Evaluation of several soybean genotypes for pod shattering resistance

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Abstract. Shattering in soybean occurs after the pods reached maturity which can cause considerable yield loss. The aims of this study were to evaluate the pod shattering resistance and the performance of the agronomic traits of several soybean genotypes. The field study was conducted at Banyuwangi (Indonesia) from July to October 2018 using twelve soybean genotypes. Pod-shattering evaluation was done as per oven-dry and sun-drying methods. The variability of shattering start to occur at oven temperature treatment of 50°C and 60°C. Based on the oven-dry method, two genotypes were found resistant, three genotypes were susceptible, and seven genotypes were highly susceptible to pod shattering. Based on the sun-drying method (15 days drying), two genotypes were categorized as resistant, three genotypes were moderate, five genotypes were susceptible, and two genotypes were highly susceptible. Soybean genotypes ATgt-18-009 and Anjasmoro showed consistently resistant to pod shattering based on the oven-dry as well as sun-drying methods. Those genotypes also produce high yield (more than 3.0 t/ha) with days to maturity ranging from 82 to 85 days, therefore it could be potentially developed in the soybean production centers in Indonesia.

1. Introduction
In Indonesia, soybean is cultivated in various growing seasons. The widest soybean cultivation is during the second dry season between June/July to September/October. During those planting seasons, the temperature continues to rise until the soybean plants reach the maturity and harvest phases. In such conditions, soybean plants are vulnerable to yield losses due to pod shattering.

Pod shattering is the opening of the pod wall after the plant reaches maturity and resulting in the loss of the seeds. The yield losses due to shattering in various soybean production centers in the world were between 34 - 99% [1,2]. In Japan, the yield loss was reported as 422 kg/ha [3]. The amount of yield loss due to pod shattering could be caused by genetic and environmental factors, and also the duration of harvest delay [4,5]. The availability of shattering-resistant cultivars as well as their economic value is important to minimize the yield losses.

One of the advantages of the shattering-resistant cultivar was that harvest delay can be done during the dry weather [6]. The use of shattering-resistant cultivar was in accordance with the climate typology for soyebeans in Indonesia, as well as the scarcity of labor during the soybean harvest. The development of shattering-resistant cultivar is associated with the selection and criteria method of shattering. In India, Barate et al. [7] evaluated 50 soybean genotypes derived from several regions and obtained nine shatter-resistant genotypes. Earlier studies by Bara et al. [8] obtained the range of shattering between 0.67 – 67% from 69 soybean genotypes, and three of them were resistant to
shattering. It was also reported that plant stage and high temperature as the factors which determine the shattering rate. Furthermore, Zhang & Boahen [4] reported that non-irrigated soybean shattered faster than irrigated soybean.

Identification for shattering resistance of 34 soybean genotypes in Ghana obtained six moderately resistant genotypes [5]. In Indonesia, a study for shattering resistance was done on 150 soybean genotypes derived from crossing, and has obtained eight very resistant genotypes [9]. A further study using 30 advanced lines has obtained 13 resistant genotypes, which the pod wall thickness and pod length as the determinant factors in pod shattering resistance [10]. A study on the determinant of shattering in Nigeria resulted in the pod diameter was negatively correlated with pod shattering [11].

Various studies that have been carried out showed that there were several soybean genotypes that have resistant to very resistant in pod shattering. Other studies supported that pod shattering was genetically controlled [12,13]. Therefore, the opportunity to obtain a shattering-resistant variety will be even greater. The research was aimed to evaluate the pod shattering resistance and the performance of the agronomic traits of several soybean genotypes.

2. Methodology

2.1. Materials and field experiment

The field experiment was conducted during the dry season in Banyuwangi (Indonesia) from July – November 2018. The plant materials consist of 12 soybean genotypes (10 lines derived from crossing and two check varieties of Demas 1 and Anjasmor).

2.2. Planting and experiment arrangement

The research was conducted in lowland after rice planting. The experiment was arranged in a randomized block design with three replications. The plot size was 2.0 m × 4.5 m, and the planting distance was 40 cm × 15 cm, two plants per hill. Plants were fertilized with 250 kg Phonska/ha + 100 kg SP 36 and 1 t/ha organic fertilizer which given entirely at the time of planting. The weeding control was done at 2 and 4 weeks after planting.

2.3. Evaluation for pod shattering resistance

The evaluation for pod shattering was done as per oven-dry and sun-drying methods. When plants were in R8 stage, four sample plants were randomly taken from each genotype. On the oven-dry method, two sample plants were dried for three days at room temperature. A total of 30 pods from two sample plants were randomly detached and be placed in petridish, and then 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 after exposing to each temperature. The evaluation for pod shattering using the sun-drying method was done by drying the two sample plants which taken at R8 stage under the sun for 15 days. Observation for pod shattering was made every day. The shattering resistance was classified according to AVRDC [14] as follows: very resistant (0%), resistant (1 to 10%), moderately resistant (11 to 25%), susceptible (26 to 50%), and very susceptible (>50%).

2.4. Agronomic traits

The data were recorded on yield and yield components (days to flowering, days to maturity, plant height, number of branches per plant, number of nodes per plant, and number filled pods per plant). The data were subjected to standard statistical techniques for analysis of variance for traits studied using Minitab and the means were tested using an LSD test at p=0.05 and p=0.01 probability levels.
3. Result and discussion

3.1. Rainfall and temperature
The field research began on July 26, 2019. Plants were gradually harvested according to the days to maturity of each genotype until October 19, 2019. In July after the field experiment has started, there was rainfall of 14 mm for 2 days, in August there was 193 mm rainfall with eight rainy days, a number of 55 mm in September with 2 rainy days, and there was absolutely no rain in October. The evaluation for pod shattering resistance using the sun-drying method was conducted at the end of October, under a condition of no rainfall with daily temperatures between 24-26°C and maximum temperatures between 25-28°C (Figure 1).

![Daily rainfall, minimum and maximal temperatures of the period 1 July to 31 October, 2018](image)

**Figure 1.** Daily rainfall, minimum and maximal temperatures of the period 1 July to 31 October, 2018

3.2. Evaluation for pod shattering resistance using the oven-dry method
The pod shattering evaluation using the oven-dry method have several advantages, i.e. provides controlled environmental condition, faster, and be able to evaluate a large number of genotypes. This method has been widely used to assess soybean resistance to pod shattering [5,8,9,15].

The pod shattering evaluation at an oven temperature of 30°C showed that there were no shattered pods. The pods started to shatter at an oven temperature of 40°C, but all genotypes were resistant to very resistant in resistance to pod shattering. The high variability of shattering resistance start to occur at the oven temperature of 50°C and 60°C (Table 1). At 50°C, twelve genotypes were consists of two resistant genotypes, one genotype was moderately resistant, two genotypes were susceptible, and seven genotypes were very susceptible to shattering. At 60°C, three genotypes were found to be resistant, two genotypes were susceptible, and seven genotypes were very susceptible to shattering. In this study showed that the oven temperature of 60°C provides a high pressure in the soybean resistance to pod shattering. Based on the results, it suggested that the resistant genotype based on the oven-dry method will be consistently resistant in the field evaluation. Soybean genotype ATgt-18-009 and Anjasmoro cultivar showed consistently resistant to pod shattering on all temperatures treatment.
quantities. I consider to the high selection pressure, fast and the ability to screen the materials in relatively large checking the degree of shattering. The use on method for evaluating resistance to pod shattering pods. The results showed that placing the pods in the desiccator for 14 days (desiccator method) or between the desiccator method and oven-dry method to assess the shattering resistance of soybean on the oven-dry as well as sun-drying method. Other studies by Romkaew & Umezaki [16] compared Soybean genotypes ATgt-18-009 and Anjasmoro showed consistently resistant to pod shattering based and two genotypes were very susceptible.

3.3. Evaluation for pod shattering resistance using the sun-drying method
The evaluation for pod shattering resistance using the sun-drying method is a simulation of a field conditions. The average of shattering up to the seventh day was 12% (moderately resistant), and at twelfth days reached 27% (susceptible to shattering) (Table 2). On the fifteenth day, two genotypes were found to be resistant, three genotypes were moderately resistant, five genotypes were susceptible, and two genotypes were very susceptible.

The sun-drying method provides relatively light pressure when compared to the oven-dry method. Soybean genotypes ATgt-18-009 and Anjasmoro showed consistently resistant to pod shattering based on the oven-dry as well as sun-drying method. Other studies by Romkaew & Umezaki [16] compared between the desiccator method and oven-dry method to assess the shattering resistance of soybean pods. The results showed that placing the pods in the desiccator for 14 days (desiccator method) or exposing the pods to 60°C for 7 hours in an oven (oven-dried method) were useful methods for checking the degree of shattering. The use on method for evaluating resistance to pod shattering consider to the high selection pressure, fast and the ability to screen the materials in relatively large quantities.

Table 1. Pod shattering resistance of 12 soybean genotypes based on the oven-dry method

| No  | Genotype      | Pod shattering (%) at oven temperature | Resistance criteria at mean square | Average |
|-----|---------------|---------------------------------------|----------------------------------|---------|
|     |               | 30°C  | 40°C  | 50°C  | 60°C  |                     | ns  | ns  | **   | **   |
| 1   | ATgt-18-001   | 0     | 6     | 100   | 100   | Very susceptible    |     |     |      |      |
| 2   | ATgt-18-002   | 0     | 1     | 94    | 100   | Very susceptible    |     |     |      |      |
| 3   | ATgt-18-003   | 0     | 10    | 100   | 100   | Very susceptible    |     |     |      |      |
| 4   | ATgt-18-004   | 0     | 6     | 100   | 100   | Very susceptible    |     |     |      |      |
| 5   | ATgt-18-005   | 0     | 2     | 33    | 43    | Susceptible         |     |     |      |      |
| 6   | ATgt-18-006   | 0     | 10    | 70    | 77    | Very susceptible    |     |     |      |      |
| 7   | ATgt-18-007   | 0     | 4     | 39    | 46    | Susceptible         |     |     |      |      |
| 8   | ATgt-18-008   | 0     | 5     | 100   | 100   | Very susceptible    |     |     |      |      |
| 9   | ATgt-18-009   | 0     | 0     | 2     | 2     | Resistant           |     |     |      |      |
| 10  | ATgt-18-010   | 0     | 1     | 13    | 41    | Susceptible         |     |     |      |      |
| 11  | Demas 1       | 0     | 4     | 90    | 100   | Very susceptible    |     |     |      |      |
| 12  | Anjasmoro     | 0     | 3     | 4     | 9     | Resistant           |     |     |      |      |

Table 2. Pod shattering resistance of 12 soybean genotypes based on the sun-drying method

| No  | Genotype | Pod shattering (%) at drying day: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|-----|----------|----------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| 1   | ATgt-18-001 | 0 0 0 0 2 12 15 22 25 30 40 41 45 45 45 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 2   | ATgt-18-002 | 0 0 0 0 4 17 29 31 31 32 32 32 34 34 34 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 3   | ATgt-18-003 | 0 0 0 0 0 9 9 9 10 11 12 17 17 25 26 28 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 4   | ATgt-18-004 | 0 0 0 0 0 11 19 35 39 41 46 47 50 50 50 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 5   | ATgt-18-005 | 0 0 0 0 0 5 10 10 12 12 13 15 18 21 21 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 6   | ATgt-18-006 | 0 0 0 0 0 3 5 11 14 14 15 16 18 21 21 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 7   | ATgt-18-007 | 0 0 0 0 3 9 17 25 28 30 32 34 37 37 37 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 8   | ATgt-18-008 | 0 0 0 0 2 10 17 36 46 53 58 58 58 58 58 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 9   | ATgt-18-009 | 0 0 0 0 0 0 0 0 0 0 0 1 1 2 2 2 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 10  | ATgt-18-010 | 0 0 0 0 0 3 3 3 6 7 7 9 10 13 16 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 11  | Demas 1     | 0 0 0 0 0 7 12 21 21 27 29 43 52 52 52 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 12  | Anjasmoro  | 0 0 0 0 0 1 5 6 6 9 9 9 9 9 9 9 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

Average: 0 0 0 0 0 1 7 12 18 20 22 25 27 30 31 31

Resistant (1 to 10% shattering), susceptible (26 to 50% shattering), very susceptible (>50% shattering). ** = significant at 5% probability level (p < 0.05), ns = not significant.
The evaluation for resistance using the sun-drying method also provides information on the duration of delayed harvesting of a genotype so it does not cause yield losses due to shattering (Table 3). For example, soybean genotypes ATgt-18-001, ATgt-18-002, and ATgt-18-004 which showing susceptibility to shattering, can be delayed for harvesting for a maximum of five days. The harvest of ATgt-18-003 and ATgt-18-005 can be delayed up to ten days. For a shatter-resistant genotypes, such as ATgt-18-009 and Anjasmoro, the harvest can be delayed until fifteen days.

Table 3. The resistance criteria of pod shattering based on the sun-drying method

| No | Genotype     | Resistance criteria at drying day: | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
|----|--------------|-----------------------------------|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|
| 1  | ATgt-18-001  | VR VR VR VR R M M M M S S S S S S |
| 2  | ATgt-18-002  | VR VR VR VR R M S S S S S S S S S |
| 3  | ATgt-18-003  | VR VR VR VR R R R R R M M S S S S |
| 4  | ATgt-18-004  | VR VR VR VR M M M M M S S S S S |
| 5  | ATgt-18-005  | VR VR VR VR R R R R R M M M M M M |
| 6  | ATgt-18-006  | VR VR VR VR R R R R R M M M M M M |
| 7  | ATgt-18-007  | VR VR VR VR R M M M M S S S S S |
| 8  | ATgt-18-008  | VR VR VR VR R R M S S S VS VS VS V VS |
| 9  | ATgt-18-009  | VR VR VR VR V VR VR VR VR R R R R M M |
| 10 | ATgt-18-010  | VR VR VR VR R R R R R R R R R R M M S VS V VS |
| 11 | Demas 1      | VR VR VR VR R R M M M M M S VS V VS |
| 12 | Anjasmoro    | VR VR VR VR R R R R R R R R R R M M |
|    | **Average**  | VR VR VR VR R R M M M M M S S S S S |

VR = very resistant, R = resistant, M = moderate, S = susceptible, VS = very susceptible

**Maximum limit for harvest delays**

Figure 2. The relationship of pod shattering evaluation between the oven-dry with sun-drying methods.

The correlation value between the oven-dry and sun-drying method was \( r = 0.832 \) **. This shows that the oven-dry method is sufficiently reliable to detect soybean resistance to pod shattering (Figure 2).

3.4. Agronomic characters

The days to flowering of 12 soybean genotypes ranged from 29 – 35 days with an average of 32 days. The days to maturity ranged from 81- 86 days (an average of 84 days). The ATgt-18-007 has the earliest maturity than 11 other genotypes (Table 4).
Figure 3. Days to flowering and days to maturity of 12 soybean genotypes

Table 4. Days to flowering and days to maturity of 12 soybean genotypes

| No | Genotype     | Plant age (days) | Flowering | Maturity |
|----|--------------|------------------|-----------|----------|
|    |              |                  |           |          |
| 1  | ATgt-18-001  |                  | 35 a      | 84 ab    |
| 2  | ATgt-18-002  |                  | 35 a      | 85 a     |
| 3  | ATgt-18-003  |                  | 35 a      | 85 a     |
| 4  | ATgt-18-004  |                  | 35 a      | 84 abc   |
| 5  | ATgt-18-005  |                  | 33 b      | 86 a     |
| 6  | ATgt-18-006  |                  | 29 c      | 84 ab    |
| 7  | ATgt-18-007  |                  | 30 c      | 81 d     |
| 8  | ATgt-18-008  |                  | 29 c      | 83 bcd   |
| 9  | ATgt-18-009  |                  | 29 c      | 82 cd    |
| 10 | ATgt-18-010  |                  | 30 c      | 84 ab    |
| 11 | Demas 1      |                  | 36 a      | 86 a     |
| 12 | Anjasmoro    |                  | 33 b      | 85 ab    |

Average 32 84

Mean square **

** = significant at 1% probability level (p < 0.01). Mean values with the same letter within a column are not significantly different at 1% probability level.

The yield components which consist of plant height, number of branches, number of nodes, and number of filled pods were presented in Table 5. The plant height ranged from 46 – 66 cm (an average of 55.86 cm), the number of branches were between 2.67 to 5.33 branches an average of 3.64 branches per plant), the number of nodes ranged from 13.33 – 31 nodes (an average of 22.33 nodes per plant), and the filled pods ranged from 43.00 – 102.33 pods (an average of 73.36 pod per plant). Demas 1 variety has the highest number of branches, number of nodes, and number of filled pods.
Table 5. Plant height, number of branches, number of nodes, and number of filled pods per plant of 12 soybean genotypes

| No | Genotype     | Plant height (cm) | Number of branches | Number of nodes | Number of filled pods |
|----|--------------|-------------------|--------------------|-----------------|----------------------|
| 1  | ATgt-18-001  | 58.33 abc         | 4.00 b             | 25.67 ab        | 86.67 ab             |
| 2  | ATgt-18-002  | 59.33 abc         | 3.67 bc            | 23.00 bc        | 73.33 bc             |
| 3  | ATgt-18-003  | 56.33 abc         | 3.67 bc            | 21.33 bc        | 72.33 bc             |
| 4  | ATgt-18-004  | 53.00 bcde        | 3.67 bc            | 26.33 ab        | 85.33 ab             |
| 5  | ATgt-18-005  | 49.33 cde         | 3.67 bc            | 22.67 bc        | 83.00 ab             |
| 6  | ATgt-18-006  | 57.67 abc         | 3.33 bc            | 21.00 bc        | 76.67 b              |
| 7  | ATgt-18-007  | 66.00 a           | 3.67 bc            | 23.33 b         | 65.33 bcd            |
| 8  | ATgt-18-008  | 55.33 bcde        | 3.00 bc            | 13.33 d         | 43.00 d              |
| 9  | ATgt-18-009  | 46.67 de          | 2.67 c             | 16.67 cd        | 48.67 cd             |
| 10 | ATgt-18-010  | 46.00 e           | 3.00 bc            | 21.00 bc        | 66.33 bcd            |
| 11 | Demas 1      | 62.00 ab          | 5.33 a             | 31.00 a         | 102.33 a             |
| 12 | Anjasmoro    | 60.33 abc         | 4.00 b             | 22.67 bc        | 77.33 ab             |

Average | 55.86 | 3.64 | 22.33 | 73.36 |

** = significant at 1% probability level \( (p < 0.01) \). Mean values with the same letter within a column are not significantly different at 1% probability level.

The seed yield of 12 genotypes ranged from 2.34 – 3.54 t/ha with an average of 2.97 t/ha (Table 6). There were four genotypes that produce yield over 3.0 t/ha, including the Anjasmoro variety which produce yield up to 3.48 t/ha. The ATgt-18-003 (3.54 t/ha) produce the highest yield, comparable to the potential yield of Anjasmoro variety.

Table 6. Seed yield of 12 soybean genotypes and their resistance to pod shattering

| No | Genotype    | Seed yield (t/ha) | The pod shattering resistance based on Oven-dry method | Sun-drying method |
|----|-------------|-------------------|-------------------------------------------------------|------------------|
| 1  | ATgt-18-001 | 2.92 bcd          | Very susceptible                                       | Susceptible      |
| 2  | ATgt-18-002 | 2.34 f            | Very susceptible                                       | Susceptible      |
| 3  | ATgt-18-003 | 3.54 a            | Very susceptible                                       | Susceptible      |
| 4  | ATgt-18-004 | 2.71 def          | Very susceptible                                       | Susceptible      |
| 5  | ATgt-18-005 | 2.46 ef           | Susceptible                                            | Moderate         |
| 6  | ATgt-18-006 | 2.77 cde          | Very susceptible                                       | Susceptible      |
| 7  | ATgt-18-007 | 2.87 bcd          | Susceptible                                            | Susceptible      |
| 8  | ATgt-18-008 | 3.42 a            | Very susceptible                                       | Very susceptible |
| 9  | ATgt-18-009 | 3.17 abc          | Resistant                                              | Resistant        |
| 10 | ATgt-18-010 | 3.21 ab           | Susceptible                                            | Moderate         |
| 11 | Demas 1     | 2.80 cde          | Very susceptible                                       | Very susceptible |
| 12 | Anjasmoro   | 3.48 a            | Resistant                                              | Resistant        |

Average | 2.97 |

** = significant at 1% probability level \( (p < 0.01) \). Mean values with the same letter within a column are not significantly different at 1% probability level.

The soybean resistance to pod shattering combined with the seed yield character is shown in Table 6. Soybean genotype which showed consistently resistant to pod shattering, ATgt-18-009, was able to produce a relatively high seed yield (3.17 t/ha). Anjasmoro variety (3.48 t/ha), which was also categorized as resistant to pod shattering, has a higher seed yield than ATgt-18-009. However, the
days to maturity of ATgt-18-009 was three days earlier than Anjasmoro. Soybean genotypes which classified as resistant to pod shattering as well as produce high were potential to be further developed in soybean production centers in Indonesia.

4. Conclusion
The evaluations for shattering resistance based on the oven-dry method provides a greater pressure than based on sun-drying one. Soybean genotypes ATgt-18-009 and Anjasmoro showed consistently resistant to pod shattering based on the oven-dry as well as sun-drying methods. Those genotypes also produce high yield (more than 3.0 t/ha) with days to maturity ranging from 82 to 85 days, therefore it could be potentially developed in the soybean production centres in Indonesia.

Acknowledgment
The author would like to thank the Indonesian Agency for Agricultural Research and Development (IAARD) for the financial support. The authors would also like to thank Mr. Arifin, S.P., and Mr. Mispan for their assistance during the field and laboratory researches.

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