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Characterization and performance of agronomic characters of soybean genotypes resistant to pod shattering

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Abstract. *Krisnawati A, Adie MM. 2017. Characterization and performance of agronomic characters of soybean genotypes resistant to pod shattering. Biodiversitas 18: 1158-1164.* Pod shattering is one of the major obstacles of soybean cultivation in Indonesia's tropical climate. A total of 24 soybean genotypes, including Anjasmoro (check variety for pod-shatter resistant), Argomulyo and Grobogan (susceptible to pod shattering). The field experiment was conducted in Banyuwangi (East Java, Indonesia) during the dry season II 2016. The experimental design was randomized block, consisted of 24 soybean genotypes as sample trait with four replications. Pods from six random plants at physiological maturity (R8) were detached for pod shattering evaluation. The pod shattering evaluation was conducted in Laboratory of Plant Breeding, Indonesian Legumes and Tuber Crops Research Institutes (Malang, Indonesia) by using oven method and ambient temperature method. The classification of shattering resistance was according to Bailey et al. (1997) and Mohammed (2010), i.e. resistant (0-10% shattered pods), intermediate (11-70 % shattered pods) and susceptible (71-100% shattered pods). The average shattered pods of 24 genotypes by oven method reached 42.67%, higher than those of ambient method (21.81%). Six soybean genotypes showed consistently resistant to pod shattering based on oven as well as ambient method. Pods position at lower part was more susceptible to pod shattering than those at middle and upper part. The limit of pod shattering was ranging from two to 38 days. Genotype of G511H/Anjs/Anjs-1-2 which characterized by pod shatter resistant, produced high yield, and large seed size, was potentially developed at the tropical area, such as Indonesia.

Keywords: Agronomic character, *Glycine max*, pod position, pod shattering

INTRODUCTION

Soybeans in Indonesia are mostly cultivated during the dry season (June/July-September/October). As a consequence, the seed maturing process and the period thereafter often occur in the peak of dry season, which poses a different production problem, such as pod shattering. The use of susceptible variety to pod shattering will aggravate the seed losses. The yield losses due to shattering were varied from 34 to 99% (Tiwari and Bhatnagar 1991) depend on the susceptibility of the variety, environmental factors, and delayed harvesting.

The efficient and reasonable effort to minimize the yield losses due to pod shattering is through the use of resistant variety. The success in increasing soybean resistance to pod shattering is determined by the availability of genetic diversity, an understanding of the genes controlling shattering resistance, and an efficient selection method. Various research revealed that pod shattering was genetically controlled (Bailey et al. 1997; Caviness 1969; Saxe et al. 1996). Mohammed et al. (2014) observed ratios at F2 population, and then concluded that inheritance of resistance to pod shattering was quantitative and under the influence of either duplicate recessive or dominant and recessive epistasis depending on the parental genotypes used in the cross. Another study revealed a presence of two major genes along with inhibitory epistasis for the inheritance of pod shattering in soybean (Bhor et al. 2014). Similarly, Tukamuhabwa et al. (2002) reported that pod shattering in soybean is under control of two genes and is partially dominant over resistance which influenced by non-allelic interactions resulting in classical dominant epistasis. Furthermore, using quantitative trait locus (QTL), Yamada et al. (2009) and Funatsuki et al. (2014) obtained qPDH1 which potentially be used as a marker-assisted selection for shattering resistance in soybean.

The phenomenon of pod shattering is to be a problem within soybean cultivation not only in sub-tropical regions, but also in soybean production centers in the tropics. Identification of soybean resistance to pod shattering have been conducted, and resistant genotype has also been used as a parent to improve resistance to shattering soybean pods. In Thailand, a cultivar of SJ2 was reported to be resistant to pod shattering (Yumoto et al. 2000). Moreover, in India, a cultivar of NRC 7 was reported to be resistant, but EC 241780 and Kalitur were susceptible (Bhor et al. 2014). Tukamuhabwa et al. (2002) conducted a study of genetic resistance to pod shattering using susceptible cultivars (AGS 292 and TGm 737P), resistant (Duiker, Gc81090-48, Roan and TGx 1448-2E0) and moderate (Kabanyolo 1 and Samsoy 1). Meanwhile, in Indonesia, the result of field observation revealed that Anjasmoro cultivar was resistant to pod shattering. The availability the genetic diversity of soybean resistance to pod shattering provide opportunities for improving resistance to pod shattering.

Soybean resistance to pod shattering was determined by various aspects, such as plant architecture, structure of pod anatomy, chemical composition of pod wall, genetic constituent, and environmental condition during pods at maturity phase (Gulluoglu et al. 2006). A study by Tiwari and Bhatia (1995) showed that the thickness and length of the bundle cap on the dorsal side of the pod and pod-wall thickness became the determinant factors of soybean resistance to pod shattering. Bara et al. (2013) examined the relationship between morphological characters with pod shattering resistance, and he reported that soybean with small pod, less pod width and low volume/weight of seed were tolerant to pod shattering. Differences in pod morphological characters as a determinant of resistance to pod shattering depends on the cultivar and evaluation methods of pod shattering resistance. Agrawal et al. (2000) suggested the evaluation of pod shattering resistance could be done in the laboratory. Morgan et al. (1998) evaluated pod shattering in oilseed rape, and revealed that resistance to pod shattering determined in the laboratory was broadly linked to field assessment scores. However, Adeyeye et al. (2014) did not found consistently resistant variety when examining pod shattering in 15 soybean cultivars in the pot and field, respectively.

Nowadays, the problems during soybean cultivation in Indonesia are climate change and the labor scarcity. Shortage of labor can delay harvesting, leading to yield losses. A significant yield loss was reported by Tiwari & Bhatnagar (1991) due to delayed harvesting at maturity, particularly in susceptible varieties to pod shattering. The availability of soybean resistant to pod shattering would reduce the yield losses and increase the farmers' income. A study by Tukamuhabwa et al. (2002) showed that resistant varieties did not shatter even when harvested after a delayed harvesting period of 21 days. The aim of the research was to characterize soybean resistance to pod shattering and the agronomic characters of several soybean genotypes.

MATERIALS AND METHODS

The field experiment was conducted in Banyuwangi (East Java, Indonesia) on dry season II (August-October) 2016. The materials consist of 24 soybean genotypes, including three check varieties, i.e. Anjasmoro (pod shatter resistant), Argomulyo and Grobogan (susceptible to pod shattering). The experimental design was randomized block, 24 soybean genotypes as sample trait, and each genotype had four replications. The plot size was 2.0 × 4.5 m, with 40 cm × 15 cm planting distance, two plants per hill. Fertilizer of 250 kg Phonska/ha + 100 kg SP 36 and 1 t/ha organic fertilizer was applied prior sowing. Weeding was done on two and four weeks after planting. The observation was made on days to maturity, plant height, 100 seed weight, and seed yield.

Pods from six random plants at physiological maturity (R8) were detached for pod shattering evaluation. The pod shattering evaluation was conducted in Laboratory of Plant Breeding, Indonesian Legumes and Tuber Crops Research Institutes (Malang, Indonesia) by using oven method and ambient temperature method. On oven method, 30 fully matured pods were randomly taken from three soybean plants of each genotype, and then placed in petri dishes and kept in the oven. Oven temperature was set at 30˚C for three days, and then elevated into 40˚C (one day), 50˚C (one day), 60˚C (three days). On ambient temperature method, three randomly sample plants were placed at room temperature. Each sample plant was marked into three parts, i.e. ⅓ upper part, ⅓ middle part, and ⅓ lower part. The observation was made on number of shattered pods at each part.

The classification of shattering resistance was according to Bailey et al. (1997) and Mohammed (2010) as follows: (i) Resistant = 0-10% shattered pods, (ii) Intermediate = 11-70 % shattered pods, (iii) Susceptible = 71-100% shattered pods

RESULTS AND DISCUSSION

The grouping of resistance

The evaluation of soybean resistance to pod shattering based on oven method showed heavy selection pressure compared to the ambient temperature method (Table 1). The pod shattering average of 24 soybean genotypes by oven method was 42.67%, higher than those of ambient temperature method (21.81%) (Figure 1). By oven method, six soybean genotypes showed resistant reaction, 11 genotypes categorized as intermediate, and seven genotypes were susceptible to pod shattering. The resistance evaluation by placing soybean at natural condition (ambient temperature) showed 12 genotypes as resistant, ten genotypes were intermediate, and the rest two were susceptible to pod shattering.

Six resistant genotypes based on oven method showed a consistent resistant reaction when assessed using ambient temperature. However, the other genotypes which classified as intermediate based on oven method, turn into resistant based on ambient temperature method. The resistant check variety (Anjasmoro) was categorized as intermediate based on oven method, but resistant based on ambient temperature method. The other two susceptible check-varieties (Argomulyo and Grobogan) showed a consistently susceptible reaction for both methods.

The pattern of pod shattering

The pattern of pod shattering occurrence on each individual plant was studied through pod shattering evaluation by placing fully mature soybean plant at ambient temperature. The number of pod per plant was different between genotypes, as well as the number of pods at upper, middle and lower part of plant, respectively. A similar pattern also found on the pod shattering of each part of plant as well as between genotypes (Table 2).

The average number of pods at upper, middle and lower part of plant was 13.47, 15.59, and 13.56 pods per plant, respectively. The number of pods at middle part of plant was greater than those at upper and lower part. However, if we observed the number of pod shattering between parts of the plant (Table 2, Figure 2), it showed that pod on lower part of plant was more susceptible to pod shattering

(27.36%) than those at upper part (17.03%) and lower part (18.99%).

Figure 2 shows the pod shattering patterns of three parts of the plants (upper, middle, and lower part). It indicates that the resistant-ability average of 24 soybean genotypes to pod shattering was only up to 12 days. However, the distribution of resistant limit (0-10% shattered pod) of 24 genotypes was ranged from two to 38 days (Fig. 3). For example, Grobogan variety had a resistant limit to pod shattering only up to two days after full maturity, but on the contrary, G511H/Anjs/Anjs-5-5 had a resistant limit to pod shattering up to 38 days. This is revealed that G511H/Anjs/Anjs-5-5 held seed better when the delayed harvest until 38 days on the ambient temperature.

Characters of agronomy

Agronomic characters which consist of days to maturity, plant height, 100 seed weight, and seed yield were significantly different between genotype (Table 3). The days to maturity ranged from 75-85 days (an average of 81 days), plant height ranged from 50.30 to 71.75 cm (an average of 60.98 cm), 100 seed weight ranged from

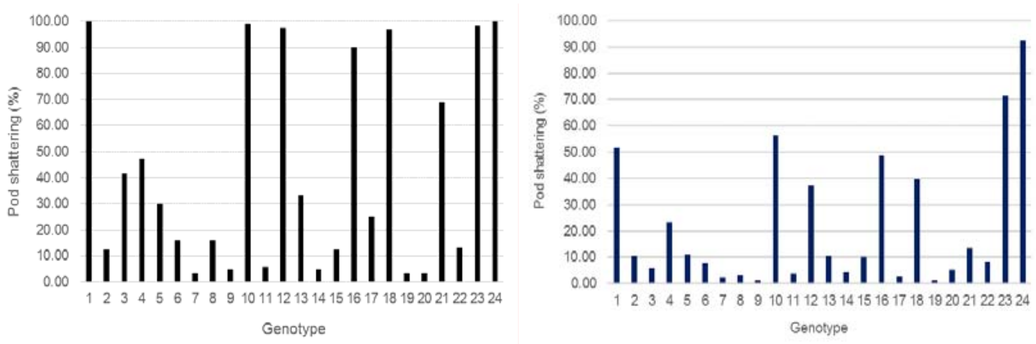

Figure 1. Percentage of pod shattering based on oven method (*right*) and ambient temperature method (*left*)

Table 1. Grouping of soybean resistance to pod shattering in 2016

Genotype	Pod shattering			
	Oven method		Ambient temperature method	
	%	Criteria	%	Criteria
G511H/Anjs/Anjs-2-13	100.00	S	51.80	I
G511H/Anjs-1-1	12.50	I	10.41	I
G511H/Arg//Arg///Arg-30-7	41.67	I	5.88	R
G511H/Kaba//Kaba///-4-4	47.50	I	23.21	I
G511H/Kaba//Kaba///Kaba////Kaba 16-2	30.00	I	11.12	I
G511H/Anjs/Anjs///Anjs-3-3	15.83	I	7.80	R
G511H/Anjs/Anjs///Anjs-6-13	3.33	R	2.27	R
G511H/Anjs/Anjs-1-2	15.83	I	3.12	R
G511H/Anjs/Anjs-5-5	5.00	R	1.14	R
G511H/Anjs/Anjs///Anjs-6-11	99.17	S	56.35	I
G511H/Anjs/Anjs///Anjs-8-1	5.83	R	3.85	R
G511H/Anjs/Anjs-1-3	97.50	S	37.46	I
G511H/Anjs/Anjs///Anjs-6-12	33.33	I	10.44	I
G511H/Anj//Anj///Anj////Anjs-6-8	5.00	R	4.47	R
G511H/Anjasmoro//Anjasmoro-2-8	12.50	I	10.13	R
G511H/Arg//Arg///Arg///Arg-12-15	90.00	S	48.98	I
G511H/Anj//Anj///Anj-6-3	25.00	I	2.74	R
G511H/Arg//Arg///Arg///Arg-19-7	96.67	S	39.66	I
G511H/Anjasmoro-1-7	3.33	R	1.27	R
G511H/Anj//Anj///Anj////Anjs-6-7	3.33	R	5.30	R
G511H/Anjasmoro-1-4	69.17	I	13.58	I
Anjasmoro	13.33	I	8.37	R
Argomulyo	98.33	S	71.53	S
Grobogan	100.00	S	92.53	S
Average	42.67		21.81	
Mean Square	**		**	

Note: R = resistant (1-10%), I = intermediate (11-70%), S = susceptible (71-100%), ** = significant at 5 % probability level ($p < 0.05$)

Table 2. Number of pod and pod shattering at upper, middle, and lower part of the plant based on ambient temperature method in 2016

Genotype	Number of pod/plant			Pod shattering (%)		
	Upper	Middle	Lower	Upper	Middle	Lower
G511H/Anjs/Anjs-2-13	13.25	13.00	13.25	42.96	64.21	50.72
G511H/Anjs-1-1	12.75	16.75	11.75	13.32	5.44	19.15
G511H/Arg//Arg///Arg-30-7	11.00	12.75	12.25	0.00	5.24	12.50
G511H/Kaba//Kaba///-4-4	13.25	18.00	17.00	18.81	25.80	26.33
G511H/Kaba//Kaba///Kaba////Kaba 16-2	18.00	14.25	13.50	6.72	8.62	19.64
G511H/Anjs/Anjs///Anjs-3-3	16.25	18.00	18.00	0.00	6.61	19.60
G511H/Anjs/Anjs///Anjs-6-13	16.50	20.25	22.50	0.00	1.47	4.86
G511H/Anjs/Anjs-1-2	16.25	15.50	16.75	5.80	0.00	5.05
G511H/Anjs/Anjs-5-5	15.00	14.00	12.00	0.00	0.00	3.85
G511H/Anjs/Anjs///Anjs-6-11	10.50	14.00	11.75	60.83	58.71	52.08
G511H/Anjs/Anjs///Anjs-8-1	17.00	14.25	11.00	2.50	2.27	9.23
G511H/Anjs/Anjs-1-3	10.00	19.25	8.75	24.20	40.47	47.74
G511H/Anjs/Anjs///Anjs-6-12	9.50	16.50	16.25	1.92	3.43	23.39
G511H/Anj//Anj///Anj////Anjs-6-8	15.00	16.50	13.75	2.78	2.08	9.94
G511H/Anjasmoro//Anjasmoro-2-8	13.00	13.00	7.75	1.47	1.47	41.16
G511H/Arg//Arg///Arg///Arg-12-15	10.25	16.50	14.50	66.62	45.97	45.00
G511H/Anj//Anj///Anj-6-3	18.50	21.25	18.75	0.00	1.79	5.69
G511H/Arg//Arg///Arg///Arg-19-7	8.25	9.25	9.00	30.83	40.28	47.89
G511H/Anjasmoro-1-7	14.75	13.75	13.25	0.00	0.00	4.77
G511H/Anj//Anj///Anj////Anjs-6-7	12.50	16.75	7.75	0.00	2.95	21.88
G511H/Anjasmoro-1-4	19.00	20.75	15.00	8.74	16.40	22.33
Anjasmoro	16.50	19.00	19.00	1.92	3.57	17.93
Argomulyo	6.75	11.00	10.75	71.53	61.07	77.41
Grobogan	9.50	10.00	11.25	47.78	57.95	68.51
Average	13.47	15.59	13.56	17.03	18.99	27.36
Mean square :						
Pod position (P)		**			**	
Genotype (G)		**			**	
P × G		ns			ns	

Note: ** = significant at 5 % probability level ($p < 0.05$), ns = not significant

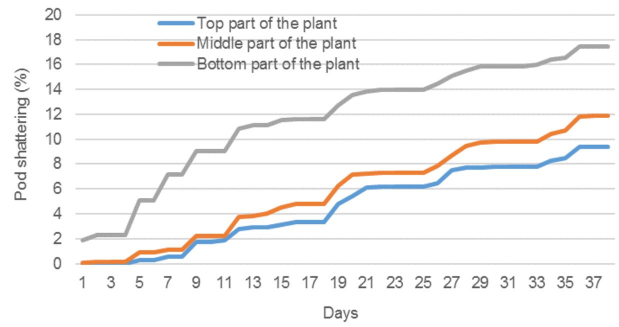

Figure 2. Pod shattering at upper, middle, and lower part of the soybean plants

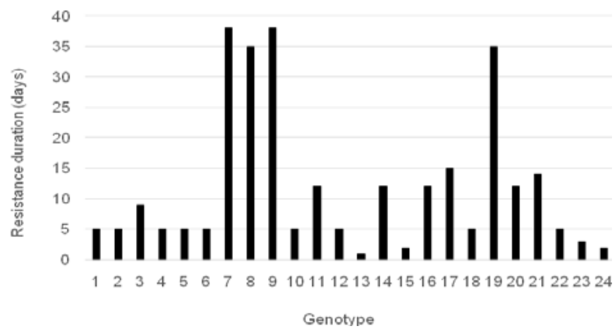

Figure 3. Resistance limit to pod shattering of 24 soybean genotypes

16.06-21.09 g (an average of 17.57 g/100 seeds), and seed yield ranged from 2.08-3.35 t/ha (an average of 2.67 t/ha). A total of seven soybean genotypes was classified as early days to maturity (under 80 days). Moreover, all tested genotypes have large seed size (> 14.00 g/100 seeds).

Evaluation of shattering resistance showed that six soybean genotypes (G511H/Anjs/Anjs///Anjs-6-13, G511H/Anjs/Anjs-5-5, G511H/Anjs/Anjs///Anjs-8-1, G511H/Anj//Anj///Anj////Anjs-6-8, G511H/Anjasmoro-1-7, and G511H/Anj//Anj/// Anj////Anjs-6-7) were consistently resistant based on oven method as well as ambient temperature method. Those genotypes have days to maturity ranged from 83-84 days, plant height ranged from 60.15-83.35 cm, 100 seed weight ranged from 16.21-17.81 g, and seed yield ranged from 2.23-3.17 t/ha. Genotype of G511H/Anjs/Anjs///Anjs-8-1 produced the highest yield (3.17 t/ha), higher than those of resistant check of Anjasmoro (2.63 t/ha); hence, it is potentially be developed at various soybean production centers in Indonesia.

Table 3. Days to maturity, plant height, 100 seed weight, and seed yield of 24 soybean genotypes in 2016

Genotype	Days to maturity (day)	Plant height (cm)	100 seed weight (g)	Seed yield (t/h)
G511H/Anjs/Anjs-2-13	79	56.70	20.33	2.91
G511H/Anjs-1-1	84	58.00	17.42	2.11
G511H/Arg//Arg///Arg-30-7	82	51.35	17.41	2.61
G511H/Kaba//Kaba///-4-4	82	68.05	17.28	3.35
G511H/Kaba//Kaba///Kaba////Kaba 16-2	84	57.20	17.64	2.08
G511H/Anjs/Anjs///Anjs-3-3	80	44.85	18.18	2.64
G511H/Anjs/Anjs///Anjs-6-13	83	83.35	16.91	2.67
G511H/Anjs/Anjs-1-2	84	75.35	16.47	3.22
G511H/Anjs/Anjs-5-5	84	60.15	16.90	2.23
G511H/Anjs/Anjs///Anjs-6-11	79	58.55	18.45	3.05
G511H/Anjs/Anjs///Anjs-8-1	85	67.55	17.81	3.17
G511H/Anjs/Anjs-1-3	81	50.30	16.14	2.64
G511H/Anjs/Anjs///Anjs-6-12	82	62.25	18.08	2.82
G511H/Anj//Anj///Anj////Anjs-6-8	83	64.40	16.38	2.52
G511H/Anjasmoro//Anjasmoro-2-8	78	49.00	18.76	2.67
G511H/Arg//Arg///Arg///Arg-12-15	79	51.60	19.60	2.09
G511H/Anj//Anj///Anj-6-3	83	69.10	17.06	2.71
G511H/Arg//Arg///Arg///Arg-19-7	79	55.90	17.81	2.95
G511H/Anjasmoro-1-7	83	60.15	16.21	2.25
G511H/Anj//Anj///Anj////Anjs-6-7	83	74.45	16.96	2.78
G511H/Anjasmoro-1-4	80	65.00	16.03	2.42
Anjasmoro	85	71.75	16.06	2.63
Argomulyo	75	58.00	16.84	3.09
Grobogan	77	50.40	21.09	2.38
Average	81	60.98	17.57	2.67
Mean Square	**	**	**	**

Note: ** = significantly different at p=0.01

Discussion

Yield losses are the major problems related to the fulfilling the needs of food crops in the world, including in Indonesia. Yield losses in soybean can occur during planting, at maturity phase, and processing. Pod shattering which takes place after maturity phase will be aggravated by delayed harvesting. In the tropical area, such as Indonesia, the larger cultivation area of soybean is at the peak of dry season, and due to the labor scarcity will result in delayed harvesting, and then lead to considerable yield losses, especially on variety which susceptible to pod shattering.

The prospective effort to suppress the yield losses is by providing soybean variety resistant to pod shattering. Characterization of 24 soybean genotypes obtained six resistant genotypes to pod shattering based on both oven (range of pod shattering was 33.33-5.83%) and ambient temperature method (range of pod shattering was 1.14-5.30%). The resistance evaluation based on oven method showing a high selection pressure, whereas ambient temperature method was more closely reflect the real condition in the field. Thus, resistant genotype based on oven method will also resistant on ambient temperature condition.

In Indonesia, Anjasmoro is categorized as popular soybean variety and widely grown by farmers. In this study, Anjasmoro showed intermediate resistant (based on oven method), but became resistant when evaluated at ambient temperature. Based on oven method, six genotypes were categorized as resistant to pod shattering. Moreover, their resistance based on ambient temperature method were higher than Anjasmoro. Furthermore, Argomulyo and Grobogan varieties were susceptible to pod shattering, which was also shown in previous studies (Krisnawati and Adie 2017). The susceptibility of Grobogan was higher than Argomulyo. In Southern Japan, the yield losses due to pod shattering reached 422 kg/ha (Shirota et al. 2001). Another study reported the yield losses ranged from 34-99% (Tiwari and Bhatnagar 1991) and 50-100% (IITA 1986). Tukamuhabwa et al. (2002) also reported that the soybean yield losses on susceptible and moderate variety were 57-175 kg/ha and 0-186 kg/ha, respectively. The quantities of yield losses is determined by various factors, such as genetic, environment, as well as the duration of delayed harvesting after plant maturity. The important environmental factors that affect the pod shattering are dry climate, low humidity, high temperature, and rapid temperature changes (Agrawal et al. 2002). Zhang and Boahen (2010) reported that the rate of shattering was faster on non-irrigated soybean than irrigated soybean. Furthermore, Zhang and Bellaloui (2012) stated that temperature and rainfall as essential factors affecting soybean seed shattering. Another study revealed that pod wall thickness as a determinant factor of soybean resistance to pod shattering (Tiwari and Bhatia 1995; Kuai et al. 2016).

Soybean resistance to pod shattering was varied between genotypes, as well as the limit of resistance to pod shattering. This research has revealed two things, i.e. (1) mapping the pod shattering pattern in a single plant, and (2) describe the resistance duration of a genotype to pod shattering. Currently, those aspects in soybean have not been investigated. The pod position at lower part was more susceptible (27.36% shattered pod) compared to the middle (18.99% shattered pods) and upper part (17.03% shattered pod) of the soybean plant. In terms of physiological maturity, pods on the lower part will mature earliest than those of middle and upper part. It is likely that position of the pods affects pod shattering attributes. From this study indicated that soybean genotypes with pods position more concentrated at upper and middle parts may show less shattered pods. But this result was not in agreement with Romkaew et al. (2007), who reported that the frequency of pod shattering was higher at the upper part of the stem than other parts of the stem. However, a further study is needed because other factors may be involved, such as the moisture content of the pods. The resistance duration of a genotype to pod shattering based on ambient temperature method was varied, which ranged from 2-38 days. Grobogan variety, which categorized as susceptible, only resistant up to two days, and on the third day has turned into an intermediate resistance. In this study, two genotypes (G511H/Anjs/Anjs///Anjs-6-13 and G511H/Anjs/Anjs-5-5) were able to hold seeds relatively well up to 38 days after maturity. Another genotype (G511H/Anjs/Anjs-1-2) had resistance limit to pod shattering up to 35 days. This result showed that the harvest of those genotypes can possibly be delayed for relatively longer periods after maturity without significant yield losses. Thus, those genotypes are good sources of resistance for breeding for shattering resistance.

Observing the various environmental factors which may induce the pod shattering on soybean, hence, most of those factors are difficult to manipulate. During these conditions, the availability of variety resistant to pod shattering could minimize the yield losses. The efforts to improve soybean resistance to pod shattering have been conducted in various countries, however, in Indonesia has not done much to develop the pod shatter resistant variety. Tukamuhabwa et al. (2000) studied the inheritance pattern of soybean resistance to pod shattering through the hybridization between resistant and susceptible genotypes. The study revealed that the inheritance of pod shattering in soybean was controlled by two genes.

The choice to secure the soybean productivity is specific for each tropical agroecology. In Indonesia, soybeans are planted three times a year, i.e. in early wet season (November/December-February/March) on dry land, in the first dry season (March to June on upland or lowland with limited irrigation, and in the dry season (July-September) on lowland. The essential soybean characteristics in such planting pattern are early days to maturity (< 80 days) up to medium maturity (80-90 days), and large seed size (> 14 g/100 seeds). Those conditions are different with other soybean production countries. Thus, selection of soybean genotypes in tropical area of Indonesia is emphasized to pod shattering resistance, high yield, large seed size, and early to medium maturity group.

For a summary, the opportunity to obtain soybean pod shattering resistance is considerably higher due to the large genetic variability of soybean resistance to pod shattering. The pod position at lower part of the plant was more susceptible to pod shattering compared to those at middle as well as upper part. Genotype of G511H/Anjs/Anjs-1-2 produces high yield, large seed size, and resistant to pod shattering, thus, potentially developed in tropical area of Indonesia.

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REFERENCES

Adeyeye AS, Togun AO, Akanbi WB, Adepoju IO, Ibirinde DO. 2014. Pod shattering of different soybean varieties, *Glycine max* (L) Merrill, as affected by some growth and yield parameters. Intl J Agric Policy Res 2 (1): 10-15.

Agrawal AP, Patil SA, Salimath PM. 2000. Identification of potential soybean genotypes for pod shattering resistance and seed yield. J Crop Improv 27: 236-239.

Agrawal AP, Basarkar PM, Salimath PW, Patil SA. 2002. Role of cell wall-degrading enzymes in pod shattering process of soybean. *Glycine max* (L) Merrill. Curr Sci 82 (1): 58-61.

Bailey MA, Mian MAR, Carter TE, Ashley DA, Boerma HR. 1997. Pod dehiscence of soybean: Identification of quantitative trait loci. J Heredity 88: 152-154.

Bara N, Khare D, Srivastava AN. 2013. Studies on the factors affecting pod shattering in soybean. Indian J Genet 73 (3): 270-277.

Bhor TJ, Chimote VP, Deshmukh MP. 2014. Inheritance of pod shattering in soybean [*Glycine max* (L.) Merrill]. Electric J Plant Breed 5 (4): 671-676.

Caviness CE. 1969. Heritability of pod dehiscence and its association with some agronomic characters in soybeans. Crop Sci 9: 207-209.

Funatsuki H, Hajika M, Hagihara S, Yamada T, Tanaka T, Tsuji H, Ishimoto M, Fujino K. 2008. Confirmation of the location and the effects of a major QTL controlling pod dehiscence, qPDHI, in soybean. Breed Sci 58: 63-69.

Gulluoglu L, Halis A, Mehmet A. 2006. Effects of some plant growth regulators and nutrient complexes on pod shattering and yield losses of soybean under hot and dry conditions. Asian J Plant Sci 5: 368-372.

International Institute of Tropical Agriculture (IITA). 1986. A Laboratory Method for Evaluating Resistance to Pod Shattering in Soybeans. Annual Report. IITA, Ibadan, Nigeria.

Krisnawati A, Adie MM. 2017. Variability on morphological characters associated with pod shattering resistance in soybean. Biodiversitas 17: 73-77.

Kuai J, Sun Y, Liu T, Zhang P, Zhou M, Wu J, Zhou G. 2016. Physiological mechanisms behind differences in pod shattering resistance in rapeseed (*Brassica napus* L.) varieties. PLoS One. DOI: 10.1371/journal.pone.0157341 June 14, 2016.

Mohammed H, Akromah R, Abudulai M, Mashark SA, Issah A. 2014. Genetic analysis of resistance to pod shattering in soybean. J Crop Improv 28: 17-26.

Morgan CL, Bruce DM. Child R, Ladbrooke ZL, Arthur AE. 1998. Genetic variation for pod shatters resistance among lines of oilseed rape developed from synthetic *Brassica napus*. Field Crops Res 58: 153-165.

Romkaew J, Umezaki T, Suzuki K, Nagaya Y. 2007. Pod dehiscence in relation to pod position and moisture content in soybean. Plant Prod Sci 10 (3): 292-296.

Tukamuhabwa P, Rubaihayo PR, Dashiell K, Adipala E. 2000. Inheritance of resistance to pod shattering in soybean. Afr Crop Sci J 8: 203-212.

Saxe LA, Clark C, Lin SF, Lumpkin TA. 1996. Mapping the pod-shattering trait in soybean. Soybean Genet Newslet 24: 250-253.

Shirota M, Hamada Y, Nakajima Y, Tani T, Yoshida T, Shaku I, Uchida T. 2001. Study on actual condition of pre-harvest shatter loss on soybean cultivation in Aichi Prefecture. Japan J Crop Sci 70 (Suppl. 2): 23-24.

Tiwari S, Bhatia VS. 1995. Characterization of pod anatomy associated with resistance to pod-shattering in soybeans. Ann Bot 72: 483-485.

Tiwari S, Bhatnagar P. 1991. Pod shattering as related to other agronomic attributes in soybean. Trop Agric (Trinidad) 68: 102-103.

Tukamuhabwa P, Dashiell K, Rubaihayo PR, Nabasirye M. 2002. Determination of field yield loss and effect of environment on pod shattering in soybean. Afr Crop Sci J 10 (3): 203-209.

Yamada T, Funatsuki H, Hagihara S, Fujita S, Tanaka Y, Tsuji H, Ishimoto M, Fujino K, Hajika M. 2009. A major QTL, qPDH1, is commonly involved in shattering resistance of soybean cultivars. Breed Sci 59: 435-440.

Yumoto S, Tanaka Y, Kurosaki H, Yamazaki H, Suzuki C, Matsukawa I, Tsuchiya T, Shirai K, Tomita K, Sasaki K, et al. (2000) A new soybean variety ‘Hayahikari’. Bull Hokkaido Pref Agric Exp Station 78: 19-37.

Zhang L, Boahen S. 2010. Evaluation of critical shattering time of early-maturity soybeans under early soybean production system. Agric Biol J North Amer 1 (4): 440-447.

Zhang L, Bellaloui N. 2012. Effects of planting and maturity dates on shattering patterns under early soybean production system. Amer J Plant Sci 3: 119-124.