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POD SHATTERING RESISTANCE AND AGRONOMIC TRAITS IN F_5 SEGREGATING POPULATIONS OF SOYBEAN

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SUMMARY

The soybean productivity can be increased by constant enhancement in the genetic yield potential of the genotypes and to reduce the yield losses due to different factors. The objectives of the present study were to screen and identify the F_5 soybean promising lines through agronomic characters and pod shattering resistance. For soybean yield, the selection was made in the segregating populations through pedigree method which resulted in a total of 591 F_5 populations and their four parental genotypes (Anjasmoro, G100H, Rajabasa, and Grobogan). Parental cultivar Anjasmoro is highly resistant to pod shattering, whereas the three other parental cultivars are high yielder but medium to susceptible in resistance to pod shattering. For shattering resistance, each soybean line was planted in 4.0 m single row, and then screened as per oven-dry method. Based on resistance to pod shattering, and the resistant gene source (found in cultivar Anjasmoro), 104 populations (16.40%) were selected out of 591 F_5 lines and were classified as 'very resistant' to pod shattering. The pod length was one of the important contributors to the pod shattering resistance. New recombinations between Anjasmoro and other susceptible parental genotypes were able to have resistance to pod shattering and perform better for agronomic traits. Through simultaneous selection for pod shattering resistance and agronomic traits, the 30 lines were further selected based on maximum resistance to pod shattering and high grain yield. These selected F_5 lines could be used in future breeding program for the development of soybean genotypes with genetic potential of pod shattering resistance and good yield in the tropical regions.

Key words: Soybean, F_5 populations, recombinant lines, path analysis, seed productivity, shattering effect, yield losses

Key findings: Pod shattering is one of major constraints in the soybean production in the tropical regions. In Indonesia, the research on improving soybean for resistance to pod shattering is still scanty. The availability of shattering-resistant lines as well as their suitability to consumer preferences is important in varietal improvement program to reduce the yield losses and increase the soybean productivity potential.

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INTRODUCTION

Pod shattering has become an important problem in the soybean production in the tropical climate of Indonesia, especially in the dry season due to high temperature and low humidity (Krisnawati and Adie, 2016). Pod shattering also become one of major constraints to the soybean production in several soybean production regions of the world since it caused considerable yield losses (Tukamuhabwa *et al*., 2002; Zhang and Bellaloui, 2012; Bara *et al.*, 2013). Resistant to pod shattering is an important trait for soybean improvement to minimize the potential yield losses (Antwi-Boasiako, 2017; Kang *et al.,* 2017; Krisnawati and Adie, 2017a). The significant yield losses caused by pod shattering have been reported in several studies, from negligible to significant levels in the range of zero to 100% shattering (Agrawal *et al.,* 2003). According Tiwari and Bhatnagar (1991), the use of shattering susceptible cultivars and delayed harvesting caused 34-99% seed losses. Earlier studies reported that yield losses in susceptible and intermediate susceptible cultivars ranged from 57 to 175 kg ha^{-1} and 0 to 186 kg ha^{-1}, respectively (Tukamuhabwa *et al.*, 2002). However, the ratio of shattering vary and it depend on genotype, environmental factors, and the time of harvesting (Zhang and Boahen, 2010; Antwi-Boasiako, 2017).

Genetic diversity is essential for the selection of suitable parental genotypes and their segregating populations for improvement in soybean shattering resistance and ultimately yield. Resistant cultivars can be developed by introducing resistance genes into susceptible cultivars through quantitative genetics and conventional breeding (Carpenter and Fehr, 1986; Tiwari and Bhatnagar, 1992). In breeding for the development of shattering resistant progenies, the important factors like availability of gene source and suitable selection method should be considered (Krisnawati and Adie, 2017b). Screening for shattering resistance has been using several methods in soybean (Bhor *et al*., 2014; Antwi-Boasiako, 2017; Umar *et al*., 2017). The oven-dry method is suggested as one of useful methods for assessing the degree of shattering (Agrawal *et al*., 2002; Krisnawati and Adie, 2016; Romkaew and Umezaki, 2006). Soybean breeding for shattering resistance has been carried out in several soybean production areas of the world. Breeding for pod shattering resistance has also been a major priority of IITA's soybean breeding program (IITA, 1992). In Japan, breeding for soybean resistance to pod shattering using several genes sources from Thailand (SJ 2), USA (Clark-Dt2), and China (Zihua 4) (Yamada *et al*., 2009). Soybean cultivar Hayahikari was one of shattering resistance cultivar which derived from selection of SJ 2 (Yumoto *et al*., 2000). The improvement in shattering resistance in North America was fulfilled by inserting genes from shattering resistant germplasm or the wild species (Bailey *et al*., 1997).

Previous studies reported that soybean shattering resistance is highly heritable and controlled genetically (Caviness, 1969; Tsuchiya, 1987; Bailey *et al*., 1997). The broad sense heritability of shattering resistance in soybean was reported over 90% (Tsuchiya 1987; Tiwari and Bhatnagar, 1991; Bailey *et al*., 1997) while narrow sense heritability was less (0.79). (Tukamuhabwa *et al*., 2000). Furthermore, the narrow sense heritability (0.46) with in range of 0.40–0.53 as reported by Mohammed *et al*. (2014). Narrow sense heritability is more meaningful than the broad sense heritability, which serves as a direct measure of additive variance which is predictably inherited to the next generation (Mohammed *et al*., 2014). The shattering resistance in soybean was reported to be controlled by two genes and was not influenced by maternal effects (Tukamuhabwa *et al*., 2000). Similarly, in other studies the lack of maternal/cytoplasmic influence was reported for pod shattering trait, and inheritance of resistance was under the influence of either duplicate recessive or dominant and recessive epistasis, depending on the parental genotypes used in the crosses (Mohammed *et al*., 2014). Furthermore, Bhor *et al*. (2014) reported that inheritance of pod shattering was to be governed by partial dominance of susceptibility over the resistance, and two major genes with inhibitory epistasis were involved. A study by Agrawal *et al*. (2003) revealed that segregation of pod shattering was highly complex in F_2 populations and showed quantitative response in the cross between susceptible and resistant cultivars. Their results further revealed that success of any conventional breeding program for pod shattering resistance depends upon the desirable segregates in soybean. In such cases, the parental genotype that to be used as a gene source must have a very high resistance to pod shattering, hence, the chance to obtain a high resistance progeny will be even greater.

In Indonesia, the breeding for shattering resistant lines has just begun in 2015 by recombination using the source of resistance gene from Anjasmoro cultivar, even though the evaluation on the homozygous lines have been conducted earlier (Adie and Krisnawati, 2016; Krisnawati and Adie, 2016). The economic values of a soybean cultivar in the country consisted of early maturity (< 80 days), larger seed size (> 14 g/100 seeds) and high yield. These characters must be integrated with the trait of resistance to pod shattering, since soybeans are mostly cultivated in the dry season, where pod shattering becomes an important problem. Early maturity is an important trait and because of that the soybean can be cultivated three times a year in Indonesia. In addition, large seed size is needed for raw material of the tempeh industry. In our country, the insufficient research was carried out on improving soybean for resistance to pod shattering, as well as the identification of determinant factor for shattering resistance. So far, the distribution of shattering resistance in the early generation, especially in the F_5 has not been identified. Therefore, the information gained from this study will be helpful in varietal improvement program to obtain soybean shatter-resistant advanced lines. Therefore, the said study was undertaken to assess the various agronomic traits and pod shattering resistance in F_5 soybean lines which suits the consumer preferences in Indonesia.

MATERIALS AND METHODS

Plant material

The breeding material comprising F_5 segregating populations derived from six cross combinations made in three parental genotypes in soybean. Those F_5 lines were developed during 2015 through hybridization. The selection in segregating populations of four different generations (F_2, F_3, F_4, and F_5) was carried out through pedigree method for high yield. Soybean cultivar Anjasmoro was used as gene source for shattering resistance, and was reciprocally crossed with three other soybean genotypes i.e., G100H, Rajabasa, and Grobogan.

Field experiment and procedure

The field research was conducted at Genteng, Banyuwangi, East Java, Indonesia (located at 8° 22′ 44.4″ South Latitude and 114° 8′ 45.6″ East Longitude, 168 m above sea level, C2 (Oldeman) climate type, rainfall 4300 mm/year, 23°C minimum temperature, 30°C maximum temperature, 82.5% relative humidity, and soil type of Light Entisol). The research was conducted during the dry season (July to October) 2017. The experiment was conducted in lowland after rice planting and without soil tillage. Each line was planted in 4.0 m single row, with plant spacing of 40 × 15 cm, two plants per hill. Plants were fertilized with 23:36:45 kg NKP ha^{-1} which given entirely after sowing. The weeds and plant diseases were intensively controlled.

Screening for pod shattering resistance

The screening and selection for pod shattering resistance in soybean populations was carried out by using oven-dry method (Krisnawati and Adie, 2017). When plants were in R_8 stage (the leaves of the plant have turned yellow), three sample plants were randomly taken from each line, then dried for three days at room temperature for moisture content to equilibrate. Then 30 (fully matured) pods from three sample plants of each line were randomly collected to be placed in khaki envelops, and were placed in an oven (oven-dry method). Pod shattering was assessed by exposing the pods to 30°C for three days, then elevated up to 40°C for one day, elevated up to 50°C for one day, and lastly elevated up to 60°C for one day. The degree of pod shattering was recorded at 7^{th} day (after exposing to 60°C for one day). The shattering percentage was calculated as the number of shattered pods per total number of pod expressed as percentage. The shattering resistance was classified according to AVRDC (1979) as follows: very resistant (0%), resistant (1 to 10%), moderately resistant (11 to

25%), moderately susceptible (26 to 50%), and very susceptible (>50%).

Agronomic traits

The data were recorded on pod morphological and agronomic variables. Pod morphological characters consisted of pod length (cm), pod width (cm), pod wall weight to pod weight ratio (%), and seed weight to pod weight ratio (%). Agronomic characters were recorded on three randomly sample plants, i.e., plant height, branches per plant, nodes per plant, filled pods per plant, empty pods per plant, 100-seed weight, and seed weight per plant.

Biometrical analysis

All the data were subjected to descriptive analysis which consisted of mean, minimum value, and maximum value. Data on percentage were subjected to arcsine-square root transformation prior to descriptive analysis (Singh and Chaudhary, 1977). Path analysis was calculated based on phenotypic correlation to observe the determinant factors of pod shattering resistance.

RESULTS AND DISCUSSION

Shattering resistance distribution in F_5 population

Crosses between pod shattering resistant soybean cultivar (Anjasmoro) with three other parental genotypes (G100H, Rajabasa, and Grobogan) resulted diverse progeny with varying degree of resistance (Table 1, Figure 1). The F_5 lines derived from six cross combinations (Anjasmoro × G100H, Anjasmoro × Rajabasa, and Anjasmoro × Grobogan and their reciprocals) have similar range of shattering, from 0 - 100%. This showed that distribution of the shattering resistance in F_5 populations was ranging from very resistant to very susceptible. The cross combination Grobogan × Anjasmoro resulted only two selected F_5 lines based on previous yield selection in F_4, thus it does not reflect the distribution of shattering resistance. Out of six parental genotypes used in the population development, the cultivars Anjasmoro and G100H were categorized as resistant to pod shattering, while genotypes Rajabasa and Grobogan showed very high susceptibility to pod shattering.

The classification of shattering resistance in F_5 soybean lines was presented in Table 2 and Figure 2. In selected progeny (88 lines) obtained from cross Anjasmoro × G100H, a total of 13 lines were very resistant while 33 lines were resistant to pod shattering. Furthermore, the selected progeny (59 lines) of its reciprocal cross showed that 12 lines were very resistant and 12 lines were resistant. The selected progeny (381 lines) from cross between Anjasmoro (shattering resistant) with Rajabasa (shattering susceptible), revealed that 76 lines were found very resistant lines while 67 were resistant to pod shattering. The selected progeny (25 lines) from the its reciprocal cross showed one line as very resistant and five were resistant to pod shattering. In similar resistance pattern, the cultivar Anjasmoro (resistant) was crossed with Grobogan (susceptible), resulted 36 selected F_5 lines, in which two lines were categorized as very resistant while eight were resistant to pod shattering. The progeny from its reciprocal resulted two selected lines

Table 1. Pod shattering and morphological traits in F_5 lines of soybean derived from six cross combinations.

Soybean cross combinations	Number of F_5 lines	Descriptive data	Pod shattering (%)	Pod length (cm)	Pod width (cm)	Seed weight per pod weight (%)	Pod wall weight per pod weight (%)
Anjasmoro × G100H	88	Mean	38	4.53	1.00	74.53	25.47
		Minimum	0	3.10	0.76	71.40	28.60
		Maximum	100	14.48	2.96	73.11	26.89
G100H × Anjasmoro	59	Mean	52	4.21	0.95	72.91	27.09
		Minimum	0	3.24	0.76	15.03	84.97
		Maximum	100	11.40	1.04	77.45	22.55
Anjasmoro × Rajabasa	381	Mean	48	4.72	1.05	74.36	25.64
		Minimum	0	3.40	0.68	43.97	56.03
		Maximum	100	6.40	3.00	97.32	67.17
Rajabasa × Anjasmoro	25	Mean	61	4.72	1.03	71.42	28.58
		Minimum	0	3.92	0.88	59.13	40.87
		Maximum	100	5.70	1.20	72.42	27.58
Anjasmoro × Grobogan	36	Mean	55	4.29	1.02	74.23	25.77
		Minimum	0	3.52	0.86	70.75	29.25
		Maximum	100	5.74	2.96	78.69	21.31
Grobogan × Anjasmoro	2	Mean	5	5.48	1.12	70.04	29.96
		Minimum	3	5.46	1.12	71.51	28.49
		Maximum	7	5.50	1.12	68.72	31.28
Parental genotypes							
Anjasmoro	1		3	4.58	0.98	78.03	21.97
G100H	1		3	3.86	0.88	69.71	30.29
Rajabasa	1		100	5.86	1.18	73.36	26.64
Grobogan	1		100	5.94	1.12	77.06	22.94

Table 2. Grouping of F_5 lines of soybean for pod shattering resistance.

Soybean cross combinations	Number of F_5 lines	Descriptive data	Number of lines on each resistance criteria				
			VR	R	M	S	VS
Anjasmoro × G100H	88	Total	13	33	6	4	32
		%	14.77	37.50	6.82	4.55	36.36
G100H × Anjasmoro	59	Total	12	12	1	3	31
		%	20.34	20.34	1.69	5.08	52.54
Anjasmoro × Rajabasa	381	Total	76	67	33	30	175
		%	19.95	17.59	8.66	7.87	45.93
Rajabasa × Anjasmoro	25	Total	1	5	2	1	16
		%	4.00	20.00	8.00	4.00	64.00
Anjasmoro × Grobogan	36	Total	2	8	2	4	20
		%	5.56	22.22	5.56	11.11	55.56
Grobogan × Anjasmoro	2	Total	0	2	0	0	0
		%	0.00	100.00	0.00	0.00	0.00
Parental genotypes	-	-	-	-	-	-	-
Anjasmoro	1	-	-	R	-	-	-
G100H	1	-	-	R	-	-	-
Rajabasa	1	-	-	-	-	-	VS
Grobogan	1	-	-	-	-	-	VS

VR = very resistant, R = resistant, M = moderately resistant, S = moderately susceptible, VS = very susceptible and both were resistant to pod shattering.

Based on the resistance in F_5 populations derived from various cross combinations, it was suggested that success and improvement in soybean resistance to pod shattering have greater chances through hybridization using resistant parent. Out of 591 F_5 lines derived from six cross combinations, a total of 104 lines (16.40%) were categorized as very

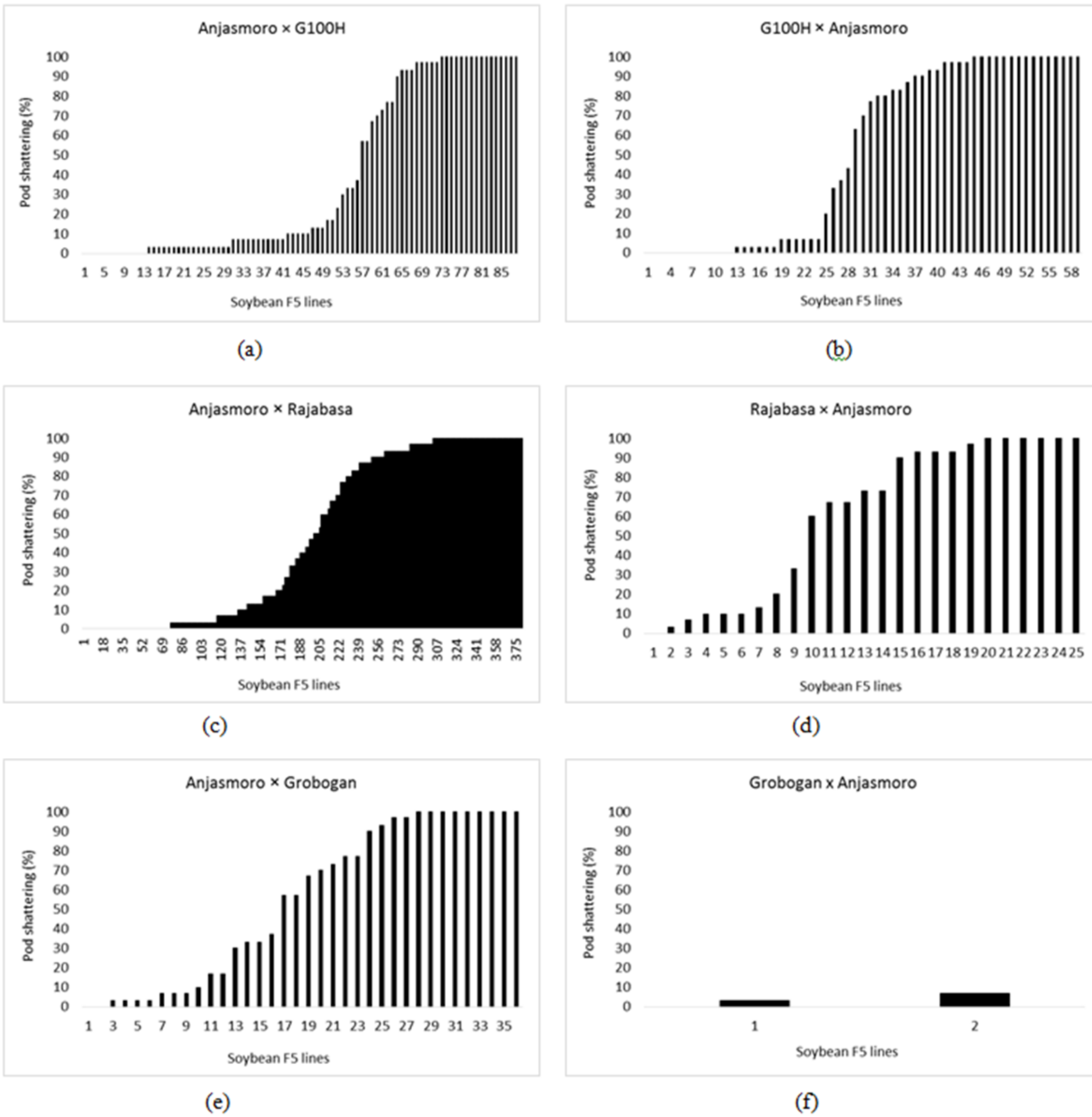

Figure 1. Pod shattering resistance in F_5 lines of soybean derived from six crosses i.e., a) Anjasmoro × G100H, b) G100H × Anjasmoro, c) Anjasmoro × Rajabasa, d) Rajabasa × Anjasmoro, e) Anjasmoro × Grobogan, and f) Grobogan × Anjasmoro.

resistant to pod shattering. Studies on enhancing the pod shattering resistance in soybean through recombination have been conducted in several countries i.e., North America (Bailey *et al*., 1997), Japan (Yamada *et al*., 2009; Yumoto *et al*., 2000), China (Jiang *et al*., 1991). These

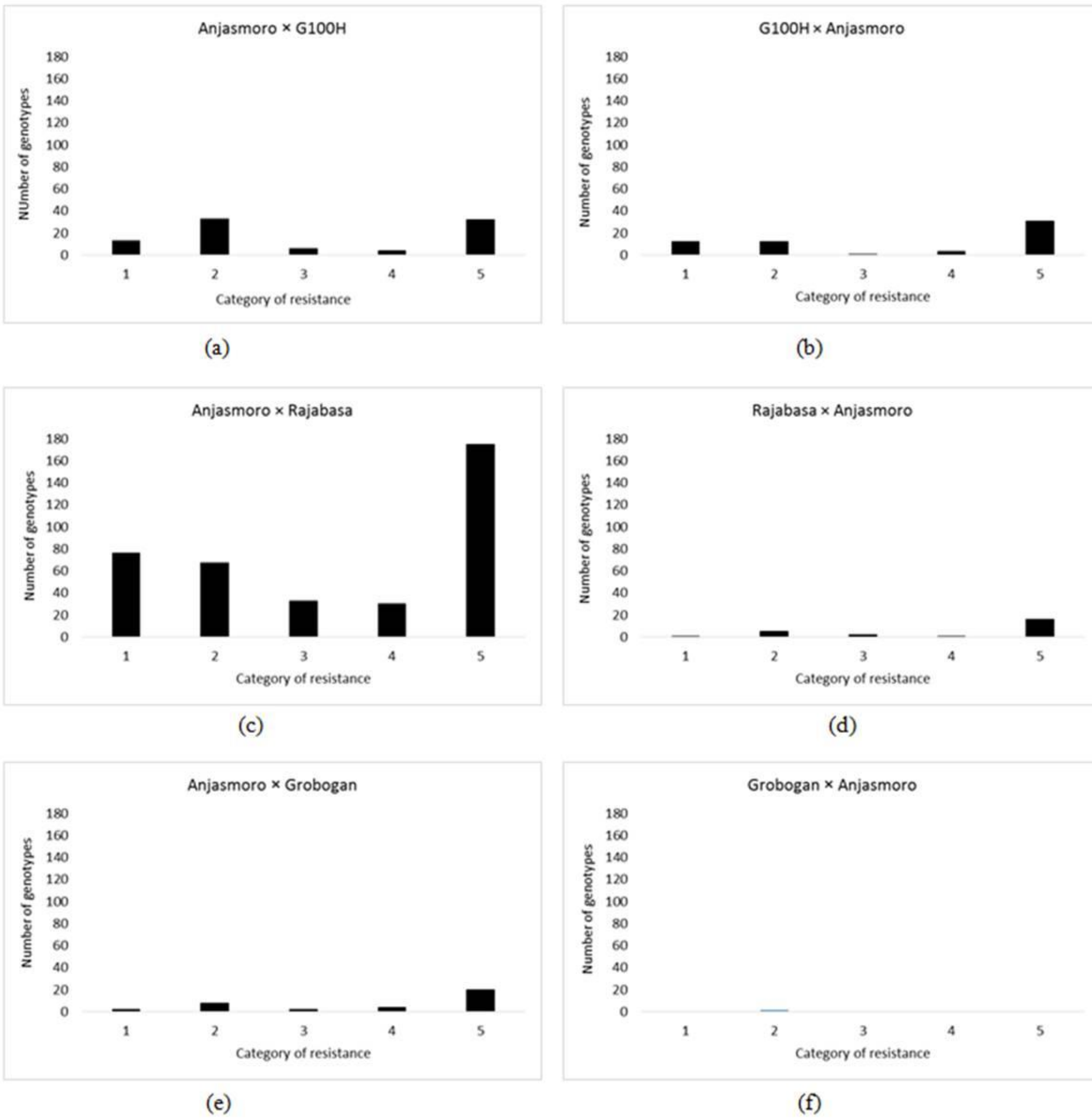

Figure 2. Grouping of F_5 lines of soybean based on pod shattering resistance derived from six cross combinations i.e., a) Anjasmoro × G100H, b) G100H × Anjasmoro, c) Anjasmoro × Rajabasa, d) Rajabasa × Anjasmoro, e) Anjasmoro × Grobogan, and f) Grobogan × Anjasmoro. 1 = VR (very resistant), 2 = R (resistant), 3 = M (moderately resistant), 4 = S (moderately susceptible), 5 = VS (very susceptible).

efforts are considered as the most appropriate with significant chance of success in increasing the soybean resistance to pod shattering (Caviness, 1963; Carpenter and Fehr, 1986; Tukamuhabwa *et al*., 2000). In Indonesia, the first hybridization to develop soybean improved cultivar for pod shattering resistance was conducted in 2015. However, the screening in the homozygous soybean lines has successfully obtained several resistant genotypes which will be further studied in future breeding program for confirmation (Krisnawati and Adie, 2016).

Relationship between yield traits and pod morphology with shattering resistance

The effects of yield components and pod morphology on the pod shattering resistance were studied through several yield components, and pod morphological characters (pod length, pod width, pod wall weight to pod weight ratio, and seed weight to pod weight ratio (Table 3). Among the pod morphological characters, the pod length showed a significant positive correlation with pod shattering (r = 0.292**). Furthermore, among the yield components, the 100-seed weight showed a significant positive correlation with pod shattering (r = 0.262**). This indicated that longer soybean pods will increase the chances of pod shattering, as well as larger seed size will tend to increase the susceptibility to pod shattering. Pod length showed a significant positive correlation with the characters i.e., 100-seed weight (r = 0.578**) and pod width (r = 0.241**). This suggested that larger seed size causes the longer and wider pods, thus increasing the chances of susceptibility to pod shattering. Roth (1977) reported that fruit length was one of morphological traits that reduce dehiscence. A significantly positive correlation between pod length and pod shattering also reported in other studies (Summers *et al*., 2003; Child *et al*., 2003; Bara *et al*., 2013; Krisnawati and Adie, 2017). In present study, there was a complex relationship between yield components and pod morphological characters with pod shattering. Hence, the path analysis was used to describe the relationship. Path analysis distinguishes the role of each character into direct and indirect effect, or each correlation value of each character was explained into direct and indirect effect.

Three traits which have the largest direct effect were nodes per plant (0.442), pods per plant (-0.356), and pod length (0.163) (Table 4). Correlation between nodes per plant and pod shattering was very small (r = -0.095), however, it has a relatively high direct effect on shattering. The role of direct effect of nodes per plant was strongly weakened by its indirect effect through pods per plant (-0.262). Interestingly, the direct effect of pods per plant was negative (-0.356), while its correlation with pod shattering was positive (r = 0.148). The direct effect of pods per plant was weakened by the indirect effect through nodes per plant. Thus, the traits i.e., nodes per plant and pods per plant make weaken each other. According to Singh and Chaudhary (1977), in such situation the indirect effects should be considered.

The correlation between pod length and pod shattering was higher when compared with other morphological characters (r = 0.292) and it was followed by its high direct

Table 3. Correlation between pod shattering resistance, yield components, and pod morphological characters in soybean.

Traits	PSH	PLG	PWD	W/W	S/W	DMT	PHE	BRP	NDP	POD	HWS	S/P
PSH	1	0.292**	0.147**	-0.058	0.058	-0.037	-0.059	0.185**	0.003	-0.159**	0.263**	-0.006
PLG		1	0.241**	0.009	-0.009	-0.299**	0.025	0.005	-0.214**	-0.416**	0.578**	-0.135**
PWD			1	0.001	-0.001	-0.140**	-0.016	-0.007	-0.141**	-0.155**	0.293**	0.022
W/W				1	-0.900**	-0.074	-0.016	-0.015	-0.046	-0.082*	0.080*	-0.011
S/W					1	0.074	0.016	0.015	0.046	0.082*	-0.080*	0.011
DMT						1	0.147**	0.204**	0.346**	0.546**	-0.369**	-0.040
PHE							1	0.129**	0.293	0.195**	-0.093*	-0.126**
BRP								1	0.643**	0.372**	-0.079*	0.377**
NDP									1	0.736**	-0.345**	0.596**
POD										1	-0.514**	0.732**
HSW											1	-0.056
S/P												1

PSH = pod shattering, PLG = pod length, PWD = pod width, W/W = pod wall weight to pod weight ratio, S/W = seed weight to pod weight ratio, DMT = Days to maturity, PHE = plant height, BRP = branches per plant, NDP = nodes per plant, POD = pods per plant, HSW = 100-seed weight, S/P = seed weight to plant weight ratio, * = significant at $P \leq 0.05$, ** = significant at $P \leq 0.01$

Table 4. Direct (diagonal) and indirect effects of yield components and pod morphological traits on pod shattering resistance in soybean.

Traits	PLG	PWD	S/W	W/W	DMT	PHE	BRP	NDP	POD	HWS	S/P	r
PLG	**0.163**	0.021	-0.000	-0.000	-0.037	-0.004	0.000	-0.095	0.148	0.088	0.006	0.292
PWD	0.039	**0.086**	-0.000	-0.000	-0.017	0.002	-0.000	-0.062	0.055	0.045	-0.001	0.147
W/W	0.001	0.000	**-0.035**	-0.039	-0.009	0.002	-0.001	-0.020	0.029	0.012	0.001	-0.058
S/W	-0.001	-0.001	0.032	**0.043**	0.009	-0.002	0.001	0.020	-0.029	-0.012	-0.001	0.058
DMT	-0.049	-0.012	0.003	0.003	**0.124**	-0.021	0.012	0.153	-0.194	-0.056	0.002	-0.037
PHE	0.004	-0.001	0.001	0.001	0.018	**-0.140**	0.007	0.130	-0.069	-0.014	0.006	-0.059
BRP	0.001	-0.001	0.001	-0.001	0.025	-0.018	**0.057**	0.284	-0.132	-0.012	-0.018	0.185
NDP	-0.035	-0.012	0.002	-0.002	-0.043	-0.041	0.037	**0.442**	-0.262	-0.053	-0.029	0.003
POD	-0.068	-0.013	0.003	0.004	0.068	-0.027	0.021	0.325	**-0.356**	-0.079	-0.035	-0.159
HSW	0.094	0.025	-0.003	-0.003	-0.046	0.013	-0.005	-0.152	0.183	**0.153**	0.003	0.263
S/P	-0.022	-0.002	0.000	0.000	0.051	-0.018	0.021	0.263	-0.261	0.009	**-0.048**	-0.006

Bold numbers = direct effect, r = coefficient of correlation, PSH = pod shattering, PLG = pod length, PWD = pod width, S/W = seed weight to pod weight ratio, W/W = pod wall weight to pod weight ratio, DMT = Days to maturity, PHE = plant height, BRP = branches per plant, NDP = nodes per plant, POD = pods per plant, HSW = 100-seed weight, S/P = seed weight to plant weight ratio.

effect on pod shattering (0.163). As described by Singh and Chaudhary (1977), if the correlation coefficient between a causal factor and the effect is almost equal to its direct effect, then the correlation explains the true relationship and a direct selection through this character will be effective. Hence, the character of pod length needs to be considered as one of characters which determine the resistance to pod shattering in soybean, and in future it can be considered as indirect selection criteria in soybean resistance to pod shattering. Bara *et al*. (2013) studied morphological traits in 69 soybean genotypes, and reported that genotypes with less width of pod were found to be tolerant to pod shattering. Similarly, Krisnawati and Adie (2017) reported the highest direct effects were observed on the pod length, suggesting that this character was the most important contributor to the pod shattering resistance. However, these reports were partly contradictory to those of Suzuki *et al*. (2009) which found nonsignificant differences for pod length among the soybean NILs.

Agronomic performance and simultaneous selection

The performance of genotypes for agronomic traits varies between cross combinations (Table 5). The chance to obtain early maturing line (<80 days) was showed by cross combination between cultivars Anjasmoro and G100H, as seen in their minimum value for days maturity (80 days). The use of early maturing cultivar Grobogan as parent did not produce early maturing progeny. Cultivar Anjasmoro has relatively taller plants, and when recombined with various parents, it has the opportunity to produce taller plants as seen in their maximum values in each cross combination.

The traits branches and nodes per plant were the supporting characters for pods per plant. Branches of parental cultivars and their progenies less vary, however, the number of nodes showed more variability. There were some progenies having higher number of nodes as compared to the parents. The pods and seed size are agronomic characters that have a direct role in managing the seed yield. Selected progenies derived from several cross combinations significantly increased the pods per plant. Maximum number of pods obtained from seven cross combinations ranged from 24.67 to 82.33 pods per plant. Selection in new recombinations was able to obtain soybean lines with greater number of pods per plant as compared to parental cultivars.

The seed size was measured through 100-seed weight. The seed size of the progenies tends to be located between the seed size of the both parental genotypes. The seed yield is the most important character in the progeny selection of soybean. Five parents used to produce seed weight ranging from 9.63 to 20.51 g per plant. Cultivar Rajabasa produced the lowest seed yield per plant, while the highest seed yield was produced by cultivar Anjasmoro. The seed yield per plant in six cross combinations was ranging from 19.24 to 25.11 g per plant. Results revealed greater chances of improvement in seed yield of selected soybean lines.

The simultaneous selection for shattering resistance and seed yield per plant in 591 F_5 lines were presented in Table 6. By selecting 30 highest yielding lines, followed by their resistance to pod shattering, thus the obtained range in seed yield was 16.31 to 22.66 g per plant. The degree of pod shattering resistance in five parental cultivars was ranging from resistant (Anjasmoro and G100H) to very susceptible (Rajabasa and Grobogan). However, a total of 30 selected lines with high yield were classified as very resistant to pod shattering.

Development of soybean approved lines with genetic potential of pod shattering resistance and higher yield in tropical regions, especially in Indonesia, will not only increase the productivity per unit area, but will increase the value of farming efficiency by suppressing the yield losses due to pod shattering.

CONCLUSION

Soybean improvement for shattering resistance, followed by their promising performance for agronomic characters will effectively use new recombinations which using gene as a source of shattering resistance. The pod length was one of the important morphological traits which determine the pod shattering resistance. Through simultaneous selection for pod shattering resistance and agronomic traits, the 30 lines were selected and considered as with very resistant to pod shattering with good seed yield ranging from 16.31 to 22.66 g per plant.

Table 5. Mean peformance of F_5 lines of soybean for agronomic traits.

Soybean cross combinations	Number of F_5 lines	Descriptive data	Days to maturity	Plant height (cm)	Branches per plant	Nodes per plant	Pods per plant	100-seed weight (g)	Seed per plant (g)
Anjasmoro ×	88	Mean	83	55.19	2.75	15.20	35.58	17.13	12.88
G100H		Minimum	78	33.00	1.00	10.00	17.33	13.30	5.80
		Maximum	89	72.00	4.00	21.67	69.67	25.11	32.46
G100H ×	59	Mean	84	61.02	2.73	16.38	38.72	15.41	12.37
Anjasmoro		Minimum	81	45.00	1.00	7.67	22.33	11.49	8.27
		Maximum	89	93.67	5.00	38.33	62.33	19.24	19.30
Anjasmoro ×	381	Mean	85	63.44	3.00	16.52	40.95	16.53	15.79
Rajabasa		Minimum	80	32.67	1.33	9.67	14.33	8.84	6.48
		Maximum	89	131.33	5.33	31.33	82.33	25.07	31.20
Rajabasa ×	25	Mean	85	67.23	3.13	17.93	43.91	18.00	16.57
Anjasmoro		Minimum	82	51.67	2.00	13.00	25.33	14.49	12.29
		Maximum	87	96.67	4.33	23.33	72.00	21.51	23.61
Anjasmoro ×	36	Mean	86	49.87	2.82	15.80	43.81	16.33	15.43
Grobogan		Minimum	84	33.00	2.00	10.00	17.33	13.30	9.08
		Maximum	89	70.00	4.00	21.33	69.67	21.55	28.66
Grobogan ×	2	Mean	84	55.67	3.00	15.34	29.00	24.17	15.28
Anjasmoro		Minimum	84	54.00	2.67	13.67	23.33	24.07	13.11
		Maximum	84	57.33	3.33	17.00	34.67	24.26	17.44
Parental genotypes									
Anjasmoro	1	-	84	76.67	2.67	16.00	50.33	18.19	20.51
G100H	1	-	87	46.00	2.33	12.33	30.00	17.20	12.94
Rajabasa	1	-	80	45.00	2.00	10.67	22.00	27.53	9.63
Grobogan	1	-	80	53.33	2.00	11.67	22.67	24.74	10.55

Table 6. Mean performance of selected lines of soybean for pod shattering resistance and other agronomic traits.

Soybean lines	Pod shattering (%)	Seeds per plant (g)	Days to maturity	Plant height (cm)	Branches per plant	Nodes per plant	Pods per plant	100-seed weight (g)
Anjasmoro × Rajabasa-279	0	22.66	85	69.67	2.67	18.67	59.33	18.84
Anjasmoro × Rajabasa-300	0	22.40	87	63.33	3.67	22.00	69.33	15.91
Anjasmoro × Rajabasa-106	0	21.70	87	68.33	4.00	21.33	53.67	16.28
Anjasmoro × Rajabasa-205	0	21.68	87	56.33	3.33	18.33	43.33	17.74
Anjasmoro × Rajabasa-47	0	21.57	87	72.00	4.33	27.33	68.33	17.46
Anjasmoro × Rajabasa-7	0	21.25	85	60.33	3.67	22.67	57.67	15.97
Anjasmoro × Rajabasa-292	0	20.87	87	84.00	4.00	28.67	60.67	16.10
Anjasmoro × Rajabasa-291	0	20.73	87	80.67	4.00	23.67	52.33	17.25
Anjasmoro × Rajabasa-158	0	20.46	87	68.00	2.00	14.67	48.00	13.47
Anjasmoro × Rajabasa-311	0	19.84	82	60.00	2.00	15.33	41.33	21.23
Anjasmoro × Rajabasa-145	0	19.83	87	53.67	3.33	20.67	72.67	14.15
Anjasmoro × Rajabasa-157	0	19.39	87	68.33	3.67	21.00	64.33	13.55
Anjasmoro × Rajabasa-23	0	19.26	89	58.33	3.67	15.00	57.33	15.98
G100H × Anjasmoro-36	0	18.91	84	67.33	2.67	20.67	61.33	14.45
Anjasmoro × Rajabasa-165	0	18.89	87	70.33	3.33	18.00	64.67	13.36
Anjasmoro × Rajabasa-177	0	18.78	87	52.33	2.67	17.33	46.67	15.85
Anjasmoro × Rajabasa-162	0	18.76	87	75.33	3.00	20.67	75.33	11.71
Anjasmoro × Rajabasa-88	0	18.17	87	64.67	4.00	19.33	47.50	19.41
Anjasmoro × Rajabasa-295	0	17.67	87	98.33	3.67	27.00	69.67	13.82
Anjasmoro × Rajabasa-212	0	17.50	87	60.67	3.33	21.00	53.67	15.12
Anjasmoro × Rajabasa-241	0	17.31	85	74.33	2.67	18.33	49.00	8.84
Anjasmoro × Rajabasa-261	0	17.24	85	69.00	3.33	21.00	46.67	14.35
Anjasmoro × Rajabasa-50	0	17.24	89	56.33	4.00	22.67	70.33	14.42
Anjasmoro × Rajabasa-276	0	17.13	87	80.00	3.00	17.67	54.00	15.16
Anjasmoro × Rajabasa-167	0	17.06	87	81.00	2.67	17.67	59.33	11.73
Anjasmoro × Rajabasa-249	0	16.88	87	82.00	3.00	20.33	54.33	17.35
Anjasmoro × Rajabasa-45	0	16.75	85	58.33	2.33	17.00	42.67	16.44
Anjasmoro × Rajabasa-299	0	16.47	85	64.00	3.67	17.67	42.67	15.95
Anjasmoro × Rajabasa-288	0	16.31	87	82.00	2.67	15.67	51.33	14.61
Anjasmoro × Rajabasa-283	0	16.29	87	65.00	2.33	16.67	45.67	16.11
Means	0	18.97	86	68.80	3.22	19.93	56.11	15.42
Parental genotypes								
Anjasmoro	3	20.51	84	76.67	2.67	16.00	50.33	18.19
G100H	3	12.94	87	46.00	2.33	12.33	30.00	17.20
Rajabasa	100	9.63	80	45.00	2.00	10.67	22.00	27.53
Grobogan	100	10.55	80	53.33	2.00	11.67	22.67	24.74
Means	52	13.41	82.75	55.25	2.25	12.67	31.25	21.92

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