrid plant populations, and heterogeneous populations can be segregated plant populations. The higher the phenotypic variance than genotypic variance to each target character per generation, which is indicated by the high heritability value, showed that the genetic factor has a greater influence on the character’s expression (Yunandra et al., 2017; Maryono et al, 2019). Heritability is the ratio of genetic variance to phenotypic variance in a character (Baloch et al., 2016). This parameter is very important in selection (Islam et al., 2015).

Sorghum can be used directly for human consumption in its whole grain form to get the most nutrition. It can be prepared similarly to rice, known as “sorghum rice”. Therefore, sorghum plant breeding generally aims to obtain plants with high grain productivity and grain quality. In its importance as food, the grain quality of sorghum includes the edible or eating quality of sorghum rice such as the hardness and stickiness in the texture characteristics. The texture of sorghum rice can be used to evaluate the softness versus hardness and looseness versus stickiness of the rice which is defined as fluffy and sticky rice in a sensory evaluation. Thus, the texture of the whole grain is of great importance to consumers. Amylose content has been traditionally used by breeders and the food industry as the most important texture determinant (Ni et al., 2019).

In this study, the 14 F2 sorghum population tested came from cross-pollination between the “Bioguma I Agritan” variety, which is a new high-yielding sweet sorghum variety with moderate eating quality (Lestari et al, 2019), with the local West Nusa Tenggara (NTB) sorghum variety “Gando Keta” which is adaptive to drought (Fitrahtunnisa, 2020). The end of the activity will be the release of new varieties of sorghum with the characteristics of high seed production and good eating quality grain matched with that of consumers’ preference.

In plant breeding, selection activities are essential to determine the desired character (Yunandra et al., 2017; Wirnas et al., 2020). The selection effectiveness can be seen from the selection’s progress by calculating the selection differential’s value. In this research, pedigree selection, heritability analysis, and analysis on the genetic gain in the selection process were implemented in F2 populations of sorghum in order to obtain genotypes with better agronomic and eating quality characteristics than their parents. Therefore, the research aimed to study genetic variance including heritability and genetic gain progress, and determined the amylose and amylopectin content of the F2 population.

Materials and methods

The experiment was conducted at the ICABIOGRAD “Cikeumeh Experimental Station” in Bogor (altitude: 240 m above sea level, latosol soil type) from February to July 2021.

Materials

The genetic material used was sorghum varieties “Bioguma 1 Agritan” and “Gando Keta” as well as 14 F2 populations resulting from cross-pollination between “Bioguma 1 Agritan” (female parent) and “Gando Keta” (male parent). The sorghum variety “Bioguma 1 Agritan” is a genotype of sweet sorghum with high productivity and moderate rice quality. Meanwhile, “Gando Keta” is a genotype of sorghum that is claimed to have loose rice properties but has a low yield.

Sorghum planting

The seeds of Bioguma 1 Agritan and Gando Keta varieties (controls, parents) and 14 F2 populations derived from cross-pollinations of the two parents were directly planted in the plots. The spacing used is 75 cm x 25 cm. Each population was planted in 4 rows containing 25 plants/row.

Plant care includes fertilization and control of plant pests and diseases. Fertilization was carried out twice, namely when the plant was 15 and 42 days after planting (DAP). The fertilizer doses used were 150 kg/ha Urea, 100 kg/ha SP-36, and 100 kg/ha KCl. Urea fertilizer is given twice, namely 2/3 part at planting and 1/3 part at 42 DAP. Pest and disease control is carried out as needed, including the application of carbofuran at planting and other pesticides if necessary.

Experimental observation

The variables observed in this experiment consisted of agronomic characters, which included plant height (cm), stem diameter (mm), panicle length (cm), panicle diameter (cm), panicle fresh weight (g), panicle dry weight (g) and seed weight (g). In addition to the agronomic characters, the levels of amylose and amylopectin were also evaluated in the selected F2 population.

Data analysis

The Kruskal-Wallis test was used to evaluate the differences in the characters of each population. In this experiment, a comparison of the mean values of 14 F2 populations with control varieties was also carried out through a two-way t-test. The method used is unweighted simultaneous selection using selected characters that positively correlate with seed weight. The correlation between characters was analyzed using the Spearman correlation approach. The character that is the focus in sorghum plant breeding is the productivity character, so in this experiment, the character used in the selection is “Seed weight”.

Analysis of the components of variance and heritability was carried out for each observation variable by following the following formulas:

$$\sigma^2 e = (\sigma^2{}_{P1} + \sigma^2{}_{P2})/2 \tag{Eq.1}$$

$$\sigma^2 p = \sigma^2{}_{F3} \tag{Eq.2}$$

$$\sigma^2 g = \sigma^2 p - \sigma^2 e \tag{Eq.3}$$

$$h^2 bs = (\sigma^2 g / \sigma^2 p) \times 100\% \tag{Eq.4}$$

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where: σ^2e: variance of the environment; σ^2_{P1}: variance in the female parent population; σ^2_{P2}: variance in the male parent population; σ^2p: variance of phenotype; σ^2g: variance of genotype; h^2bs: broad sense heritability.

Heritability values are categorized based on the criteria proposed by Whirter (1979) namely; low ($0 < X < 20\%$); moderate ($20 \leq X < 50\%$); and high ($X \geq 50$). Cluster, heatmap, and bi-plot analyses were also performed on 14 F2 populations to determine the dissimilarity of phenotypes and population groupings. A pedigree selection is carried out to get a genotype with superior characters.

Results

Evaluation of plant performance

The comparison of the mean values between the F2 population and the two parents (Bioguma 1 Agritan and Gando Keta) is using the Kruskal-Wallis test. The mean between the populations on all the observed variables (*Table 1*) showed a significant difference, so a selection could be made through these variables in this experiment. The difference in the mean value between populations indicates diversity within the population.

Table 1. *Analysis of the difference in the mean value based on the Kruskal-Wallis test*

Population	N	The mean value of the observation variable						
		PHt	SDm	PLt	PWt	PFW	PDW	SWT
F2-1	12	155.50	19.35	20.00	7.25	87.45	76.08	42.85
F2-2	17	186.00	18.00	19.50	6.50	73.60	62.70	47.00
F2-3	11	170.00	18.40	19.50	7.20	85.50	73.40	31.30
F2-4	17	161.00	16.90	20.00	6.10	58.10	44.20	24.20
F2-5	7	158.00	17.40	18.50	6.00	70.41	53.60	33.50
F2-6	12	164.00	17.50	19.80	6.00	57.15	49.80	23.65
F2-7	11	155.00	17.30	18.60	6.00	76.96	60.30	33.00
F2-8	10	181.50	18.10	19.75	6.50	74.70	64.25	35.35
F2-9	15	164.00	17.30	20.00	5.50	66.30	58.90	31.60
F2-10	13	168.00	18.50	20.30	7.00	83.06	72.60	47.00
F2-11	13	195.00	17.00	20.00	6.00	53.60	49.70	31.30
F2-12	14	207.00	16.90	18.70	6.00	52.85	46.55	30.35
F2-13	15	189.00	16.50	18.50	6.00	66.05	49.70	34.50
F2-14	14	192.50	16.95	18.70	5.95	78.68	57.92	41.00
Bioguma	10	157.10	19.05	20.50	7.00	117.56	91.25	
Gando Keta	10	202.25	10.45	12.00	6.00	37.45	26.95	
Value-H		56.33**	60.67**	48.01**	41.51**	64.04**	62.88**	39.58**

** = has a significant effect on $\alpha = 0.01$ based on Kruskal-Wallis test; PHt = plant height (cm); SDm = stem diameter (cm); PLt = panicle length (cm); PWt = panicle width (cm); PFW = panicle fresh weight (g); PDW = panicle dry weight (g); SWt = seed weight (g)

In this experiment, cluster analysis and heatmap were also carried out to determine the level of similarity between the tested populations. Based on the results of the

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analysis, it is known that there are significant differences between the two parents, namely the varieties “Bioguma 1 Agritan” and “Gando Keta” because they only have a similarity coefficient of 14.6%. The populations that have the most significant similarity to the genotypes of the parent “Bioguma 1 Agritan” are the populations “F2-1” and “F2-3”. The population of “F2-1” has a similarity of 89.1% with “Bioguma 1 Agritan” and 17.8% with “Gando Keta”. The population of “F2-3” has a similarity of 88.2% with “Bioguma 1 Agritan” and 26.3% with “Gando Keta”. Visualization of the level of similarity analysis between the test populations is presented in the form of a Heatmap matrix (*Fig. 1*).

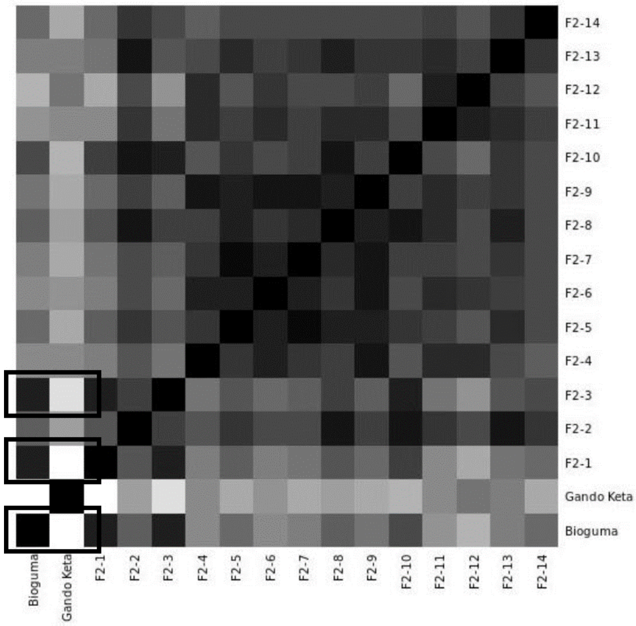

Figure 1. *Heatmap matrix of similarity between 14 populations*

The selection process is carried out by focusing on the character of superior plants with high production. The main character used as selection character is the seed weight character and other production characters. It takes a longer time to obtain information on the character of the results and productivity. A better understanding of the relationship between grain yield and yield component characters becomes necessary (Kumar et al, 2014). Then, a correlation analysis was carried out between the observed variables on the production character to obtain a selection character.

The results of the correlation analysis showed that all variables had a significant correlation to the character of seed weight. Variables of stem diameter, panicle length, panicle width, panicle fresh weight, and panicle dry weight positively correlated with the character of seed weight (*Table 2*). It shows that the larger the stem diameter and the panicle character, the higher the plant production, as indicated by the value of seed weight. On the other hand, the plant height variable negatively correlated with the seed weight variable, so the higher the sorghum plant, the lower the crop production. The results of the correlation analysis also showed that the dry weight character of the panicle had the most significant correlation coefficient value on the weight of sorghum seeds. So these characters are used in the initial selection to select the F2 population to be continued in the plant breeding program in this experiment.

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***Table 2.** Correlation between variables in the F2 population of sorghum from the cross-pollinations of "Bioguma 1 Agritan" and "Gando Keta"*

	PHt		SDm		PLt		PWt		PFW		PDW	
PHt	- 0.059	ns										
SDm	- 0.328	**	0.461	**								
PLt	- 0.064	ns	0.647	**	0.460	**						
PWt	- 0.206	**	0.644	**	0.435	**	0.751	**				
PFW	- 0.214	**	0.690	**	0.541	**	0.765	**	0.966	**		
PDW	- 0.214	**	0.616	**	0.496	**	0.674	**	0.911	**	0.933	**

ns = has not significantly correlated with α = 0.05; ** = has significantly correlated α = 0.01 based on Spearman correlation test; PHt = plant height; SDm = stem diameter; PLt = panicle length; PWt = panicle width; PFW = panicle fresh weight; PDW = panicle dry weight

F2 population selection

The selection of the F2 population is done by selecting the genotype with a high variable value, better or equal to the best parents, which in this case is the "Bioguma 1 Agritan" genotype. A t-test was carried out between the F2 plant population and the parent's genotype to determine the mean value difference of each variable.

The results show that most of the F2 population have different and better characters than the "Gando Keta" genotype. In addition, several genotypes have panicle dry-weight characters that are not significantly different from the "Bioguma 1 Agritan" parents. These F2 populations were "F2-1" (80.60 g), "F2-3" (73.60 g), "F2-5" (57.60 g), "F2-8" (62.20 g), "F2-10" (63.80 g), and "F2-14" (69.30 g) (*Table 3*). Based on these results, those F2 populations were then selected in the initial selection stage.

The following selection focuses on the six previously selected F2 population by considering each observation variable's value. The "F2-1", "F2-3" and "F2-14" populations were selected at this stage of selection because they had significantly better target agronomic variable values than the "Gando Keta" parent while were not significantly different from the "Bioguma 1 Agritan" parent as their best parent. The "F2-1" and "F2-3" populations had average plant growth that tended to be short (165.70 cm and 171.80 cm), large stem diameter (19.84 mm and 18.55 mm), and high production (PDW = 80.60 g and 73.60 g). While the "F2-14" genotype had high plant performance (189.20 cm), narrow stem diameter (16.81 mm), and lower production (69.30 g) compared to the two previous genotypes.

In determining the genotype to be used in the breeding program for high-yielding sorghum plants, information regarding the population's genetic variability is required, because the success of the selection heavily relies on the occurrence of variability controlled by a genetic factor (Hidayatullah et al., 2018). Thus, the components of genetic variance and heritability were analyzed to obtain the information. The results of the analysis showed heritability for panicle fresh weight and panicle dry weight characters in the F2-1 population = 34.66%; F2-3 = 68.30% and F2-14 = 85.52%. If the heritability is high, the selection can start at the F2 generation (Sa'diyah and Barmawi, 2012). In general, it can be seen that the character of plant height and stem diameter in the F2-14 population does not have a chance to be genetically corrected because it has a value of h2bs = 0% (*Table 4*). The population "F2-1" had low heritability for most characters and moderate heritability for panicle dry-weight

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characters. The population “F2-3” has a high heritability value for panicle fresh and dry-weight characters. Thus, the pedigree selection method can be applied as the best selection method.

In addition to obtaining genotypes with high production, sorghum plant breeding has another goal: to obtain sorghum varieties with good eating quality properties. The nature of meal quality in cereals such as rice, corn, and sorghum is generally influenced by the balance of amylose and amylopectin levels in the seeds (Mohd Yusof et al., 2005). The sorghum rice with more amylopectin content was wet, and the taste was better. Seeds that have a low amylose content will produce fluffier rice which has a soft and loose texture when consumed as a carbohydrate source in a meal (Ni et al., 2019). Therefore, in this study, the F2 population of sorghum, which has low amylose and high amylopectin content, will be selected for further use in the breeding programs.

Table 3. *The results of the t-test between the parental genotype population and the F2 population*

Population	The average value of observation variables											
	PHt (cm)		SDm (mm)		PLt (cm)		PWt (cm)		PFW (g)		PDW (g)	
F2-1	165.70	b	19.84	b	20.88	b	7.38	b	94.60	b	80.60	b
F2-2	190.30	a	18.18	b	20.23	b	6.43	b	74.20	ab	63.10	ab
F2-3	171.80	b	18.55	b	20.26	b	7.16	b	88.10	b	73.60	b
F2-4	165.80	b	16.78	b	20.23	b	5.92	a	55.80	ab	47.80	ab
F2-5	158.70	b	17.71	b	19.04	b	6.23		73.80	ab	57.60	b
F2-6	165.90	b	17.21	b	17.95	b	5.97	a	63.80	ab	54.30	ab
F2-7	154.40	b	16.88	b	19.05	ab	6.09	a	73.50	ab	56.10	ab
F2-8	177.40	b	17.93	b	20.30	b	6.43		70.40	ab	62.20	b
F2-9	164.50	b	16.81	b	20.09	b	5.87	a	68.60	ab	59.50	ab
F2-10	174.20	b	18.38	b	20.55	b	6.72		74.40	ab	63.80	b
F2-11	190.80	a	17.22	b	20.62	b	5.93	a	59.40	ab	52.70	ab
F2-12	198.50	a	16.61	ab	19.28	ab	5.79	ab	51.30	ab	46.60	ab
F2-13	189.40	a	16.19	ab	19.01	ab	6.43		74.30	ab	58.30	ab
F2-14	189.20	a	16.81	b	17.85	ab	5.95	a	88.50	b	69.30	b
Bioguma	165.90		18.68		20.90		7.15		108.60		81.60	
Gando Keta	193.40		10.14		12.20		6.40		38.33		28.47	

a = significantly different from the “Bioguma 1 Agritan” variety; b = significantly different from the “Gando Keta” variety at $p < 0.05$ based on the results of the t test; PHt = Plant Height (cm); SDm = Stem Diameter (cm); PLt = panicle length (cm); PWt = panicle width (cm); PFW = panicle fresh weight (g); PDW = panicle dry weight (g)

Based on amylose and amylopectin contents analysis in sorghum seeds, the results obtained were quite diverse in both the F2 population and the parents (*Table 5*). From the test results, it was found that there were F2 genotypes that had high amylopectin and lower amylose content than the two parents, namely the “F2 2-13” (81.50% and 18.50%, respectively) and “F2 3-4” (81.88% and 18.12%, respectively), indicating that both were sorghum genotypes with good eating quality, especially in the sorghum rice fluffiness which is indicated by the softness and looseness of the rice characteristics. However, in this experiment, only the “F2-3” population was selected to be used in breeding high-yielding and better texture in sorghum rice quality due to its high

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heritability in panicle fresh and dry weight and low amylose content. Characters having high heritability indicated that genetic factors contributed more to the characters than environmental factors (Hidayatullah et al., 2018).

Table 4. *The genetic variance and heritability of agronomic characters of the selected population*

Characters	Population	σ^2 p	σ^2 e	σ^2 g	2σ σ^2 g	h^2 bs (%)
Plant height (cm)	F2-1	593.15	541.47	51.68^{W}	14.38	8.71L
	F2-3	370.96		0.00^{N}	0.00	0.00^{L}
	F2-14	237.72		0.00^{N}	0.00	0.00^{L}
Stem diameter (mm)	F2-1	4.45	6.93	0.00^{N}	0.00	0.00^{L}
	F2-3	4.68		0.00^{N}	0.00	0.00^{L}
	F2-14	5.28		0.00^{N}	0.00	0.00^{L}
Panicle length (cm)	F2-1	3.37	4.08	0.00^{N}	0.00	0.00^{L}
	F2-3	2.84		0.00^{S}	0.00	0.00^{L}
	F2-14	10.35		6.28^{W}	5.01	60.61^{H}
Panicle width (cm)	F2-1	0.78	0.87	0.00^{N}	0.00	0.00^{L}
	F2-3	0.85		0.00^{N}	0.00	0.00^{L}
	F2-14	1.05		0.18	0.84	16.87^{L}
Panicle fresh weight (g)	F2-1	550.33	166.75	383.58^{W}	39.17	69.70^{H}
	F2-3	634.58		467.83^{W}	43.26	73.72^{H}
	F2-14	1768.40		1601.65^{W}	80.04	90.57^{H}
Panicle dry weight (g)	F2-1	192.02	125.46	66.56^{W}	16.32	34.66^{M}
	F2-3	395.77		270.31^{W}	32.88	68.30^{H}
	F2-14	866.57		741.11^{W}	54.45	85.52^{H}

σ^2e: variance of environment; σ^2_{P1}: variance in the female parent population; σ^2_{P2}: variance in the male parent population; σ^2p: variance of phenotype; σ^2g: variance of genotype; h^2bs: broad sense heritability. W = wide genetic variability; N = narrow genetic variability; H = high heritability category; M = moderate/medium heritability category; L = low heritability category

Table 5. *Amylose and amylopectin levels of sorghum seed F2 population and parents genotypes*

No.	Population	Amylose (%)	Amylopectin (%)	No.	Population	Amylose (%)	Amylopectin (%)
1.	F2 1-4	41.15	58.85	12.	F2 9-4	46.41	53.59
2.	F2 1-5	40.56	59.44	13.	F2 9-8	32.96	67.04
3.	F2 2-13	18.50	81.50	14.	F2 10-7	41.82	58.18
4.	F2 3-4	18.12	81.88	15.	F2 11-9	47.57	52.43
5.	F2 4-15	42.97	57.03	16.	F2 12-12	21.89	68.11
6.	F2 5-6	54.31	45.69	17.	F2 13-12/2	39.31	60.69
7.	F2 6-11	54.71	45.29	18.	F2 14-13	44.17	55.83
8.	F2 7-5	25.12	74.88	19.	Bioguma (1)	21.98	78.02
9.	F2 7-6	20.40	79.60	20.	Bioguma (2)	20.57	79.43
10.	F2 8-4	58.61	41.39	21.	Gando Keta (1)	40.40	59.60
11.	F2 8-8	58.35	41.65	22.	Gando Keta (2)	37.40	62.60

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Simultaneous selection and selection progress

The selection was carried out on 11 individual plants which were in the “F2-3” population, namely the genotypes “F2-3-1” (G1) to “F2-3-11” (G11) (*Table 6*). The selection was done using yield characters, namely panicle fresh weight, panicle dry weight, and seed weight, with an unweighted simultaneous selection method.

If a single selection was made on panicle fresh weight characters, the genotypes G3, G4, G6, and G8 were selected with an average value of 112.86 g or 3.90% higher than “Bioguma 1 Agritan” and 194.44% higher than “Gando Keta”. However, if the unweighted simultaneous selection is carried out, the average value is 85.72 g or 21.08% lower than “Bioguma 1 Agritan” but 123.63% higher than “Gando Keta”.

Table 6. *Simultaneous selection of F2-3 population genotypes*

No	Population	Selection Variable			Average of simultaneous selection of F2-3 genotypes (g)
		Panicle fresh weight (g)	Panicle dry weight (g)	Seed weight (g)	
G1	F2-3-1	81.90	69.30	40.00	63.73
G2	F2-3-2	85.50	76.20	50.00	70.57
G3	F2-3-3	135.97	114.20	84.00	111.39
G4	F2-3-4	111.04	92.50	66.00	89.85
G5	F2-3-5	79.10	67.90	38.00	61.67
G6	F2-3-6	113.70	80.20	55.00	82.97
G7	F2-3-7	53.80	45.50	30.00	43.10
G8	F2-3-8	90.71	73.40	55.00	73.04
G9	F2-3-9	82.80	70.50	47.00	66.77
G10	F2-3-10	49.00	41.50	22.00	37.50
G11	F2-3-11	85.60	78.20	52.00	71.93
Average per variable (g)		88.10	73.58	49.00	70.23
The average genotype of simultaneous selection (g)		85.72	85.78	60.33	77.28
Average difference (g)		- 2.38	12.20	11.33	7.05
		108.62	81.56	54.31	
		38.33	28.47	20.93	

If a single selection was made on the panicle dry weight character, the genotypes G2, G3, G4, G6, and G11 were selected with an average value of 88.26 g or 8.21% higher than “Bioguma 1 Agritan” and 210% higher than “Gando Keta”. However, if the unweighted simultaneous selection is carried out, the average value is 85.78 g or 5.17% higher than “Bioguma 1 Agritan” and 201.3% higher than “Gando Keta”. If a single selection is made on the seed weight character, the genotypes G2, G3, G4, G6, G8, and G11 are selected with an average value of 60.33 g or 11.08% higher than “Bioguma 1 Agritan” and 188.25% higher than “Gando Keta.” The result is also the same if an unweighted simultaneous selection is carried out (*Table 6*).

The analysis found that there was an increase in the mean value of the panicle dry weight variable between the parent population (mid-parent) and the “F2-3” population of 18.57 g or 33.75%. There was an increase in panicle dry weight mean value variable between the “F2-3” population in a single selection and the “F2-3” population from the

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unweighted simultaneous selection of 12.2 g or 16.58%. So, an unweighted simultaneous selection can be used further. In that case, there will be an increase in the median value of the panicle dry weight variable between the parent genotype (mid-parent) and the “F2-3” genotype resulting from the unweighted simultaneous selection of 30.77 g or 55.94% (*Fig. 2*).

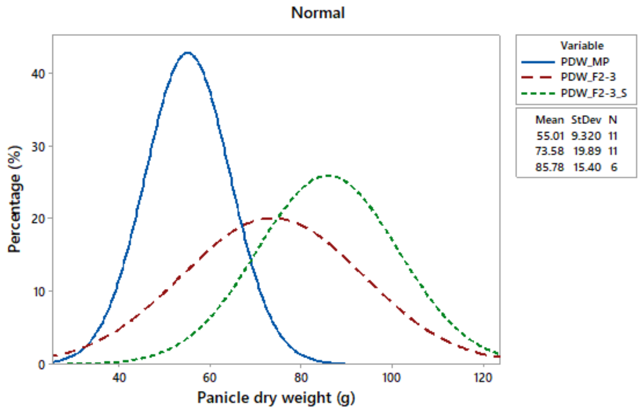

Figure 2. *The normal distribution curve of panicle dry weight of the mid-parent population, population F2-3, and population F2-3 from the simultaneous selection*

The mean value of the variable dry weight and seed weight of the F3 population can be estimated through genetic gain analysis (*Table 7; Fig. 2*). The F3 genotype population based on the previous unweighted simultaneous selection of the “F2-3” population mean value for the panicle dry weight character is estimated to be around 77.28 g, or an increase of 5.05% from the population of F2-3, with a maximum mean of 81.59 g. The yield obtained was 5.25% lower than the mean panicle dry weight of the “Bioguma 1 Agritan” variety but 171.44% higher than the “Gando Keta” variety. The F3 genotype generation means value based on the unweighted simultaneous selection of the F2-3 population for the seed weight character is estimated to be around 52.69 g, or an increase of 7.53% from the F2-3 population, with a maximum mean of 57.01 g. The yield was 2.98% lower than the mean seed weight of the “Bioguma 1 Agritan” variety but 151.74% higher than the “Gando Keta” variety.

Discussion

Genetic variability is an essential component needed in plant breeding programs. This genetic variability is crucial because it is related to the opportunity to obtain superior plant genotypes (Usman et al., 2017). Increasing the genetic variability of plant populations can be done through several methods, one of which is hybridization or artificial cross-pollination (Yunandra et al., 2017). Cross-pollinations need to be carried out using two or more parents with significantly different characters to create maximum variability (Goulet et al., 2017). The two parents of sorghum used in this experiment had a reasonably low similarity (14.6%) value (*Fig. 1*), so it can be concluded that they had different properties on various variables (distinct).

Sorghum breeding currently focuses on the development of high-yielding and good cooking and eating quality varieties of sorghum. Thus, in this research, the selection is

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carried out on variables related to production and selected grain quality. However, apart from using production characters, selection can also be made using other characters known to be positively correlated with the target character. Correlation analysis is needed to determine alternative characters that can be used in the selection process. The results showed a positive correlation between stem diameter and seed production and a negative correlation between plant height and seed production. It is well recognized that when a plant grows higher, the likelihood of lodging or stem breakage increases due to the narrower stem diameter. This information is necessary for sorghum breeding in the context of climate change. In addition, excessive (very high) vegetative growth of plants is suspected to cause photosynthate accumulation to be focused on growth but not grain filling. The analysis showed that in addition to use production characters (seed weight), variables of stem diameter, panicle length, panicle width, panicle fresh weight, and panicle dry weight positively correlated with the character of seed weight can also be used as a selection characters for high yielding sorghum plants (*Table 2*).

Table 7. *Estimation of the mean value of panicle dry weight and seed weight characters in the F3 generation*

Types of heritability	Average PDW F2-3 (g)	Selected F2-3 PDW Average (g)	S PDW	G PDW	G SWt (Corr = 0.961)	F3 Average Estimation	
						PDW (g)	SWt (g)
h^2ns (31.5%)	73.58	85.78	12.20	3.84	3.69	77.28	52.69
h^2bs (68.3%)	73.58	85.78	12.20	8.33	8.01	81.59	57.01

h^2ns = narrow sense heritability; h^2bs = broad sense heritability; S = selection differential; G = genetic gain in selection progress; Corr = Spearman correlation coefficient; PDW = panicle dry weight; SWt = seed weight

Inheritance of a character is primarily determined by the value of genetic variability, heritability, and the action of genes that control the character. The value of heritability determines the success of the selection because it can be an indication of a trait influenced by environmental or genetic factors (Kusuma et al., 2017). A character that has a high broad sense heritability value and is controlled by additive gene action with complementary epistasis, then that character can be inherited in the next generation (Barmawi et al., 2013; Sihaloho et al., 2015). Thus, panicle dry weight and seed weight per panicle can be selected as selection characters because they have high broad sense heritability values with broad genetic variability. The use of seed weight characters per panicle as a selection criterion has been widely carried out in other studies such as that of Sungkono et al. (2009), Mao et al. (2011), and Sami et al. (2013).

In addition to selecting plants with high productivity, the good eating quality of sorghum seeds is also a concern in sorghum breeding for food. The eating quality of cereals, including sorghum, is generally influenced by the ratio of amylose and amylopectin content in the seeds (Sang et al., 2013; Ni et al., 2019). The higher amylose content compared to amylopectin, will produce hard and coarse meals, and conversely, the lower amylose content will produce soft and sticky meals (Sang et al., 2013). According to Frei et al. (2003), amylose content in seeds was categorized into five categories, namely waxy (1-2%), very low amylose content (2-12%), low (12-20%), moderate (20-25%), and high (25 – 33%). Based on these categories, both parents had moderate to high amylose levels, so in selecting segregated populations, the selection

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was made on populations with lower amylose levels than the two parents. Most of Indonesia's national sorghum varieties have grain with high amylose content ranging from 29.01% to 35.00% (Budijanto and Yuliyanti, 2012). Genotype "F2-3" has a low amylose content (18.12%) supported by high heritability in panicle dry weight, so it is the potential to be used in the breeding program of high-yielding and good-eating quality sorghum varieties.

After conducting the unweighted simultaneous selection of several characters is carried out in the population "F2-3". Individual genotypes that have an above-average value were selected to be used in the next breeding program. Based on seed weight (SWt) character, genotypes G2 (F2-3-2), G3 (F2-3-3), G4 (F2-3-4), G6 (F2-3-6), G8 (F2-3-8), and G11. (F2-3-11) was selected to be continued in the F3 generation. The results of the genetic gain analysis for panicle dry weight (PDW) and SWt characters indicated that in F3 generation, PWD was estimated to increase by about 5.05% or up to 77.28 g and SWt character to increase by about 7.53% or up to 52.69 g.

Conclusion

A significant difference in the mean value between populations was observed in all observed variables. The population of "F2-3" has a similarity of 88.2% with high yielding variety "Bioguma 1 Agritan" and 26.3% with the local variety "Gando Keta". Unweighted simultaneous selection on the F2-3 population showed that individual genotypes derived from F2-3 population, i.e. G2, G3, G4, G6, G8, and G11 can be selected based on seed weight character to be used in the next high-yielding sorghum breeding program. Furthermore, the significant finding of this research is that the "F2-3" population can be selected to be used in the breeding program of high-yielding and better eating quality in sorghum rice due to high seed weight and panicle weight characteristics and high amylopectin or low amylose content in the grain.

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