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Pod shattering incidence in relation to seed dispersal and maximum harvest delay in soybean genotypes

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Abstract

The efforts to minimize the pod shattering incidence in soybean can be done by the use of resistant variety and the determination on the limit of harvest delay. The study aims to evaluate the pod shattering resistance and to determine the maximum limit for harvest delay in soybean. Sixteen soybean genotypes were planted during the dry season 2019. After plants reached the F_8 phase, ten randomly sample plants were taken from each plot. The examination for the effect of the harvest delay on the pod shattering incidence was based on the simulation on the pot. The experiment was arranged in a randomized block design with four replications. Pod shattering on each fertile node and seed dispersal were observed for twenty days. The number of fertile nodes, number of pods per fertile node, and pod shattering on the fertile node varied between genotypes. The highest number of pods where found at the third node ($7.50^a \pm 4.26$) and fourth node ($7.44^a \pm 4.23$) from the lower part of the stem. Pod shattering in the nodes at the lower part of the stem (17 % ± 4.96 %) was higher than in the nodes at the middle (8% ± 6.86%), and upper part of the stem (3% ± 3.79%). The evaluation for pod shattering resistance resulted in two very resistant genotypes, ten resistant, two moderately resistant, one susceptible, and one very susceptible genotype. The seed dispersal of very resistant and resistant genotypes ranged from 0 - 8.55%, the moderately resistant genotypes were 12 – 15%, and the susceptible and very susceptible genotypes were between 23.72 – 48.65%. The harvest delay in resistant or very resistant genotypes could be done 20 days after maturity, meanwhile in susceptible and very susceptible genotypes, the harvest delay should not exceed three days after maturity.

Keywords: pod number, pod drop, maturity, harvesting time, seed loss.
Abbreviations: AVRDC_Asian Vegetable Research and Development Centre, ANOVA_analysis of variance, CV_coeficient of variation, ILETRI_Indonesian Legume and Tuber Crops Research Institute, LSD_least significant difference, SE_standard of error.

Introduction

Soybean is a family of Leguminosae with a high source of seed protein content. Soybean seeds formed inside the pod is located on the fertile nodes in a plant. The developing pod is initiated from the upper node of the plant where flowering first began. Along with the plant growth, pods that are in the upper nodes at the time of initial formation will shift to the lower nodes. The pod character in the soybean plant is considered to have an important role in determining yield productivity. Thus, the potential productivity of soybean can be estimated from characters of the number of pods, the number of seeds per pod, and seed weight. However, the pod shattering incidence after pod maturity in soybeans causes considerable yield losses.

Pod shattering is opening the pod wall or the silique, allowing the release of seeds. The yield loss due to pod shattering has been reported in different crops, such as lentil (Erskine, 1985), soybean (Tukamuhabwa et al., 2002), canola (Østergaard et al., 2006), rapeseed (Kuai et al., 2016), and common vetch (Dong et al., 2017). Savings for yield losses due to pod shattering have been attempted in various strategies, such as the use of pod sealant (Nunes et al., 2015; Steponaviˇcius et al., 2019), the application of polymer cyclohexane (Aslan et al., 2018), and the use of pod-shatter resistant variety (Bara et al., 2013; Liu et al., 2016; Krisnawati and Adie, 2017a). The primary requirements for improving resistance to pod shattering include the availability of gene sources, the genetic understanding of pod shattering, and the method of selection. In India, a screening for pod shattering resistance in 40 soybean genotypes had obtained a resistant genotype (Girase et al., 2018). In Japan, a screening for pod shattering obtained two soybean genotypes (SJ5 and CM60) as the most resistant cultivars (Romkaew and Umezaki, 2006). Another study reported thirty resistant lines were successfully selected among 150 genotypes from the recombination using pod-resistant parents (Krisnawati and Adie, 2017b). This shows that there is a potential for improvement in resistance to pod shattering to result in good progress.

The pod shattering resistance is strongly influenced by several factors, such as plant architecture, pod morphology and anatomy structures, the pod chemical composition, the genetic constituent, and the growing conditions (Gulluoglu et al., 2006; Raman et al., 2014; Dong et al., 2014; Liu et al., 2019). In soybean, the pod thickness-to-width ratio could be used as one of the resistance indicators to pod shattering (Zhang et al., 2018). A study by Bara et al. (2013) reported that genotype with a small pod, less width and low volume/weight of seed was considered resistant to pod shattering. To optimize the genetic approach in designing resistance to pod shattering, it should also consider the appropriate harvest management. The use of shattering resistant cultivar in combination with the adoption of straight combining practices reportedly could minimize the yield losses (Gan et al., 2008). Furthermore, Zhang and Singh (2020) suggested that the understanding of pod shattering in soybean can be improved by emphasizing the adaptation of genetic control to specific climatic conditions.

Screening for pod shattering resistance can be done using the oven-dry method in the laboratory or under field condition. The pod shattering selection on the 591 F_5 soybean population based on the oven-dry method resulted in a range of shattering from 0 – 100%, and it obtained 17.5% very resistant lines (Krisnawati et al., 2019). This showed that the use of very resistant lines (0% shattered pods) may save the 100% yield losses. Pod shattering also could occur due to harvest delays after the pod reached maturity. According to Hancock (2004), resistance to pod shattering before harvest is crucial. In canola, the harvest delay caused the yield loss up to 50% (Price et al., 1996), and the yield loss will increase if the harvest is delayed up to 3-4 weeks (Holzapfel et al., 2014). In soybean, a significant increase in total losses occurred between the 14 days and the 28 days harvest delays (Philbrook and Oplinger, 1989). According to those studies, then the pod shattering resistance is not only determined by the availability of the resistant cultivars, but also by the length of the harvest delay after maturity.

Thus, it is necessary to observe the pod shattering resistance in soybean after harvest is delayed. Therefore, the purposes of the present study were to evaluate the pod shattering resistance and to determine the maximum limit for harvest delay in soybean.

Results and discussion

The analysis of variance showed that the number of pods was not significantly different between genotypes; however, number of pods per fertile nodes, pod shattering per fertile nodes, pod shattering and seed dispersal, and days for seed dispersal were significantly different between genotypes (Table 1).

Number of pods and fertile nodes

The number of fertile nodes and the number of pods per fertile nodes vary between soybean genotypes (Table 2). The number of fertile nodes ranged from 9 – 12 nodes per plant and the average number of pods per fertile nodes ranged from 0.5 – 7.50 pods per plant (Figure 1). The distribution of fertile nodes of sixteen genotypes shows that three genotypes had nine fertile nodes, four genotypes had ten fertile nodes, another four genotypes had eleven fertile nodes, and the rests (five genotypes) had twelve fertile nodes.

The number of pods on the fertile nodes tend to form the sigmoid curve (Figure 1). The pattern of pod formation as shown in Figure 1 is related to the pattern of the flower development in soybeans. In the beginning, the number of flowers produced increased gradually and then increase sharply until at a certain time it began to slow down. When soybean stem was divided into three parts (four nodes each), then the average number of pods in the fertile nodes at the lower, middle, and upper parts was 4.77, 4.03, and 2.69 pods, respectively.

The highest number of pods was located at the third node and fourth node from the lower part of the stem. A study by Bing et al. (2015) showed that the pod number was mostly produced in the middle layer of the main stem. Furthermore, the number of seeds per pod in the middle layer was also higher than the lower and upper layers of the canopy. Liu et al. (2010) reported that more pods were formed on the upper and middle parts of the stem than on the lower part. However, those previous findings revealed that the number of pods and seeds were not uniform throughout the plant (Ning et al., 2018).

Pod shattering on each node

So far, a study related to pod shattering on each node of soybean stem has never been done. In this study, it is revealed that the pod shattering on each fertile node varies between soybean genotypes (Table 3). The average of pod shattering on each fertile node ranged from 0 – 23%. The highest percentage of pod shattering was derived from the second node, and followed by third, sixth, and fourth nodes of the lower part of the stem (Figure 2).

When the soybean stem was divided into three parts (four nodes each), the average of pod shattering in the nodes at the lower part, middle part, and upper part were 17%, 8%, and 3%, respectively. This shows that the pod shattering was concentrated in the nodes at the lower part of the stem. This result was in line with a study by Krisnawati and Adie (2017a) which showed that the pods at the lower part of the soybean stem produced highest pod shattering than the middle and upper part of the stem. According to the previous study, the flowering of soybean plants started from the basal order racemes to the upper order racemes (Saitoh et al., 2004), thus the pods in the lower part may age more than the pods in the center and upper part of the plant.

The classification of pod shattering resistance

A resistant genotype is important to minimize the yield losses. The evaluation for pod shattering resistance resulted in two very resistant genotypes, ten resistant, two moderately resistant, one susceptible, and one very susceptible genotype (Figure 3). The development of pod-shatter resistant cultivar in soybean was potentially through the recombination using the resistant genotypes as sources of the resistance gene. A study in Japan reported the SJ5 as a shattering-resistant cultivars derived from Thailand and it was used in soybean breeding (Yamada et al., 2009). In addition to SJ2, two other shattering resistance genotypes have been used in the soybean breeding program in Hokkaido (Tsuchiya, 1986). In this study, the genotypes used were derived from the selection of the shatter-resistant soybean progeny. One of these parental genotypes was Anjasmoro variety which is considered as resistant to pod shattering (Krisnawati and Adie, 2017a). Two very resistant and ten resistant genotypes of sixteen tested genotypes were successfully obtained. The very resistant and resistant genotypes showed a lower percentage of pod shattering on the nodes of the lowermost and middle part of the stem. On the contrary, the very susceptible and susceptible genotypes showed a higher percentage of pod shattering on those parts. This is related to the difference in the flowers and pods development (Saitoh et al., 2004).

Table 1. Analysis of variance for measured trait.

No	Character	Mean square		CV (%)
		Replication	Genotype	
1.	Number of pods per plant	97.7500^{ns}	333.9500^{ns}	32.76
2.	Number of pods per fertile nodes	0.0477^{ns}	1.3005^{**}	15.08
3.	Pod shattering per fertile nodes (%)	0.0338^{ns}	1.5075^{**}	21.03
4.	Pod shattering of 16 genotypes (%)	0.0540^{*}	3.4589^{**}	8.69
5.	Seed dispersal of 16 genotypes (%)	0.0182^{ns}	2.1196^{**}	16.58
6.	Days for seed dispersal (day)	4.5259^{ns}	8.1572^{**}	32.04

ns = not significant, * = significant at 5 % probability level ($p < 0.05$), ** = significant at 1 % probability level ($p < 0.01$), CV = coefficient of variation

Table 2. Number of pods on each fertile node.

Geno-type	Number of pods on fertile node:											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0 ± 0.00	9 ± 3.54	17 ± 2.83	5 ± 4.95	6 ± 0.71	3 ± 1.41	1 ± 2.83	2 ± 0.71	2 ± 0.00	2 ± 0.00	9 ± 2.83	0 ± 0.00
2	0 ± 0.00	0 ± 0.00	10 ± 1.41	3 ± 2.12	7 ± 1.41	3 ± 0.71	4 ± 0.71	5 ± 0.71	4 ± 0.71	3 ± 0.71	2 ± 1.41	4 ± 0.71
3	0 ± 0.00	2 ± 0.00	7 ± 3.54	5 ± 0.00	5 ± 0.71	4 ± 0.71	4 ± 0.71	2 ± 1.41	3 ± 0.71	7 ± 0.71	0 ± 0.00	0 ± 0.00
4	0 ± 0.00	4 ±0.71	10 ± 4.24	3 ± 0.71	3 ± 1.41	1 ± 1.41	3 ± 0.00	2 ± 0.00	3 ± 0.71	5 ± 1.41	0 ± 0.00	0 ± 0.00
5	0 ± 0.00	2 ± 0.71	7 ± 0.00	5 ± 0.71	4 ± 0.71	3 ± 0.71	4 ± 0.71	4 ± 0.00	5 ± 2.83	1 ± 0.71	4 ± 0.71	0 ± 0.00
6	1 ± 0.00	4 ± 0.00	2 ± 0.71	16 ± 1.41	6 ± 0.71	6 ± 2.12	3 ± 0.00	4 ± 0.00	2 ± 0.71	5 ± 0.71	9 ± 0.71	0 ± 0.00
7	1 ± 0.71	5 ± 1.41	14 ± 1.41	16 ± 2.12	10 ± 0.71	5 ± 0.00	6 ± 0.71	3 ± 0.00	5 ± 1.41	4 ± 2.12	3 ± 0.71	6 ± 0.71
8	1 ± 0.71	7 ± 0.71	9 ± 1.41	12 ± 0.71	10 ± 3.54	5 ± 1.41	5 ± 0.71	4 ± 0.71	3 ± 1.41	3 ± 0.71	3 ± 0.00	8 ± 0.71
9	0 ± 0.00	1 ± 0.00	7 ± 3.54	5 ± 0.71	3 ± 3.54	4 ± 1.41	4 ± 0.00	3 ± 0.00	2 ± 0.00	5 ± 2.12	0 ± 0.00	0 ± 0.00
10	2 ± 0.71	1 ± 0.71	7 ± 0.00	9 ± 0.71	4 ± 0.71	3 ± 0.71	3 ± 0.00	2 ± 0.00	3 ± 0.71	6 ± 1.41	0 ± 0.00	0 ± 0.00
11	0 ± 0.00	9 ± 1.41	8 ± 0.71	5 ± 0.71	4 ± 0.71	3 ± 0.00	3 ± 1.41	3 ± 0.00	7 ± 1.41	0 ± 0.00	0 ± 0.00	0 ± 0.00
12	2 ± 0.00	6 ±2.83	7 ± 0.00	6 ± 0.71	5 ± 0.71	5 ± 1.41	3 ± 0.00	3 ± 0.00	3 ± 0.00	3 ± 0.71	5 ± 0.00	0 ± 0.00
13	0 ± 0.00	2 ± 0.71	5 ± 1.41	6 ± 0.71	4 ± 1.41	3 ± 1.41	3 ± 1.41	1 ± 0.00	3 ± 2.12	0 ± 0.00	0 ± 0.00	0 ± 0.00
14	0 ± 0.00	0 ± 0.00	0 ± 0.00	11 ± 2.12	8 ± 1.41	7 ± 2.12	5 ± 2.12	5 ± 1.41	4 ± 1.41	2 ± 0.71	3 ±1.41	7 ± 2.12
15	1 ± 0.00	6 ± 2.12	8 ± 2.83	4 ± 0.71	4 ± 0.00	3 ±0.71	4 ± 1.41	2 ± 2.12	5 ± 1.41	0 ± 0.00	0 ± 0.00	0 ± 0.00
16	0 ± 0.00	0 ± 0.00	2 ± 1.41	8 ± 0.00	8 ± 2.83	4 ± 0.71	3 ± 0.00	2 ± 0.71	2 ± 0.00	1 ± 1.41	2 ± 0.00	4 ± 2.12
Avg^a	0.50 ± 0.73 e	3.63 ± 3.10 cd	7.50 ± 4.26 a	7.44 ± 4.23 a	5.69 ± 2.30 b	3.88 ± 1.45 c	3.63 ± 1.15 cd	2.94 ± 1.18 cd	3.50 ± 1.41 cd	2.94 ± 2.24 cd	2.50 ± 3.03 de	1.81 ± 2.93 e
Avg^b	4.77 ± 3.37				4.03 ± 1.17				2.69 ± 0.71			

Avg^a = average number of pods on each fertile node, means in the column with the same letter are not significantly different ($P < 0.05$); Avg^b = average number of pods on each three parts (four consecutive nodes). The genotype number refers to Table 4.

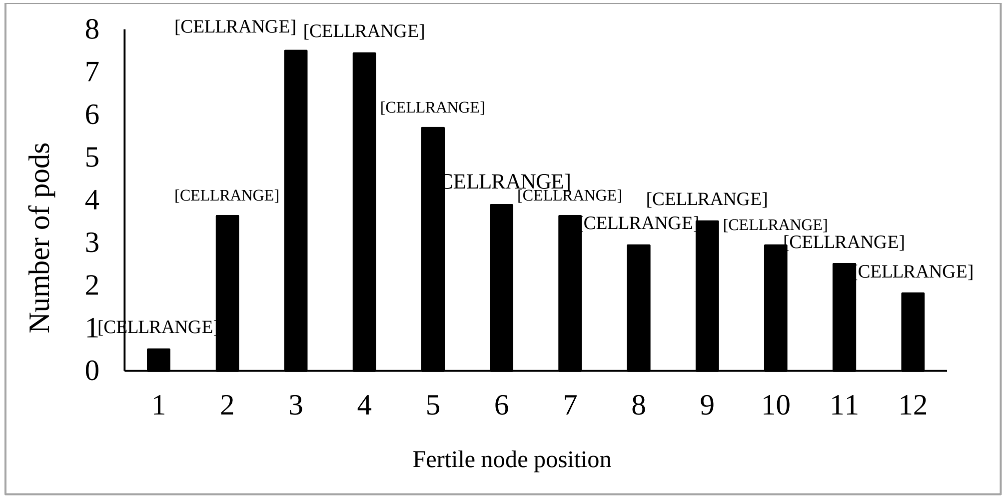

Fig 1. The average number of pods per fertile nodes on 16 soybean genotypes. The genotype code refers to Table 5.

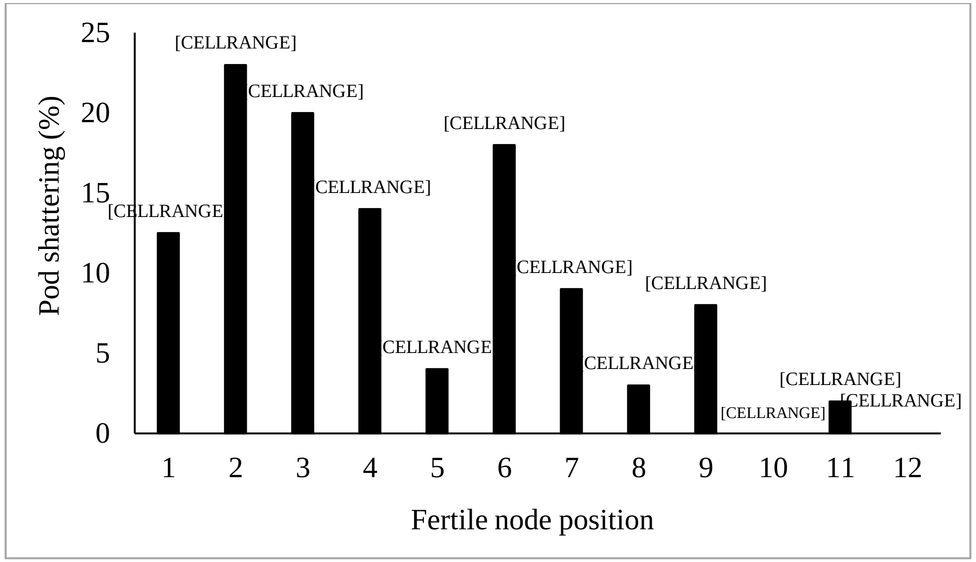

Fig 2. The average of pod shattering on each fertile node in 16 soybean genotypes. The genotype code refers to Table 5.

Table 3. Pod shattering on each fertile node.

Geno-type	Pod shattering (%) on fertile node:											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0 ± 0.00	0 ± 0.00	6 ± 1.00	20 ± 2.45	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-
2	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00
3	0 ± 0.00	0 ± 0.00	0± 0.00	20 ± 0.81	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-	-
4	0 ± 0.00	25 ± 1.52	10 ± 1.53	0 ± 0.00	0 ± 0.00	100 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-	-
5	0 ± 0.00	50 ± 5.77	14 ± 0.58	20 ± 2.16	0 ± 0.00	33 ± 2.65	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-
6	0 ± 0.00	25 ± 2.08	100 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-
7	100 ± 0.00	60 ± 5.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00
8	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	33 ± 3.61	0 ± 0.00
9	0 ± 0.00	100 ± 0.00	29 ± 3.79	20 ± 1.63	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-	-
10	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-	-
11	0 ± 0.00	0 ± 0.00	13 ± 2.52	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-	-	-
12	0 ± 0.00	33 ± 1.73	0 ± 0.00	17 ± 1.53	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	-
13	0 ± 0.00	0± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	33 ± 4.36	0 ± 0.00	0 ± 0.00	0 ± 0.00	-	-	-
14	0 ± 0.00	0 ± 0.00	0 ± 0.00	55 ± 1.53	13 ± 0.58	14 ± 1.53	100 ± 0.00	40 ± 3.51	50 ± 6.11	0 ± 0.00	0 ± 0.00	0 ± 0.00
15	100 ± 0.00	67 ± 2.52	100 ± 0.00	75 ± 2.00	50 ± 2.89	100 ± 0.00	50 ± 2.52	0 ± 0.00	80 ± 2.93	-	-	-
16	0 ± 0.00	0 ± 0.00	50 ± 3.51	00 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00	0 ± 0.00
Avg[a]	13 ± 34.16 bc	23 ± 31.44 a	20 ± 34.02 ab	14 ± 22.09 bc	4 ± 12.70 def	18 ± 34.13 ab	9 ± 27.20 cd	3 ± 10.00 efg	8 ± 22.87 cde	0 ± 0.00 g	2 ± 11.00 fg	0 ± 0.00 g
Avg[b]	17 ± 4.96				8 ± 6.86				3 ± 3.79			

Avg[a] = average number of pods on each fertile node, means in the column with the same letter are not significantly different ($P < 0.05$); Avg[b] = average number of pods on each three parts (four nodes each). The genotype number refers to Table 4.

Table 4. Days required for initiation of pod shattering (seed dispersal).

No	Genotype	Pod shattering (%) after maturity on the day:																			
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	Anj/G100H-6	0	2	2	2	2	2	2	2	2	2	2	4	4	4	4	4	4	4	4	4
2	Anj/G100H-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Anj/G100H-16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	3	3
4	Anj/G100H-21	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	9	9	9	9	15
5	Anj/G100H-24	0	0	0	0	0	0	0	0	0	0	0	0	3	3	3	8	8	8	8	10
6	Anj/G100H-28	0	2	2	2	2	2	2	2	2	2	2	2	2	2	2	3	3	5	5	5
7	Anj/G100H-44	0	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	5	5	5
8	Anj/IAC100-19	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
9	Anj/Rjbs-304	0	0	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	12	12	12
10	Anj/Rjbs-305	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	Anj/Rjbs-306	0	0	0	0	0	0	0	0	0	0	0	0	2	2	2	2	2	2	2	2
12	Anj/Rjbs-309	0	0	2	2	2	2	2	2	2	2	2	2	2	4	4	4	6	6	6	6
13	Anj/ Rjbs-311	0	0	0	0	0	0	0	0	0	0	0	4	4	4	4	4	4	4	4	4
14	Grbg/Anj-2	0	0	2	4	4	4	4	4	4	4	4	4	6	6	6	6	15	15	33	33
15	Dega 1	3	8	8	11	14	16	16	16	38	38	41	41	51	51	54	68	68	68	68	73
16	Detap 1	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Grey background = suggestion for the maximum day limit of the harvest delay

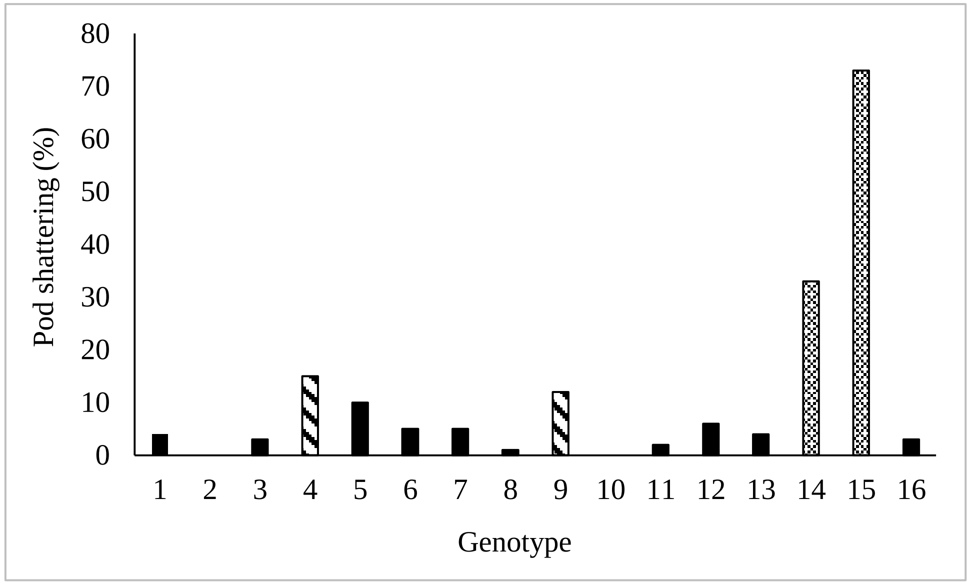

Fig 3. Pod shattering resistance of 16 soybean genotypes. The genotype code refers to Table 5. No bar = very resistant, black fill pattern = resistant, wide downward diagonal pattern = moderately resistant, 30% fill pattern = very susceptible. The genotype code refers to Table 5.

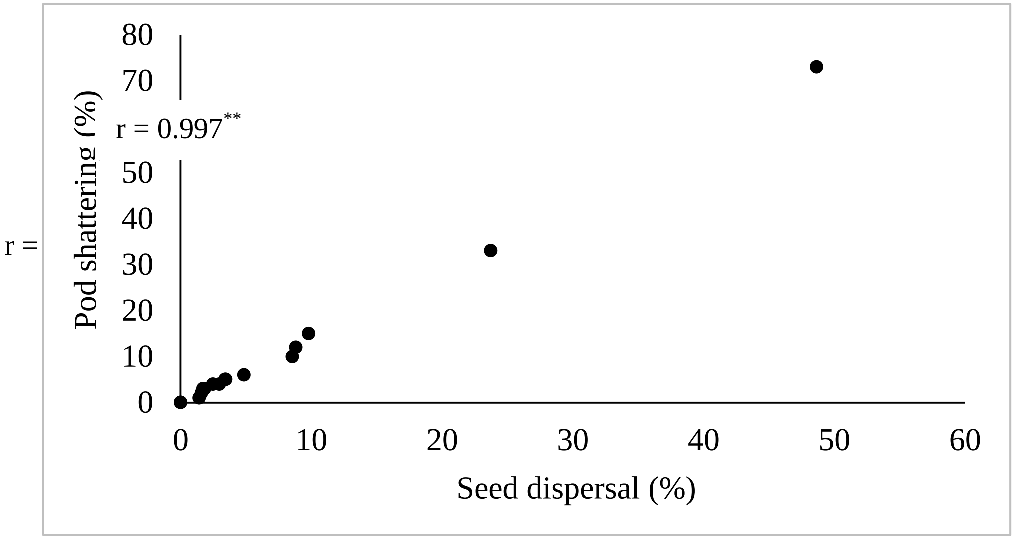

Fig 4. The relationship between the seed dispersal with pod shattering in soybean.

Table 5. The description of research materials developed by the breeding programme in Indonesian Legume and Tuber Crops Research Institute (ILETRI), Indonesia.

Code	Genotype	Pedigree	Remark
1	Anj/G100H-6	Anjasmoro × G100H	Promising line
2	Anj/G100H-14	Anjasmoro × G100H	Promising line
3	Anj/G100H-16	Anjasmoro × G100H	Promising line
4	Anj/G100H-21	Anjasmoro × G100H	Promising line
5	Anj/G100H-24	Anjasmoro × G100H	Promising line
6	Anj/G100H-28	Anjasmoro × G100H	Promising line
7	Anj/G100H-44	Anjasmoro × G100H	Promising line
8	Anj/IAC100-19	Anjasmoro × IAC100	Promising line
9	Anj/Rjbs-304	Anjasmoro × Rajabasa	Promising line
10	Anj/Rjbs-305	Anjasmoro × Rajabasa	Promising line
11	Anj/Rjbs-306	Anjasmoro × Rajabasa	Promising line
12	Anj/Rjbs-309	Anjasmoro × Rajabasa	Promising line
13	Anj/ Rjbs-311	Anjasmoro × Rajabasa	Promising line
14	Grbg/Anj-2	Grobogan × Anjasmoro	Promising line
15	Dega 1	-	Released variety
16	Detap 1	-	Released variety

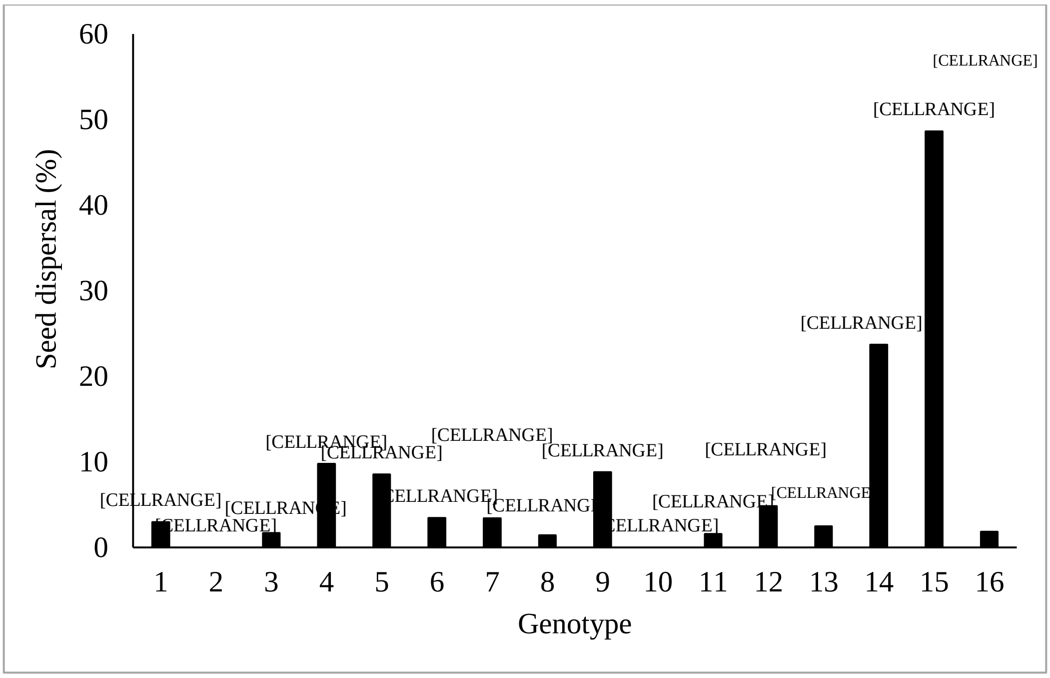

Fig 5. The seed dispersal of 16 soybean genotypes. The genotype code refers to Table 5.

Seed dispersal

Pod shattering becomes the cause of the yield losses due to shattered seeds from the pods as result of the opened soybean pod wall. A relationship between pod shattering with seed dispersal showed that the more susceptible a genotype, the higher the seed dispersal (r=0.997**) or the yield loss (Figure 4). The seed dispersal of 16 genotypes was between 0 - 48.65% (Figure 5). Seed dispersal of very resistant and resistant genotypes ranged from 0 – 8.55%, the moderately resistant genotypes were 12 – 15%, and the susceptible and very susceptible genotypes were between 23.72 – 48.65%.

The Dega 1 cultivar showed very susceptible to pod shattering (73%) with seed dispersal reached 48.65%. A resistant genotype showed the seed dispersal < 9% or saving the yield loss 91%. On the contrary, the seed dispersal of a susceptible genotype reached 48%. It showed that the use of a very susceptible genotype will potentially decrease the seed yield up to 48.65%. This was different from the use of resistant genotype which showed the yield losses of between 1 - 10%. A study by Tiwari and Bhatnagar (1991) reported the seed losses in soybean was between 34 - 99% in susceptible varieties and delayed harvesting after maturity. Furthermore, Philbrook and Oplinger (1989) reported that pod shattering in soybean has contributed to the 37% of total losses in the South Eastern USA. The difference in the amount of yield losses could be depending on genotype, location, season, and harvesting date (Tukamuhabwa et al., 2002). In other commodities, such as lentil, the seed loss due to shattering reached 55% in the regions of West Asia and North Africa (Sidahmed and Jaber, 2004). For oilseed rape, the average annual seed losses due to pod shattering are 20–50% of the total seed yield (Dong et al., 2017).

Quantification of the harvest delay

The pod shattering trait in soybean genotype needs to consider the aspect of resistance and to be combined with the ability of a genotype to hold the seeds after maturity in cases of delay in harvesting. This is important especially when there is labor scarcity. Determination on the maximum limit of harvest delays in soybean is important to avoid yield losses due to seed dispersal or pod shattering. Table 4 shows the simulation result of the maximum limit of harvest delays for each genotype. Very resistant genotypes (Anj/G100H-14 and Anj/Rjbs-305) showed no shattered seeds after delayed for twenty days. Meanwhile, the group of resistant genotypes (for example, Anj/G100H-6, Anj/G100H-16, Anj/G100H-28, Anj/G100H-44) showed the seed dispersal under seven percent.

Based on these results, the maximum limit for harvest delays for very resistant genotypes and resistant genotypes can be done in 20 days after pod maturity. Meanwhile, based on the percentage of seed dispersal for moderately resistant genotype (example, Anj/Rjbs-304) on the 18^{th} days has reached 12%. Therefore it is suggested to have a maximum limit for harvest delays of 17 days after pod maturity. The maximum limit for harvest delays for susceptible genotype (Grbg/Anj-2) was 16 days after pod maturity, because the seed dispersal on the 17^{th} days reached over ten percent. A very susceptible genotype (Dega 1) showed the seed dispersal over ten percent in the 11^{th} days after maturity. Therefore the very susceptible genotypes should not be harvested more than three days after maturity to avoid a significant yield loss. Other study in soybean showed that resistant varieties did not shatter even when it was harvested after a delayed harvesting period of 21 days (Tukamuhabwa et al., 2002). In canola, losses generally increased when harvest was delayed by 3-4 weeks (Holzapfel et al., 2014).

Quantification of the maximum limit of harvest delays is important, especially for soybean production in the tropics due to: (1) the scarcity of human labor to harvest which can delay harvesting leading to seed yield loss and (2) the soybean harvest is at the peak of the dry season. The high temperature and low humidity during the dry season become the major causes of pod shattering. However, the harvest delays could differ among countries because of differences in the environmental conditions and degrees of resistance of a genotype.

Materials and Methods

Plant materials and field experiment

The research material was fourteen soybean promising lines and two cultivars (Table 5). The soybean promising lines was derived from crossing in the breeding programme in Indonesian Legume and Tuber Crops Research Institute (ILETRI), Indonesia. Those sixteen genotypes were planted in the Muneng Research Station (Probolinggo, East Java, Indonesia) during the dry season (July to October 2019). The field experiment was designed as a randomized block design with four replicates. Two seeds per hill were shown in 1.2 m × 3.0 m plot size with 40 × 15 cm plant spacing. Plants were fertilized by 50 kg/ha Urea, 100 kg/ha SP36, and 75 kg/ha KCl which applied entirely at the sowing time.

Plant harvesting and evaluation for pod shattering incidence

After plants reached the F_8 phase which showed by the leaves turn to yellow, ten randomly sample plants were taken from each plot. The leaves were removed and the roots of the plant were cut off. Furthermore, each plant was exposed to direct sunlight in an upright position by plugging it into a polybag containing approximately 5 kg of soil. The experiment was arranged in a randomized block design with four replications, according to the field experimental design. All polybags containing soybean plants were laid out under the sun for 20 days. The pod shattering incidence was observed every day until the 20^{th} day.

Traits measured

The observation was made for each plant on the number of fertile nodes, number of pods per fertile node, number of pod shattering on each day, and number of shattered seeds from each pod on each day (seed dispersal). In each plant, the number of fertile nodes in the main stem and branches were counted after plant maturity. Within each fertile node, the number of pods was counted starting from node at the lower part (basal) of the stem. The number of pod shattering of each plant was observed on each fertile node starting from node at the lower part (basal) of the stem. The average number of pods and pod shattering were also calculated on each three parts of the stem (lower, middle, and upper part). Each part consists of four consecutive nodes. The number of pod shattering of each plant was the total of shattered pods from all fertile nodes, and it was observed every day until the 20^{th} day. The seed dispersal was the number of shattered seeds from all pods in all fertile nodes, based on the daily observation of pod shattering for twenty days.

Pod shattering and seed dispersal for each genotype were evaluated as follows:

$$\text{Pod shattering (\%)} = \left(\frac{\text{number of pod shattering per plant}}{\text{number of total pods per plant}}\right) \times 100\%$$

$$\text{Seed dispersal (\%)} = \left(\frac{\text{number of shattered seeds}}{\text{number of total seeds per plant}}\right) \times 100\%$$

The classification of pod shattering resistance was based on the AVRDC (1979) as follows: very resistant (0% shattered pod), resistant (1-10% shattered pods), moderate (11-25% shattered pods), susceptible (26 – 50% shattered pods), and very susceptible (> 50% shattered pods).

Statistical analysis

The data were subjected to analysis of variance (ANOVA) to determine the effect of treatment (genotype), and continued with the LSD test at 5% ($p < 0.05$) and 1% ($p < 0.01$) probability level. For the traits with zero value, the data were transformed by $(x+0.5)^{1/2}$ to normalize the distribution of errors. The data of pod numbers and pod shattering on each fertile node were expressed as means ± standard error.

Conclusion

According to our results, the evaluation for pod shattering resistance of sixteen soybean genotypes resulted in two very resistant genotypes, ten resistant, two moderately resistant, one susceptible, and one very susceptible genotype. The degree of resistance of a genotype will determine the yield loss as shown by the seed dispersal. A very resistant and resistant genotypes could save the yield losses between 0 - 8.55%, in contrast with susceptible and very susceptible genotypes which showed the yield losses between 23.72 - 48.65%. Based on the simulation of pod shattering under pot condition, the harvest delay in resistant or very resistant genotypes could be 20 days after maturity Meanwhile, in susceptible and very susceptible genotypes, the harvest delay should not exceed three days after maturity to avoid a higher pod shattering.

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