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Estimates of combining ability for resistance to pod shattering in soybean (*Glycine max* (L.) Merrill) genotypes

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Combining ability estimates were studied for pod shattering and other agronomic traits in eight parental soybean genotypes of different pod shattering group namely: susceptible to pod shattering, moderately resistant to pod shattering were crossed in a 4 x 4 North Carolina mating design II to generate 16 crosses, due to missing stands encountered in some crosses, 9 successful F_{1S} hybrids were obtained in the present study and evaluated along with the parents to estimate the mode of gene action controlling pod shattering in soybean and the combining ability for pod shattering and other agronomic traits in soybean. The mean square from the analysis of variance for the ten traits measured showed highly significant differences (p<0.01) among the genotypes. This has demonstrated the existence of genetic variability among soybean genotypes with pod shattering under additive gene action. TGX1955-10E, NG/AD/11/08/023 and NG/SA/07/100 were good general combiners for resistance to pod shattering, plant height, days to 50% flowering and days to maturity while NG/MR/11/11/060, NGBOO/08, TGX1740-1F and NG/SA/07/055 are good general combiner for number of seeds/ pod, pod length, hundred seed weight and grain yield. NG/SA/07/100 x TGX1740-1F, NG/MR/11/11/060 x NGBOO129 and NG/MR/11/11/060 x NG/AD/11/08/023 had positive specific combining ability effects for number of branches/ plant, number of pods/plant, pod length, number of seeds/pod, hundred seed weight and grain yield. NG/MR/11/11/060 X NG/SA/07/055had negative SCA effects for plant height. This implied that these hybrids performed better than the parents GCA effects. This suggests that the cross combination can be advanced for selection in later generation.

Key words: Combining ability effects, soybean genotypes, pod shattering, Samaru.

INTRODUCTION

Soybean (2n = 40), an important leguminous and a miracle crop of the world, has its origin in North-Eastern China (Indu, 2014). It is among the major industrial and food crops grown in every continent. It is an economically important crop with an average of 40% protein and 20% oil content (Context Network and Sahel Capital, 2016).

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Like other important economic crops, one of the major problems associated with soybean production in the tropical and sub-tropical ecology is pod shattering, an important physiological constrain in soybean production and its productivity.

Pod shattering is the opening of mature pod along the dorsal or ventral sutures and followed by seed dispersal when the crop reaches maturity and during harvesting (Bara et al., 2013). The extent of yield loss that could result due to pod shattering in soybean may range from 34 to 100% (Krisnawati and Adie, 2016). Resistance to pod shattering is the most important factor for the improvement of soybean, especially in tropics. The Nigerian climate is characterized by abundant sunshine, which provides an ideal environment for soybeans production, hence will increase in pod shattering and resulting in significant yield losses in soybean.

Understanding the mode of gene action controlling resistance to pod shattering is crucial for designing appropriate breeding strategy for the development of pod shattering resistance. Earlier studies have generated different results on the genetics of pod shattering. Caviness (1969) reported that pod shattering is a qualitative heritable trait with multiple genes governing the trait. Haruna (2010) reported that inheritance of resistance to pod shattering was under the influence of either duplicate recessive or dominant and recessive epistasis depending on the parental genotypes used in the cross.

Exploiting genetic variability in soybean through effective crosses between adapted varieties bearing pod shattering trait and cultivars with resistance to pod shattering will provide information for the development of high yielding and resistant varieties that will increase the productivity and utilization of soybean. This study was therefore undertaken to determine the mode of gene action controlling pod shattering, to estimate the general combining ability (GCA) effects of the parents and specific combining ability (SCA) effects of the hybrids.

MATERIALS AND METHODS

Eight soybean genotypes which consisted of two susceptible, two moderately resistant to pod shattering and four resistant to pod shattering were crossed in a 4 × 4 North Carolina mating design II (NC11) to generate 16 F_1s hybrids during the dry season of 2016, but due to missing stands, 9 successful F_{1s} were generated for this study and evaluated along with the 8 parents. This was planted in the screen house of Institute for Agriculture Research (IAR), Samaru Ahmadu Bello University, Zaria (Latitude 11°11′N and 7°38′ E, 600 m above sea level) which is located in the Northern Guinea Savannah Zone of Nigeria, with mean annual rainfall is about 1045 mm during the rainy season and were laid-out in a randomized complete block design (RCBD) with three replications. Each experimental unit consisted of a pot of 24.5 × 25.5 cm^2, diameter and height, respectively with each pot containing 10 kg of sandy-loam soil. Four seeds were sown per pot. All recommended agronomic practices like weeding, fertilizer application of 30 kg P_2O_5/ha in form of single super phosphate (SSP-18%) and a single spray of insecticide Cypermethrin + Dimethoate at the rate of 100 ml in 1.5 L of water for any infestation from pre-flowering through post-flowering phases were carried out to maintain healthy plants. Data were collected on number of days to flowering, number of branches per plant, number of pods per plant, plant height at maturity, number of seeds per pod, 100 seeds weight, days to maturity, pod length, and grain yield.

The level of resistance to pod shattering was evaluated using the field-screening method (Helms, 1994) on all the genotypes tested. This was scored on pods of matured genotypes (95% of pods turn tan or grey). Pod shattering score was taken at one, two and three weeks after maturity. The percentage of pod shattering was then determined on a scale of 1 to 5 used by Asian Vegetable Research and Development Centre (AVRDC, 1979) in which, 1 = 0% shattering, 2 = 1 to 10%, 3 = 11 to 25%, 4 = 26 to 50%, and 5 ≥ 50%. The shattering score was classified as follows: 1 = highly resistant; 2 = resistant; 3 = moderately resistant; 4 = susceptible; and 5 = highly susceptible (AVRDC, 1979). Percent pod shattering was estimated using the following formula:

$$\frac{\text{Number of shattered pods per plant}}{\text{Total number of pods per plant}} \times 100$$

The combining ability analysis and the estimates of GCA and SCA effects were done using NCD II for Model I method based on the procedure described by Comstock and Robinson (1948) using Statistical Analysis System (SAS) Package (2002). The significant differences among GCA and SCA effects were tested using the formula of Singh and Chaunghary (1977).

RESULTS AND DISCUSSION

Response of F_1 population and parental genotypes to pod shattering

The results in Table 1 show the mean square for pod shattering and other agronomic traits in soybean genotypes. All traits were highly significant ($p<0.01$) indicating the existence of genetic diversity among parental genotypes and their progeny. This implied that selection for desirable soybean genotypes could be made using these traits in a soybean breeding program. Similar result was reported by Nassar (2013).

Combining ability analysis

Mean square for both GCA and SCA were significant for all studied characters (Table 2), except for number of pods per plant which showed no significant difference by female parents. The significant difference observed for SCA and GCA for all the traits studied in the present study indicates the importance of additive and non-additive gene actions in the inheritance of the studied traits, though each component's contribution may vary according to each traits. The high GCA/SCA ratio obtained from the mean square due to GCA for pod shattering indicates that additive gene action was more important in the control of this trait. This is similar to the

Table 1. Mean square of all traits for NC11 crosses evaluated at Samaru, Zaria in 2016.

Source of variation	Df	Days to 50% flowering	Plant height (cm)	Number of branches/plant	Number of pods/plant	Number of seeds/pod	Pod length (cm)	Hundred seed weight (g)	Days to maturity	Grain yield (kg)	Shattering score
Genotype	15	2191.75**	3986.40**	53.62**	4368.84**	3.77**	9.61**	73.22**	7146.75**	2242228.27**	9.73**
REP	2	14.06	120.89	6.81	5.77	0.02	0.11	0.06	3.77	139.65	0.02
Error	30	11.06	164.07	3.23	515.39	0.11	0.08	0.06	4.84	98.87	0.02

**Significant at 1% level of probability, *significant at 5% level of probability, ns= not significant.

Table 2. Mean square for combining ability and GCA/SCA ratio for resistance to pod shattering and other agronomic traits in soybean genotypes evaluated at Samaru 2016.

Source of variation	Df	Days to 50% flowering	Plant height (cm)	No. of braches/plant	No. of pods/plant	No. of seeds/pod	Pod length (cm)	Days to maturity	Hundred seeds weight (g)	Grain yield (kg)	Pod shattering score
Rep	2	14.06	120.90	6.81	5.77	0.021	0.11	3.77	0.05	139.65	0.02
Female	3	1646.74**	3791.47**	12.61*	1136.74	3.92**	8.59**	6034.69**	36.31**	1141836.44**	19.83**
Male	3	1754.52**	2656.24**	73.06**	4886.19**	3.47**	10.53**	5829.81**	105.46**	2365948.25**	5.33**
M*F	9	2519.17**	4494.76**	60.81**	5273.76**	3.82**	9.64**	7956.42**	76.56**	2567785.55**	7.83**
Error	30	11.06	164.07	3.23	515.39	0.110	0.08	4.84	0.05	98.87	0.02
GCA/SCA		1.35	1.43	1.41	1.14	1.93	1.98	1.49	1.85	1.37	3.21

*Significant difference observed among the mean (P<0.05); **highly significant difference observed among mean (P<0.01). GCA: General combining ability; SCA: specific combining ability.

findings of Tiwari and Bhatnagar (1991) who reported that pod shattering is controlled by additive gene action. The preponderance of additive effects observed for days to 50% flowering, days to maturity, number of braches/plant, number of pods/plant, 100 seeds weight is in agreement with the findings of Thakare et al. (2017), Shiv et al. (2011), and Nassar (2013). The significance of additive gene effects for number of seed/pod indicates that additive gene action was more important in the control of this trait. This result is in agreement with the report of Nassar (2013). These results revealed that the traits studied can be exploited effectively by selection in breeding program.

Estimation of GCA effects

Female parents TGX1955-10E and NG/SA/07/100 showed considerable highly significant negative GCA effects for shattering score, plant height, days to 50% flowering and days to maturity, hence they are good combiners. TGX1955-10E and NG/SA/07/100 showed undesirable significant negative GCA effects for number of seeds/pod, pod length and hundred seed weight, hence they are poor combiner. NG/MR/11/11/060 and NGBOO/08 showed significant positive GCA effects for number of seeds/pod, pod length, hundred seed weight and grain yield. This suggests that these parents could be utilized in breeding for improved yield in soybean (Table 3).

Male parents TGX1740-1F and NG/SA/07/055 showed desirable significant positive GCA effects for number of seeds/pod, pod length, hundred seed weight and grain yield and undesirable significant positive GCA effects for shattering score, days to 50% flowering and days to maturity; hence, they are poor combiner for these traits. Male parent NG/AD/11/08/023 had significant negative GCA effects for shattering score, plant height, days to 50% flowering, days to maturity; hence it is a good combiner. Male parent NGBOO129 showed highly significant negative GCA effects for number of branches, pod length, hundred seed weight and grain yield. The

Table 3. General combining ability effects for male and female parents for resistance to pod shattering and other agronomic traits in soybean at Samaru in 2016.

Parent	Days to 50% flowering	Plant height (cm)	No. of branches/plant	Number of pod/plant	Number of seeds/pod	Pod length (cm)	Days to maturity	Hundred seed weight (g)	Grain yield (kg)	Pod shattering score
Female										
TGX1955-10E(P1)	-4.73**	-13.15**	-0.67	-17.31**	-0.21*	-0.17*	-7.79**	-0.38**	180.06**	-1.17**
NG/MR/11/11/060(P2)	12.69**	15.85**	0.83	15.85*	0.38**	0.51**	19.46**	1.05**	381.53**	0.50**
NGBOO/08(P3)	5.94**	14.77**	0.92**	0.69	0.54**	0.78**	16.54**	1.62**	108.04**	1.58**
NG/SA/07/100(P4)	-13.90**	-17.48**	-1.08*	0.77	-0.71**	-1.12**	-28.21**	-2.28**	-309.52	-0.92**
SE(gi)	0.96	3.70	0.52	6.55	0.10	0.08	0.63	0.07	2.90	0.04
SE(gi-gj)	1.36	5.23	0.73	9.27	0.13	0.11	0.85	0.09	4.06	0.06
Male										
TGX1740-1F(P5)	10.10**	8.85*	3.3**	28.52**	0.38**	0.756**	17.13**	2.62**	549.65**	0.33**
NG/SA/07/055(P6)	8.69**	-5.81	0.5	-6.56	0.46**	0.731**	16.46**	2.27**	34.62**	0.33**
NG/AD/11/08/023(P7)	-15.90**	-18.06**	-2.3**	-20.48*	-0.71**	-1.20**	-29.63**	-3.55**	534.50**	-1.00**
NGBOO129(P8)	-2.90**	15.02**	-1.4**	-1.48	-0.13	-0.29**	-3.96**	-1.33**	-49.77**	0.33**
SE(gi)	0.96	3.70	0.52	6.55	0.10	0.08	0.63	0.07	2.90	0.04
SE(gi -gj)	1.36	5.23	0.73	9.27	0.13	0.11	0.85	0.09	4.06	0.06

*Significant difference observed among the mean (P<0.05); **Highly significant difference observed among mean (p<0.01).

desirable significant negative GCA effect for pod shattering recorded by female parents, viz., TGX1955-10E and NG/SA/07/100 and a male parent (NG/AD/11/08/023) implied that these genotypes are good general combiners. Significant negative GCA effects recorded for plant height, days to 50% flowering and days to maturity by two female parents and male parent suggests that these genotypes are good general combiners for earliness in hybridization. The preponderance of additive gene effects observed for the studied traits implied that crossing between two good general combiners for pod shattering and other agronomic traits studied will produce hybrids with good specific combining ability. This is according to Daniel et al. (2006) who reported that two good general combiners that are governed by additive × additive gene actions will produce hybrids with good specific combining ability.

Estimation of SCA effects

The estimation of SCA effects provides opportunities to isolate crosses where all traits are in the most desirable combinations (Ercan and Mehmet 2005). The specific combining ability effects in Table 4 revealed that crosses NG/SA/07/100 × TGX1740-1F, NG/MR/11/11/060 × NGBOO129 and NG/MR/11/11/060 × NG/AD/11/08/023 showed desirable significant positive SCA effects for number of branches/plant, number of pods/plant, pod length, number of seeds/pod, hundred seeds weight, and grain yield. NGBOO/08 × NG/SA/07/055, TGX1955-10E × NG/SA/07/055, NG/MR/11/11/060 × NG/AD/11/08/023, NG/MR/11/11/060 × NGBOO129, NG/SA/07/100 × TGX1740-1F and TGX1955-10E × TGX1740-1F showed significant positive SCA effects for days to 50% flowering and days to maturity. NG/MR/11/11/060 × NG/SA/07/055 showed a desirable significant negative SCA effects for plant height.

The high significant positive SCA effects obtained by cross NG/MR/11/11/060 × NGBOO129 for grain yield and NG/SA/07/100 × TGX1740-1F and NG/MR/11/11/060 × NGBOO129 for number of pods/plant, number of seeds/pod, pod length and hundred seed weight in which NG/MR/11/11/060 and TGX1740-1F were good general combiner and agrees with Cruz et al. (2004) who reported that selection for good estimates of SCA should focus on cross combinations that involve at least

Table 4. Specific combining ability effects for crosses for resistance to pod shattering and other agronomic traits in soybean at Samaru in 2016.

Crosses	Days to 50% flowering	Plant height (cm)	Number of branches/plant	Number of pod/plant	Number of seeds/pod	Pod length (cm)	Days to maturity	Hundred seed weight (g)	Grain yield (kg)	Shattering Score
NGBOO/08 × TG 1740-1F (P3 × P5)	1.65	-8.44	1.25	-5.94	-0.13	-0.07	4.88*	-3.80**	-99.3**	0.42**
TGX1955-10E × TG X1740-1F (P1 × P5)	14.31**	26.15*	0.83	13.73	0.96**	1.58**	26.54**	1.08**	881.2**	0.17
NG/MR/11/11/060 × NG/SA/07/055 (P2 x P6)	3.31*	-16.85*	0.75	6.94	0.29*	0.49**	2.96*	1.60**	142.6**	0.50**
NGBOO/08 × NG/SA/07/055 (P3 × P6)	4.73**	14.90*	0.33	11.44	0.46	0.59**	7.54**	-0.17	594.4**	0.42**
TGX1955-10E × NG/SA/07/055 (P1 × P6)	16.06**	12.81*	2.58	14.60	0.21	0.47**	31.21**	3.83**	-198.1**	-1.50**
NG/MR/11/11/060 × NG/AD/11/08/023 (P2 × P7)	27.56**	32.40*	4.92**	19.35	1.13**	1.69**	52.04**	4.15**	456.2**	1.50**
NG/MR/11/11/060 × NGBOO129 (P2 × P8)	21.23**	43.31**	2.67**	47.02**	0.54**	1.01**	35.04**	3.20**	1146.2**	0.50**
NGBOO/08 x NGBOO129 (P3 × P8)	12.98**	24.40*	1.25	1.19	0.71**	1.00**	27.96**	2.03**	-107.8**	1.42**
NG/SA/07/100 × TG X1740-1F (P4 × P5)	36.15**	41.15**	6.25**	67.98**	1.13**	1.69**	58.63**	6.38**	963.0**	1.92**
SE(Sij)	1.92	7.40	1.04	13.11	0.19	0.16	1.27	0.13	5.74	0.08
SE(Sij-Ski)	2.71	10.46	1.47	18.54	0.26	0.23	1.80	0.19	8.12	0.11

*,**Significant difference at 0.05 and 0.01 levels of probabilities.

one parent which has shown good effect of GCA. Kadams et al. (1999) also reported that hybrid with high SCA effects involved one or both of the good general combiners as parents. The absence of negative SCA effects for shattering score, days to 50% flowering and days to maturity indicates that the hybrids obtained for the present study do not fit in for these traits.

Mean performance values for parents and their F_{1S}

The mean performance of the parental genotypes and their crosses for the studied traits are shown in Table 5. The result revealed that pod shattering score among parents and hybrids ranged from 1 (highly resistant) for NG/AD/11/08/023, NG/SA/07/055, NGBOO129, TGX1955-10E, TGX1955-10E × NG/SA/07/055 and TGX1955-10E × TGX1740-1F to 5 (highly susceptible) for NGBOO/08 and NGBOO/08 × NGBOO129. Grain yield varied from 314.3 for NG/SA/07/100 to 2291.7 kg for hybrid NG/MR/11/11/060 × NGBOO129 with a mean of 1283.04. Days to 50% flowering ranged from 43.3 for NG/SA/07/055 to 61.7 for NG/SA/07/100 × TGX1740-1F with a mean of 50.92. Number of branches varied from 4 for NG/SA/07/100 to 13 for hybrid NG/SA/07/100 × TGX1740-1F with a mean of 6.94. Plant height ranged from 27 cm for hybrid NG/MR/11/11/060 × NG/SA/07/055 to 108 cm for NG/MR/11/11/060 × NGBOO129 with a mean of 62.61. Number of pods/plant ranged from 17 for NG/SA/07/100 to 128 for hybrid NG/SA/07/100 × TGX1740-1F with a mean of 47.25. Hundred seed weight g ranged from 5 g for NG/MR/11/11/060 to 12 g for NG/SA/07/100 × TGX1740-1F. Days to maturity ranged from 87 for NGBOO129 to 104 for NG/MR/11/11/060 × NGBOO129 with a mean of 94.3. Pod length varied from 3 to 4 cm with a mean of 3.7 cm. The highest mean performance recorded by some crosses for grain yield, number of branches, number of pods/plant, and 100 seed weight which was higher than all parental genotypes was similar to the findings of Saul et al. (2017). This may be as a result of recombination of additive alleles or interaction between two alleles of two different genes due to a wide variation between genotypes of their parents (Marame et al., 2009).

Conclusion

The study has revealed that both additive and non-additive gene effects were important in the inheritance of pod shattering and other agronomic traits. However, additive gene effect was more important implying that selection could be effective. The good general combiners for resistance to pod shattering, plant height, days to 50% flowering and days to maturity were TGX1955-10E, NG/AD/11/08/023 and NG/SA/07/100, while NG/MR/11/11/060, NGBOO/08, TGX1740-1F and NG/SA/07/055 were good general combiner for number of seeds/pod, pod length, hundred seed weight and grain yield. Therefore, these parents are

Table 5. Mean performances of parents and the F_1s evaluated for Resistant to Pod Shattering and other agronomic traits using field screening methods.

Genotype	Days to 50% flowering	No. of branch/plant	Plant height (cm)	No. of pods/plant	No. of seeds/pod	Pod length (cm)	Days to maturity	Hundred seeds weight (g)	Grain yield (kg)	Pod shattering score
NG/AD/11/08/023	46.7	6	59.7	59.0	3.0	4.1	103.3	7.2	1822.4	1
NGBOO129	48.7	6.3	79.0	33.3	2.7	3.7	87.0	9.2	841.9	1
TGX1955-10E	45.3	8.0	52.3	30.0	3.0	4.4	90.3	10.2	921.1	1
NG/SA/07/055	43.3	5.7	72.7	43.0	2.7	3.7	90.7	10.4	902.6	1
NG/SA/07/100	60.7	4.3	54.0	17.0	2.7	3.2	94.0	12.0	314.3	3
NGBOO/08	44.3	6.0	76.7	31.7	2.7	4.2	93.3	7.8	1723.9	5
TGX1740-1F	48.3	7.0	61.7	29.0	2.7	3.8	98.3	11.0	1442.3	2.3
NG/MR/11/11/060	59.3	6.7	62.0	18.7	3.0	4.4	90.3	5.3	823.3	4.3
NG/MR/11/11/060 × NG/AD/11/08/023	53.7	7.7	64.3	43.7	2.0	2.9	95.3	6.9	1117.0	2.7
NG/MR/11/11/060 × NG/SA/07/055	54.0	6.3	27.3	55.0	2.3	3.7	92.3	10.2	1372.5	3
NG/MR/11/11/060 × NGBOO129	60.3	6.3	108.3	90.3	2.0	3.2	104.0	8.2	2291.7	3
NG/SA/07/100 × TGX1740-1F	61.7	12.7	66.7	128.7	2.0	3.3	101.0	12.0	2016.9	3
NGBOO/08 × NG/SA/07/055	48.7	6.0	58.0	44.3	2.7	4.0	94.0	9.0	1550.8	4
NGBOO/08 × NGBOO129	45.3	5.0	88.3	29.3	2.3	3.4	94.0	7.6	764.2	5
NGBOO/08 × TGX1740-1F	47.0	9.7	49.3	54.7	2.0	3.4	92.0	11.0	1372.1	4
TGX1955-10E x NG/SA/07/055	49.3	6.7	28.0	39.3	1.7	3.0	93.3	11.0	470.2	1
TGX1955-10E × TGX1740-1F	49.0	7.7	56.0	56.3	2.3	4.1	89.3	8.6	2064.5	1
CV%	6.84	30.55	23.28	59.96	27.14	14.40	2.79	2.79	0.74	12.38
Mean	50.92	6.94	62.61	47.25	2.45	3.67	94.27	9.27	1283.04	2.67
LSD	5.79	3.52	24.24	47.13	1.11	0.88	4.37	0.43	15.80	0.55

recommended as source of pod shattering resistance and high yielding for soybean breeding program, while the good crosses for SCA effects for yield and yield components are NG/SA/07/100 × TGX1740-1F, NG/MR/11/11/060 × NGBOO129 and NG/MR/11/11/060 × NG/AD/11/08/023. These crosses should be advanced for selection in later generations.

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