INNSPUB

International Journal of Agronomy and Agricultural Research (IJAAR)
ISSN: 2223-7054 (Print) 2225-3610 (Online)
http://www.innspub.net
Vol. 8, No. 3, p. 1-9, 2016

RESEARCH PAPER OPEN ACCESS

Heterosis of sorghum hybrid developed from local and introduced lines

Erin Puspita Rini[1], Trikoesoemaningtyas[1*], Desta Wirnas[1], Didy Sopandie[1], Tesfaye T. Tesso[2]

[1]*Department of Agronomy dan Horticulture, Faculty of Agriculture, Bogor Agricultural University, Bogor, Indonesia*

[2]*Department of Agronomy, Kansas State University, Manhattan, United States*

Article published on March 26, 2016

Key words: Combining ability, heterosis, sorghum, hybrid.

Abstract

Sorghum is a minor crop in Indonesia. The availability of hybrid variety in Indonesia will increase farmer adoption of sorghum as food crop. This study is aimed at obtaining information on combining ability of several IPB breeding lines and introduced lines which are considered as parental lines to develop the first sorghum hybrid variety in Indonesia. The study was conduced for three years from 2012 to 2014, consisted of evaluation of ferformance of Parental lines in acid soil, analysis of combing ability of parental lines and evaluation of heterosis and hybrid performance. The study showed that the B69 and PI-150-21-A lines have good general combining ability for yield and yield component. The introduced line P150-21-A showed a negative SCA value for plant height and could be used to reduced plant height in sorghum hybrids. This study showed that hybrids which have high mid parent heterosis for grain yield/plant were B-69 x Numbu with 72%, PI 150-21-A x Numbu with 66%, PI 150-20-A x Numbu with 63% and PI 10-90-A x Kawali with 62% higher yield compared to the average of the two parents. The hybrid PI 10-90-A x Kawali and B69 x Numbu also showed high high parent heterosis (HPH), which means that the two hybrids have grain yield/plant 33 % and 35% higher than the highest yielding parents. The four hybrids are good candidate for sorghum hybrid varieties with high yield potential.

* **Corresponding Author:** Trikoesoemaningtyas ✉ trikadytia@gmail.com

Introduction

Sorghum is still a minor crop in Indonesia, however, it is ranked number five as food crop in the World. It is grown on 42 million ha in 98 countries in Africa, Asia, Oceania and the Americas, Nigeria, India, USA, Mexico, Sudan, China and Agentina (Reddy *et al.*, 2010). Many factors have made sorghum as one of the most important food crop in the world. Sorghum grains are important source of dietary proteins, carbohydrates, minerals, and B group vitamins with some values higher than rice (Ratnavathi and Patil, 2013).

In addition sorghum has a wide adaptation to various abiotic stresses. Sorghum is a drought tolerant crop and suitable for cultivation in drought prone areas. According to Assefa *et al.*, (2010) a medium-to-late maturing sorghum cultivar requires approximately 450 to 650 mm of water during a growing season. Water stress or drought reduces biomass, yield and HI more in maize than in sorghum, giving higher yields for sorghum under limited water. Under limited water condition, sorghum has great ability to extract water from deep soil layers due to its deep root system (Farre and Faci, 2006). In addition, several sorghum varieties are tolerant to acid soil and able to maintain growth and yield under high Al toxicity and low P found in many acid soil in Indonesia (Agustina *et al.*, 2010). Therefore, sorghum is very potential to be develop as food crop in many marginal areas of Indonesia.

The availability of improved varieties is a major component in the adoption of sorghum by farmers in Indonesia. Several sorghum varieties are available for farmers. All of the available varieties are pure line varieties developed through mutation breeding (Human *et al.*, 2011; Puspitasari *et al.*, 2012) or introduced lines. Most sorghum pure lines have low yield potential. The average yield of the national variety Numbu is 3.11 ton ha^{-1} and Kawali is only 2.9 ton ha^{-1} (Balitsereal, 2012). Hybrid variety has been cultivated in many sorghum producing countries with productivity of 7.0 to 9.0 ton/ha even in semi arid areas (Tadesse *et al.*, 2008). The availability of hybrid variety in Indonesia will increase farmer adoption of sorghum as food crop.

The high productivity of hybrids is due to hybrid vigor or heterosis. Shull (1948) defined heterosis as interpretation of increase vigor, size, fruitfulness, speed of development, resistance to disease and to insect pests, or to climatic rigors of any kind, as the specific results of unlikeness in the constitutions of the uniting parental gametes. The value of heterosis is determined by the gene action, general combining ability and specific combining ability of the parental line Hochholdinger and Hoecker, 2007).

There are two kinds of gene action (additive, non-additive) that can be affected development of hybrid varieties. Siles *et al.*, (2004) showed that the presence of non-additive genetic variance is the primary justification for initiating the hybrid program. Knowing general and specific combining ability effect of genetic materials is practical value in breeding programs. Both components play an important role in selecting superior parents for hybrid combination and represent a powerful method to measure the nature of gene action involved in quantitative traits (Baker, 1978). GCA effects represent the fixable component of genetic variance and important to develop superior genotypes. Meanwhile SCA represent non fixable component of genetic variance and important to provide information on hybrid performance (Maarouf, 2009). In conclusion, These factors (gene action, GCA, SCA) should be use as consideration in the development of hybrid varieties.

This study is aimed at obtaining information on combining ability of several IPB breeding lines and introduced lines which are considered as parental lines to develop the first sorghum hybrid variety in Indonesia.

Materials and methods

Evaluation of Performance of Parental Lines in Acid Soil

The evaluation was conducted in a farmer field in Jasinga, West Bogor District, Bogor Indonesia with soil pH of 4.1 – 4.4 and exchangeable Al of 2.3 -5.8 cmol/kg from April to July 2012. The genetic materials used in this study were 17 F7 breeding lines from the cross of Numbu x UPCA-S1 developed by the Laboratory of Plant Breeding and Genetics, Department of Agronomy and Horticulture, Bogor Agricultural University and four introduced lines from ICRISAT and one local variety. Two national varieties UPCA-S1 and Numbu were used as comparison. The experiment was conducted in a Randomized Complete Block Design with three replicates. The planting was conducted as direct seeding with 2 seeds per hole at 70 x 10 cm planting distance in a 4 m x 5 m plot. Fertilizers of Urea, SP36 and KCl was applied at the rate of 100 kg/ha, 100 kg/ha and 60 kg/ha, respectively. Two third of the urea was applied as base fertilizers at planting with SP-36 and KCl. The rest of the urea was applied at 7 weeks after planting. Plot maintenance and pest and disease control was conducted according to standard practices. Observations were made on ten plants per plot for the following variables ; plant height (cm), time to flowering, (days after planting) Time to harvest (days after planting), Length of spike, Seed weight (g) per spike t per plant (g) measured at 13% moisture content of 10 sample plants per line, weight of 1000 seeds (g) measured at 13 % moisture content.

Study of Combining Ability of Parental Lines

The experiment was conducted at the experimental field of the Department of Agronomy and Horticulture, Bogor Agricultural University, at Leuwikopo, Dramaga, Bogor in January to April 2014. The post-harvest processing was conducted at the Laboratory of Plant Breeding Department of Agronomy and Horticulture, Bogor Agricultural University in May 2014. The plant material used was seven female parental lines (line) namely N/UP-17-10, N/UP-89-3, N/UP-32-8, PI-150-20-A, P/l-10-90-A, Pl-150-21-A, B-69, two varieties of male parent lines as tester ie varieties Numbu and Kawali, and 14 F1 from crosses of N/UP-17-10× Numbu, N/UP-17-10×Kawali, N/UP-89-3×Numbu, N/UP-89-3×Kawali, N/UP-32-8×Numbu, N/UP-32-8×Kawali, PI-150-20-A × Numbu, PI-150-20-A×Kawali, PI-10-90-A×Numbu, PI-10-90-A×Kawali, PI-150-21-A × Numbu, PI-150-21-A×Kawali, B-69×Numbu, and B-69× Kawali.

The study was conducted in a completely randomized block design (CRBD) with genotype as treatment, consisted of parental lines and F1 genotypes with three replicates, in a total of 48 experimental units. Each experimental unit was a plot measuring 2.1 × 1.4 m2. Tillage was done two weeks before planting. There were three rows in each experimental plot. Each plot consisted of three different genotypes. The first row was the female parents (P1), the second row was the F1 (P1xP2) genotype, and the third row was the male parent (P2). The seeds were planted with a spacing of 70 cm × 20 cm. Urea was applied twice, i.e 1/3 of 50 kg ha-1 was given at the beginning as a basic fertilizer along with 100 kg ha-1 SP-36 and 100 kg ha-1 KCl, whereas the 2/3 of Urea 100 kg ha-1 was appllied at 4 weeks after planting (WAP). Observations were conducted on agronomic characters and yield components in 5 samples of each experimental unit.

General combining ability value (GCA) and specific combining ability (SCA) predicted by the modified Singh and Chaudhary (1979) while the value of heterosis and heterobeltiosis character allegedly observed by Fehr (1987). General Combining Ability (GCA), was calculated based on the average genotype of female parents and both tester as

$$\textit{General combining ability} = \frac{\overline{Yi.} - \overline{Y..}}{s}$$

Where,

$\overline{Yi.}$ = means of *line i* × *tester*

$\overline{Y..}$ = means of all genotypes in *line* × *tester*

s = Standard deviation of means of all genotypes in *line* × *tester*

Special Combining (DGK) or Specific Combining Ability (SCA) was assessed based on a combination of a cross which has the largest mean.

Heterosis and F1 Hybrid Performance

The study was conducted to evaluate the performance of F1 hybrids in comparition with the performance of the mean of the two parents (mid parent heterosis) or with the highest parent (heterobeltiosis). The experiment was the same as experiment 2. Heterosis (Mid-parent heterosis), was calculated based on the average performance of the two parents (MP), with the following formula:

$$MPH\ (\%) = \left[\frac{\overline{F1}-\overline{MP}}{\overline{MP}}\right] \times 100\ \%$$

Heterobeltiosis (High-Parent Heterosis), was calculated based on the parent's best performances (HP), with the following formula:

$$HPH\ (\%) = \left[\frac{\overline{F1}-\overline{HP}}{\overline{HP}}\right] \times 100\ \%$$

notes:

$\overline{F1}$ = mean of F1

$\overline{MP}$ = means of the two parental lines

$\overline{HP}$ = mean of the higest parent

Results and discussion

Performance of Parental Lines in Acid Soil

A large areas of Indonesian dry land are consisted of aci soil with high Al toxicity and low soil fertility. The results of the field evaluation in acid soil showed that the acid soil tolerant var. Numbu performed better than the less adapted var. UPCA-S1 as shown in the yield and yield components (Table 1).

Table 1. Performance of agronomic characters of sorghum parental lines grown in acid soil.

Lines	Plant height (cm)	Panicle legth (cm)	Grain yield/panicle(g)	Weight of 1000 seeds (g)
N/UP-166-6	153,5	16,7	39,2	26,8
N/UP-4-3	146,7	15,0	15,2	26,6
N/UP-48-2	197,0	19,5	48,9	30,7
N/UP-159-9	180,9	19,1	34,3	26,6
N/UP-139-5	163,9	16,8	49,6	29,2
N/UP-82-3	180,2	16,2	39,3	29,5
N/UP-118-3	203,6	17,6	74,7	25,4
N/UP-156-8	181,1	16,7	26,9	29,4
N/UP-89-3	162,7	15,1	35,8	29,7
N/UP-39-10	184,5	16,6	35,8	35,2
N/UP-32-8	224,8	16,9	46,3	35,7
N/UP-4-8	178,0	14,8	34,2	26,8
N/UP-118-7	145,5	15,7	33,2	27,8
N/UP-151-3	166,5	16,5	35,5	26,7
N/UP-139-1	168,0	15,3	34,6	29,7
N/UP-17-10	174,5	16,4	35,1	30,2
N-UP-124-7	180,7	16,0	34,8	27,9
PI-150-21A	336,7	24,0	45,2	23,3
PI- 5-193C	323,0	28,7	68,4	33,3
PI-10-90A	274,0	32,3	48,9	26,8
WHP	279,0	23,7	64,7	25,6
PI-150 20A	119,0	23,7	55,4	25,4
UPCA S1	141,1	21,7	26,7	26,8
NUMBU	213,0	20,2	57,1	32,6

The performance of IPB breeding lines from the cross of Numbu x UPCA-S1 were between their parental lines. One IPB breeding line, N/UP-118-3 showed higher than the tolerant parent Numbu and introduced lines with 74.7 g grain yield per panicle. However, some breeding lines have plant height more than 200 cm. N/UP-118-3 was 203.6 cm in height. In acid soil, with high exchangeable Al such as the field in Jasinga, plants with height exceeding 200 cm are prone to lodging, due to limited root growth. Aluminum toxicity inhibits root growth in sorghum (Agustina *et al*, 2010).

In this study four introduced lines from ICRISAT were evaluated. At present, ICRISAT is a major repository for world sorghum germplasm with a total of 36,774 accessions from 91 countries. The introduced genotypes from ICRISAT showed performance similar to the acid soil tolerant var. Numbu, with one line, IP-5-193C has higher mean seed weight/plant of 64.7 g compared to Numbu. This result indicates that the introduced lines could be a source of genetic materials for improvement of yield of the existing varieties.

Table 2. General Combining Ability of Female Parents.

Lines	Plant height (cm)	Stem diameter (cm)	Panicle length (cm)	Panicle weight (g)	Grain yield/plant (g)	Weight 1000 seeds (g)
N/UP 17-10	-0.63	1.96	-1.23	-1.73	-1.37	-1.15
N/UP 89-3	-0.56	0.14	-0.63	-0.86	-1.01	0.42
N/UP 32-8	0.56	0.44	-1.13	0.56	0.82	1.12
PI 150-20-A	-0.96	-0.91	0.64	-0.30	-0.72	-0.67
PI 10-90-A	1.42	-0.16	0.38	0.72	0.51	-0.34
PI 150-21-A	1.10	-0.71	0.55	0.63	1.10	1.43
B-69	-0.93	-0.76	1.41	0.98	0.66	-0.81

However, the introduced lines are taller than Numbu, with plant height ranging from 274–336 cm. Only line PI-150-20-5 which has the lowest plant height of 119 cm (Table 1).

Study of Combining Ability of Parental Lines

A single cross hybrid is a hybrid of a cross between two pure lines that are not related to each other. Inbred lines used in a single cross should be homozygous, which resulted in a single cross hybrid plant that is heterozygous at all loci from the two different pure lines. Superior single cross will be more vigor and productive than the two parents. However, not all combinations of pure lines will produce superior single cross. The combination of pure lines should be tested for combining ability to find a combination which would be useful for the production of hybrid seeds. According Acquaah (2007) the main factors that determine the hybrid advantage is the combining ability of pure lines. General combining ability is the average performance a pure line in various combinations of crosses whereas specific combining ability is the appearance of the pure line in a cross a combination compared with other combinations.

Table 3. Specific Combining Ability of Sorghum Parental Lines.

Crosses	Plant height (cm)	Stem diameter (mm)	Panicle length (cm)	Panicle weight (g)	Grain yield/plant (g)	Weight 1000 seeds (g)
N/UP 17-10 x Numbu	190.67	24.87	17.00	81.07	67.90	26.63
N/UP 17-10 x Kawali	191.00	29.28	17.92	88.73	79.32	26.37
N/UP 89-3 x Numbu	208.78	19.55	18.18	89.19	76.48	32.97
N/UP 89-3 x Kawali	180.01	20.41	21.71	94.37	76.53	31.59
N/UP 32-8 x Numbu	249.00	21.17	18.75	113.72	105.25	35.36
N/UP 32-8 x Kawali	244.17	21.50	17.00	92.37	77.53	34.30
PI 150-20-A x Numbu	191.62	19.34	24.24	106.04	86.94	30.52
P/I 150-20-A x Kawali	159.88	17.52	26.20	86.35	70.89	26.02
P/I 10-90-A x Numbu	281.69	19.04	22.97	97.11	83.97	32.80
P/I 10-90-A x Kawali	291.96	19.70	25.33	111.62	93.85	26.15
P/I 150-21-A x Numbu	300.69	20.02	23.74	114.67	107.33	37.03
P/I 150-21-A x Kawali	242.88	18.81	25.95	92.59	80.09	34.90
B-69 x Numbu	184.33	20.08	29.00	132.80	116.20	30.33
B-69 x Kawali	170.00	8.59	27.81	79.99	64.03	25.13

The B-69 and PI-150-21-A have good general combining ability for yield and yield component. A cross between the two lines with any other lines will result in hybris with high yield potential. The desireable value for GCA of plant height should have a negative value, as shown by P150-21-A. The introduced line PI-150-21-A has the height of 119 cm (Table 1) and cross with PI-150-21-A will results in shorter hybrids.

Table 4. Heterosis Values of Yield Components of F1 hybrids.

F1 Genotypes	Panicle length		Panicle diameter		Panicle weight	
	MPH (%)	HPH (%)	MPH (%)	HPH (%)	MPH (%)	HPH (%)
N/UP 17-10 x Numbu	-5.90	-14.43	19.67	11.89	-6.56	-20.42
N/UP 17-10 x Kawali	-13.17	-28.33	30.36	30.23	14.24	6.01
N/UP 89-3 x Numbu	3.16	-8.47	8.66	1.90	8.39	-12.46
N/UP 89-3 x Kawali	7.50	-13.17	26.59	26.87	28.92	12.74
N/UP 32-8 x Numbu	6.43	-5.62	41.65	28.60	35.35	11.63
N/UP 32-8 x Kawali	-15.77	-32.00	25.84	21.79	23.26	10.35
P/I 150-20-A x Numbu	33.67	22.01	35.59	4.35	67.78	4.09
P/I 150-20-A x Kawali	26.55	4.79	39.93	13.24	59.56	3.16
P/I 10-90-A x Numbu	15.69	15.60	9.68	-4.49	25.97	-4.68
P/I 10-90-A x Kawali	13.01	1.33	38.67	28.30	64.13	33.35
P/I 150-21-A x Numbu	11.36	4.27	38.04	28.08	51.59	12.56
P/I 150-21-A x Kawali	8.65	3.80	18.11	17.01	39.11	10.62
B-69 x Numbu	41.12	36.58	37.99	21.67	61.83	30.36
B-69 x Kawali	20.28	11.22	57.41	47.62	9.61	-4.43

[*] MPH=Mid Parent Heterosis, HPH = High Parent Heterosis.

Heterosis and F1 Hybrid Performance

Heterosis or hybrid vigor is the performance of F1 hybrid which are higher than the parental lines. Heterosis will appear when the pure lines are crossed. The resulting progeny will bring increased value to a character previously low as a result of inbreeding of the parental lines. According to Premalatha (2006) parental lines should be selected based on the potential performance of a hybrid combining information of the average value, combining ability and heterosis. Parental lines for hybrid variety should be selected genotypes with best Specific Combining Ability (SCA) then observed for the heterosis values the the hybrid.

For the yield component characters, the cross combinations that shows high mid parent heterosis for panicle length were PI-150-20-A x Numbu and B-69 x Numbu. The two crosses also showed high mid parent heterosis for panicle weight. The two crosses also showed High Parent Heterosis for panicle legth. The cross of B69 x Numbu resulted in F1 hybrid which showed 36% longer in panicle length and 30% higher panicle weight compared to the highest parent.

This study showed that hybrids which have high mid parent heterosis for grain yield/plant were B-69 x Numbu with 72%, PI 150-21-A x Numbu with 66%, PI 150-20-A x Numbu with 63% and PI 10-90-A x Kawali with 62% higher yield compared to the average of the two parents. The hybrid PI 10-90-A x Kawali and B69 x Numbu also showed high high parent heterosis (HPH) (Table 5), which means that the two hybrids have grain yield/plant 33 % and 35% higher than the highest yielding parents. The four hybrids are good candidate for sorghum hybrid varieties with high yield potential. According Hochholdinger and Hoecker (2007) there are many factors that can affect the value of heterosis namely gene action, general combining ability, specific combining ability, the parental genetic distance and the correlation between the characters. These factors can also be used as consideration in the development of hybrid varieities. Hybrid vigor or heterosis is caused by gene action that occurs between the heterozygous gene loci. There are three hypotheses of gene action that is thought to cause heterosis which are dominant gene, over-dominant and epistasis (Falconer and Mackay 1996).

Gene action in hybrids can be predicted based on the value of the combining ability and heritability. According to Xianlin (2012) when the value of the general combining ability (GCA) is much greater than specific combining ability than the character is controlled by additive genes. The higher the value of the general combining ability (GCA) of the parent, the more minor genes provide value of additive gene action and the heritability will be higher and more stable. If the specific combining ability (SCA) is higher than the general combining ability then the non-additive gene action (dominant, dominant over, epistasis) controls the character. This will be expressed in a higher hybrid performance.

Table 5. Heterosis values of yield components of F1 hybrids.

Genotipe	Grain yield/plant (g)		Weight of 1000 grain (g)	
	MPH (%)	HPH (%)	MPH (%)	HPH (%)
N/UP 17-10 x Numbu	-7.45	-22.01	-23.09	-36.29
N/UP 17-10 x Kawali	23.09	14.61	-0.53	-3.98
N/UP 89-3 x Numbu	9.80	-12.16	-9.59	-21.13
N/UP 89-3 x Kawali	26.02	10.58	11.46	1.48
N/UP 32-8 x Numbu	46.79	20.88	-13.08	-15.42
N/UP 32-8 x Kawali	23.52	12.03	5.37	-13.28
P/I 150-20-A x Numbu	63.26	-0.15	-3.87	-26.98
P/I 150-20-A x Kawali	59.93	2.43	10.14	1.83
P/I 10-90-A x Numbu	25.67	-3.56	2.71	-21.54
P/I 10-90-A x Kawali	62.14	35.61	9.81	2.32
P/I 150-21-A x Numbu	66.33	23.28	-2.48	-11.41
P/I 150-21-A x Kawali	44.05	15.73	16.90	2.18
B-69 x Numbu	72.02	33.46	-18.61	-27.43
B-69 x Kawali	9.23	-7.48	-13.76	-23.22

*MPH=Mid Parent Heterosis, HPH = High Parent Heterosis.

Not all genotypes that have good GCA will have a good SCA. A study conducted by Xianlin *et al.* (2012) showed that GCA is not the same and are not associated with SCA. Parental lines that have high GCA have more favorable genes and heterosis from such crosses will have a higher value. To obtain hybrid with a high heterosis, then one of the parent should have high general combining ability.

The general combining ability (GCA), specific combining ability (SCA), heterosis and heterobeltiosis value in cross combination involving introduced lines (PI 150-20-A, P I-150-21-A, PI-10-90-A) and B-69 was higher compared with IPB breeding lines (N/UP 17-10, N/UP-32-8, N/UP-89-3). This is presumably because a considerable genetic distance between male and female parent lines. According Haussmann *et al.* (1999), one important concern in a breeding program is the selection of parent. The selection should be based on parental genetic diversity. The wider the genetic background of the parents will have a higher chance to collect different alleles within a genotype. Introduced lines are source of excellent parent materials. And for the hybrid further development breeders should not only focused on agronomic characters and yield potential. Observation should be made on important nutritional content of sorghum grain over environments in order to select for superior sorghum genotypes with good grain quality (Trikoesoemaningtyas *et al.* 2005).

Acknowledgements

This study was funded by a grant from the Ministry of National Education and Culture the Republic of Indonesia, under the International Colaboration and Publication Research Grant Contract no 203/SP2H/PL/ Dit. Litababmas/IV/2012 for Trikoesoemaningtyas.

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