Agronomic performance and pod shattering resistance of soybean genotypes with various pod and seed colors

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Abstract. *Krisnawati A, Adie MM. 2021. Agronomic performance and pod shattering resistance of soybean genotypes with various pod and seed colors. Biodiversitas 22: 472-479.* Climate change impacts agricultural production, including the increase of the yield loss in soybean due to pod shattering. This research aimed to identify the pod shattering resistance and agronomic performance of several soybean genotypes with various pod and seed colors. A total of 100 soybean genotypes were planted in Malang (East Java, Indonesia) during the dry season 2019. The field experiment was laid out in a randomized block design with three replications. The pod shattering resistance was assessed using the oven-dry method. The pod shattering resistance of 97 genotypes were classified into 20 very resistant genotypes, 17 resistant genotypes, 15 moderate genotypes, nine susceptible, and 36 very susceptible genotypes. The pod colors did not affect the pod shattering resistance in soybean. The new findings from this study, i.e., two very resistant genotypes (G42 and G15) which produce high yield and have medium maturity, were suggested to be developed as new cultivars, meanwhile, the other very resistant genotypes can be used in the soybean breeding program to develop shattering resistant cultivar with desirable traits.

Keywords: High yield, genetic background, oven-dry method, selection, yield loss

INTRODUCTION

Soybean is periodically planted in Indonesia during the second dry season (June/July until September/October). Therefore, the generative stage of soybean from the seed filling period to the pod maturation may occur in hot weather conditions which trigger a higher incidence of pod shattering. The negative impact of pod shattering is the release of seeds from the pod and drops to the ground, hence it reduces the harvestable yield and leading to significant yield losses. The yield loss in soybean due to pod shattering may range from 34% to 100% (Tiwari and Bhatnagar 1991; Tefera et al. 2009) depending on the genetic constitution of the variety and environmental factors (Tukamuhabwa et al. 2002; Ogutcen et al. 2018; Nevhudzholi et al. 2020). Bara et al. (2013) reported that high temperatures during the time of maturity caused severe pod-shattering incidence. Meanwhile, Zhang and Boahen (2010) found that irrigated and non-irrigated conditions caused a difference in the pod shattering resistance among soybean varieties.

Identification of the soybean resistance for pod shattering in several genotypes has been conducted in numerous studies. In Indonesia, a selection of 591 of fifth set offspring (F5) soybean population derived from six pedigree has obtained 104 resistant lines to pod shattering (Krisnawati et al. 2019a). A similar study was conducted on the ten soybean promising lines and it obtained a resistant genotype to shattering (Krisnawati et al. 2019b). In other countries, such as Ghana, the screening for shattering resistance on soybean has successfully obtained six genotypes (SIT-M TGx1904-6F, SIT-E TGx1835-10E,

SIT-M TGx1987-40F, TGx1903-7F, SIT-E TGx1448-2E, and Anidaso) with moderate resistance to pod shattering (Antwi-Boasiako 2017). In India, soybean genotype NRC 7 was found to be resistant to pod shattering, meanwhile, EC 241780 and Kalitur were susceptible (Bhor et al. 2014).

The studies to investigate the agronomic characteristics related to pod shattering resistance have been carried out. The pod characters were reported to be involved in the shattering of soybean (Bara et al. 2013). Adeyeye et al. (2014) found a significant negative correlation between pod-shattering with pod diameter while plant height had a negative but not significant effect on the number of shattered pods per plant. A newer study found that pod shattering resistance was negatively correlated with the number of seeds per pod, which means that plants with few seeds per pod tended to have high resistance to pod shattering (Kataliko et al. 2019). These facts show that pod characters could play an important role in the shattering incidence.

The soybean pod is an important component of the plant, where the seed would be placed and become the occurrence of shattering. There is a large variation in the pod wall and seed color of soybean (De Chavez et al. 2016). Several studies have documented that the pod and seed color have multifaceted effects on the agronomic characteristics of the soybean and stress resistance (He et al. 2015; Liu et al. 2017). Zhao et al. (2008) reported that soybeans with the light color of the pod coat tend to have greater resistance to pod borer than soybeans with dark-colored pods. Another study found a difference in the shattering resistance among seed colors in Brassica species (Wang et al. 2007). However, the identification of the

effect of pod and seed colors in the pod shattering resistance of soybean has not been reported yet. Furthermore, the combination of high pod shattering resistance and good agronomic characters as well as high productivity in the newly developed genotypes could benefit soybean growers.

Thus, this research aimed to identify the pod shattering resistance and agronomic performance of several soybean genotypes with various pod and seed colors.

MATERIALS AND METHODS

Study area

The field experiment was conducted during the first dry season (March to June 2019) in Kepanjen (Malang, East Java, Indonesia), which located at 8°10'30"S, 112°33'32.4"E. The elevation was 335 m asl., with E3 Oldeman climate type, rainfall of 2200 mm/year, and the soil type of alfisol. The minimum and maximum temperatures were 23.5°C and 32°C, respectively, and the relative humidity was 79%.

Plant materials and field study

The research materials were 100 soybean genotypes consisting of 97 genotypes derived from 14 pedigree, and three check cultivars (Dega 1, Derap 1, and Detap 1) (Table 1). The field experiment was conducted in the wetland with the soil tillage and laid out in a randomized block design with three replications. Each genotype was planted in a plot size of 0.8 m × 4.5 m with the plant spacing of 40 cm × 15 cm, two plants per hill. Plants were fertilized by 50 kg/ha urea, 100 kg/ha SP36, and 75 kg/ha KCl which applied entirely at the sowing time. The pests, diseases, and weeds were optimally managed. Plants were harvested at full maturity (R_8 stage). The R_8 stage is determined when 95% of the pods have reached their mature brown color.

Pod shattering evaluation

The screening for pod shattering resistance was conducted in the laboratory. When plants at the R_8 stage, three sample plants were randomly taken from each plot (or combination of the genotype and replication). Plants were then dried at room temperature for three days. Thirty pods were randomly detached from those three sample plants and then placed in a petridish ($\varnothing$ =15 cm) for shattering evaluation based on the oven-dry method (Krisnawati et al. 2019a), i.e., the pods were dried at 30°C for three days, and then elevated to 40°C (one day), 50°C (one day), and 60°C (one day). The experiment was arranged in a complete randomized design with three replications according to the field experimental design.

Data collection

Agronomic data from the field experiment were collected on the days to maturity, days to flowering, and seed yield. The seed yield was observed based on the population of plants per plot, and converted to t/ha. The observation was also made on the pod wall color and seed coat color for each genotype. The data from the laboratory experiment consist of pod shattering percentage of each genotype. The pod-shattering percentage was observed after being subjected to 60°C. The shattering percentage was the number of the shattered pods divided by the number of sample pods (thirty pods), in percentage.

Data analysis

The agronomic and pod shattering resistance data were expressed as descriptive statistics (minimum and maximum value, standard deviation, and mean). The variability of the pod as seed colors was visualized in pie charts. The agronomic data were also visualized in scatter diagrams. The seed yield of selected genotypes was visualized in a column chart. The grouping of pod shattering resistance based on the shattering percentage was following the AVRDC (1979): very resistant (0%), resistant (1-10%), moderate (11-25%), susceptible (26-50%), and very susceptible (>50%). The difference in the pod shattering among various seed and pod colors was investigated by Welch's t-test using Minitab ver. 17.1.0 (Minitab 2013).

RESULTS AND DISCUSSION

Characteristics of agronomic traits

The agronomic characteristics of 100 soybean genotypes consisted of days to flowering, days to maturity, and seed yield. Descriptive statistics of these characters are detailed in Table 2. The days to flowering ranged from 33-41 days with an average of 35 days, meanwhile, the range of days to maturity was from 77-81 days with an average of 80 days. The soybean classification for days to maturity in Indonesia was grouped into late maturity (> 90 days), medium maturity (80-90 days), and early maturity (<80 days). Then, the days to maturity of 100 genotypes ranged from early to medium maturity. The seed yield of all genotypes ranged from 0.52-3.30 t/ha with an average of 1.86 t/ha. The graphical data of the days to flowering and days to maturity of 100 soybean genotypes were presented in Figure 1, meanwhile, the seed yield data were shown in Figure 2.

Characteristics of pod and seed

The genotypes used in this study were derived from the selection of crossing of diverse parental, hence the pod and seed color showed a large variation, include the check cultivars (Figure 3). The pod color was dominated by the dark brown color (47 genotypes), followed by yellow color (39 genotypes), light brown (ten genotypes), and brown pod color (four genotypes). The seed color varies from yellow to black. A total of 69 genotypes have yellow seed coat, 19 genotypes with black seed coat, and twelve genotypes have green seed coat. The pod and seed color are frequently used in variety description and identification due to their distinguishable classes of pod color (Ramteke and Murlidharan 2012) and as markers to assess hybridity in breeding programs (Yang et al. 2010; Shingare et al. 2020). The variation in the pod and seed colors was presented in Figure 4.

The classification for pod shattering resistance

The shattering resistance inherited from the diverse parental of 97 genotypes showed a large variation of resistance (Table 3, Figure 5). Genotypes with genetic background from the parental of Anjasmoro variety tend to show resistance to pod shattering. Similarly, Krisnawati et al. (2020), using Anjasmoro variety for genetic improvement through hybridization resulted in five F8 resistant lines that have comparable resistance with the check cultivar (Detap 1). The previous selection study also reported the effectiveness of Anjasmoro variety as a parental line to produce shatter-resistant genotypes (Krisnawati et al. 2019a).

Table 1. List of pedigree, generation, and parental genotypes used in this study

Code	Pedigree	Gen.	Parental Female	Male
G1	Grobogan/Dg-210	F$_6$	Grobogan	Degra
G2	Grobogan/Dg-246	F$_6$	Grobogan	Degra
G3	Dg/Grobogan-255	F$_6$	Degra	Grobogan
G4	Dg/Grobogan-258	F$_6$	Degra	Grobogan
G5	Grobogan/Dg-264	F$_6$	Grobogan	Degra
G6	Grobogan/Dg-269	F$_6$	Grobogan	Degra
G7	Grobogan/Dg-271	F$_6$	Grobogan	Degra
G8	Grobogan/Dg-272	F$_6$	Grobogan	Degra
G9	Grobogan/Dg-288	F$_6$	Grobogan	Degra
G10	Grobogan/Dg-289	F$_6$	Grobogan	Degra
G11	Grobogan/Dg-381	F$_6$	Grobogan	Degra
G12	Grobogan/G100H-417	F$_6$	Grobogan	G100H
G13	Mahameru/IAC100-423	F$_6$	Mahameru	IAC100
G14	Dega 1/Dg-493	F$_6$	Dega 1	Degra
G15	Dega 1/Dg-507	F$_6$	Dega 1	Degra
G16	Dega 1/Dg-510	F$_6$	Dega 1	Degra
G17	Dega 1/Dg-512	F$_6$	Dega 1	Degra
G18	Anjasmoro/Dg-525	F$_6$	Anjasmoro	Degra
G19	Anjasmoro/Dg-526	F$_6$	Anjasmoro	Degra
G20	Anjasmoro/Dg-536	F$_6$	Anjasmoro	Degra
G21	Anjasmoro/Dg-536	F$_6$	Anjasmoro	Degra
G22	Dg/Anjasmoro-564	F$_6$	Degra	Anjasmoro
G23	Dg/Anjasmoro-570	F$_6$	Degra	Anjasmoro
G24	Dg/Anjasmoro-577	F$_6$	Degra	Anjasmoro
G25	Grobogan/G100H-582	F$_6$	Grobogan	G100H
G26	Grobogan/Dg-652	F$_6$	Grobogan	Degra
G27	Grobogan/Dg-654	F$_6$	Grobogan	Degra
G28	Grobogan/Dg-716	F$_6$	Grobogan	Degra
G29	Grobogan/Dg-720	F$_6$	Grobogan	Degra
G30	Grobogan/Dg-724	F$_6$	Grobogan	Degra
G31	Grobogan/Dg-727	F$_6$	Grobogan	Degra
G32	Grobogan/Dg-747	F$_6$	Grobogan	Degra
G33	Grobogan/Dg-760	F$_6$	Grobogan	Degra
G34	Grobogan/Dg-761	F$_6$	Grobogan	Degra
G35	Grobogan/Dg-763	F$_6$	Grobogan	Degra
G36	Dg/Mahameru-790	F$_6$	Degra	Mahameru
G37	Mahameru/Dg-813	F$_6$	Mahameru	Degra
G38	Mahameru/Dg-814	F$_6$	Mahameru	Degra
G39	Mahameru/Dg-842	F$_6$	Mahameru	Degra
G40	Grobogan/G100H-875	F$_6$	Grobogan	G100H
G41	Grobogan/G100H-877	F$_6$	Grobogan	G100H
G42	Grobogan/G100H-879	F$_6$	Grobogan	G100H
G43	Grobogan/G100H-959	F$_6$	Grobogan	G100H
G44	Anjasmoro/Dg-1015	F$_6$	Anjasmoro	Degra
G45	Dg/Anjasmoro-1043	F$_6$	Degra	Anjasmoro
G46	Dg/IAC100-1117	F$_6$	Degra	IAC100
G47	Grobogan/G100H-1173	F$_6$	Grobogan	G100H
G48	G2/PR15	F$_6$	G2	PR15
G49	Grobogan/Dg-1079	F$_6$	Grobogan	Degra
G50	IAC 100/Anjasmoro-1052	F$_6$	IAC100	Anjasmoro
G51	IAC 100/Anjasmoro-1053	F$_6$	IAC100	Anjasmoro
G52	IAC 100/Anjasmoro-1054	F$_6$	IAC100	Anjasmoro
G53	IAC 100/Anjasmoro-1055	F$_6$	IAC100	Anjasmoro
G54	IAC 100/Anjasmoro-1056	F$_6$	IAC100	Anjasmoro
G55	IAC 100/Anjasmoro-1057	F$_6$	IAC100	Anjasmoro
G56	JP15/Anjasmoro-937	F$_6$	JP15	Anjasmoro
G57	JP15/Anjasmoro-941-1	F$_6$	JP15	Anjasmoro
G58	JP15/Anjasmoro-941-2	F$_6$	JP15	Anjasmoro
G59	JP15/Anjasmoro-941-3	F$_6$	JP15	Anjasmoro
G60	JP15/Anjasmoro-946-4	F$_6$	JP15	Anjasmoro
G61	JP15/Anjasmoro-949-5	F$_6$	JP15	Anjasmoro
G62	JP15/Anjasmoro-972-6	F$_6$	JP15	Anjasmoro
G63	JP15/Anjasmoro-990-7	F$_6$	JP15	Anjasmoro
G64	JP15/Anjasmoro-994-8	F$_6$	JP15	Anjasmoro
G65	JP15/Anjasmoro-997-9	F$_6$	JP15	Anjasmoro
G66	Khl/Anjasmoro-1015-1	F$_6$	Khilau	Anjasmoro
G67	Khl/Anjasmoro-1015-2	F$_6$	Khilau	Anjasmoro
G68	Khl/Anjasmoro-1022-3	F$_6$	Khilau	Anjasmoro
G69	JP15/Anjasmoro-1010-10	F$_6$	JP15	Anjasmoro
G70	JP15/Anjasmoro-1010-11	F$_6$	JP15	Anjasmoro
G71	JP15/Anjasmoro-1010-12	F$_6$	JP15	Anjasmoro
G72	JP15/Anjasmoro-1011-13	F$_6$	JP15	Anjasmoro
G73	JP15/Anjasmoro-1011-14	F$_6$	JP15	Anjasmoro
G74	JP15/Anjasmoro-1012-15	F$_6$	JP15	Anjasmoro
G75	JP15/Anjasmoro-1012-16	F$_6$	JP15	Anjasmoro
G76	JP15/Anjasmoro-1025-17	F$_6$	JP15	Anjasmoro
G77	JP15/Anjasmoro-1025-18	F$_6$	JP15	Anjasmoro
G78	JP15/Anjasmoro-1026-19	F$_6$	JP15	Anjasmoro
G79	JP15/Anjasmoro-948-17	F$_6$	JP15	Anjasmoro
G80	JP15/Anjasmoro-1013-20	F$_6$	JP15	Anjasmoro
G81	JP15/Anjasmoro-1013-21	F$_6$	JP15	Anjasmoro
G82	JP15/Anjasmoro-1013-22	F$_6$	JP15	Anjasmoro
G83	JP15/Anjasmoro-1013-23	F$_6$	JP15	Anjasmoro
G84	JP15/Anjasmoro-1013-24	F$_6$	JP15	Anjasmoro
G85	JP15/Anjasmoro-1016-25	F$_6$	JP15	Anjasmoro
G86	JP15/Anjasmoro-1016-26	F$_6$	JP15	Anjasmoro
G87	JP15/Anjasmoro-1023-27	F$_6$	JP15	Anjasmoro
G88	JP15/Anjasmoro-1023-28	F$_6$	JP15	Anjasmoro
G89	JP15/Anjasmoro-1023-29	F$_6$	JP15	Anjasmoro
G90	JP15/Anjasmoro-1027-30	F$_6$	JP15	Anjasmoro
G91	JP15/Anjasmoro-1027-31	F$_6$	JP15	Anjasmoro
G92	JP15/Anjasmoro-1027-32	F$_6$	JP15	Anjasmoro
G93	JP15/Anjasmoro-1027-33	F$_6$	JP15	Anjasmoro
G94	JP15/Anjasmoro-1028-34	F$_6$	JP15	Anjasmoro
G95	JP15/Anjasmoro-1028-35	F$_6$	JP15	Anjasmoro
G96	JP15/Anjasmoro-1028-36	F$_6$	JP15	Anjasmoro
G97	JP15/Anjasmoro-1028-37	F$_6$	JP15	Anjasmoro
G98	Dega 1	Variety	Grobogan	Malabar
G99	Derap 1	Variety	G511H	Anjasmoro
G100	Detap 1	Variety	G511H	Anjasmoro

Note: Gen: Generation

Table 2. Descriptive statistics for the agronomic and pod shattering data of 100 soybean genotypes

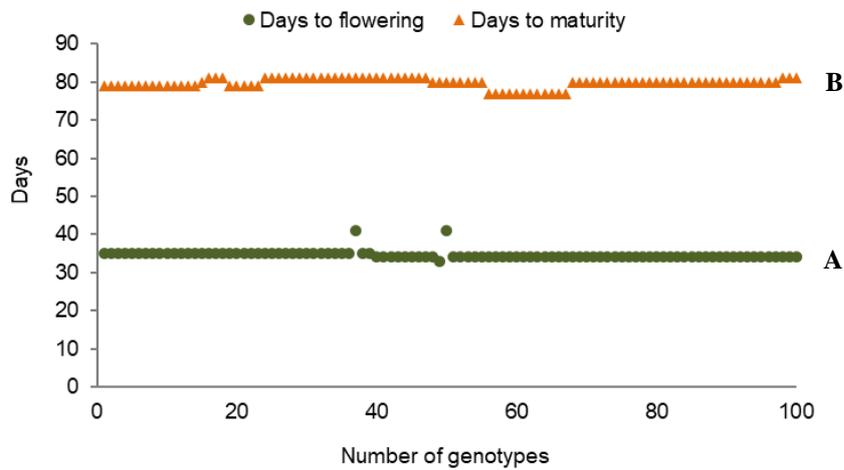| Character	Min.	Max.	SD	Mean
Days to flowering (days)	33	41	1.06	35
Days to maturity (days)	77	81	1.23	80
Seed yield (t/ha)	0.52	3.30	0.61	1.86
Pod shattering (%)	0	100	40.88	40

Figure 1. Scatter diagram of the days to flowering (A: green round points) and the days to maturity; B: orange triangle points) of 100 soybean genotypes. The x-axis was the number of genotypes which consist of 100 soybean genotypes. The average of the days to flowering and the days to maturity (y-axis) were 35 days and 80 days, respectively
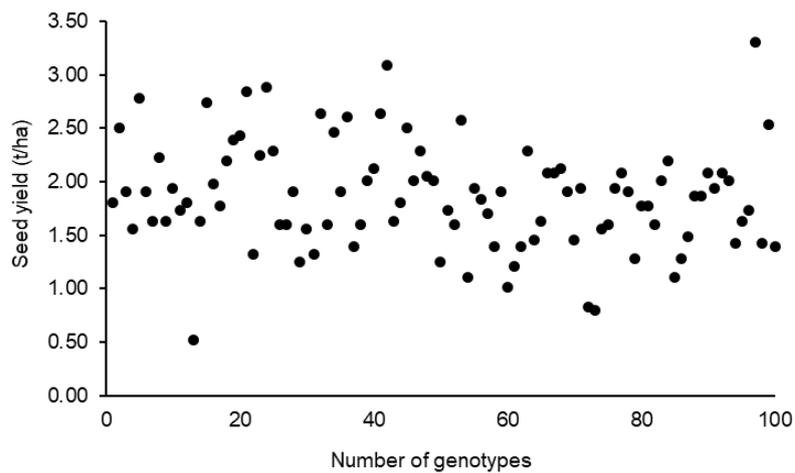

Figure 2. Scatter diagram of seed yield from 100 soybean genotypes planted during the first dry season 2019. The x-axis was number of genotypes which consist of 100 soybean genotypes. The seed yield (y-axis) ranged from 0.52-3.30 t/ha
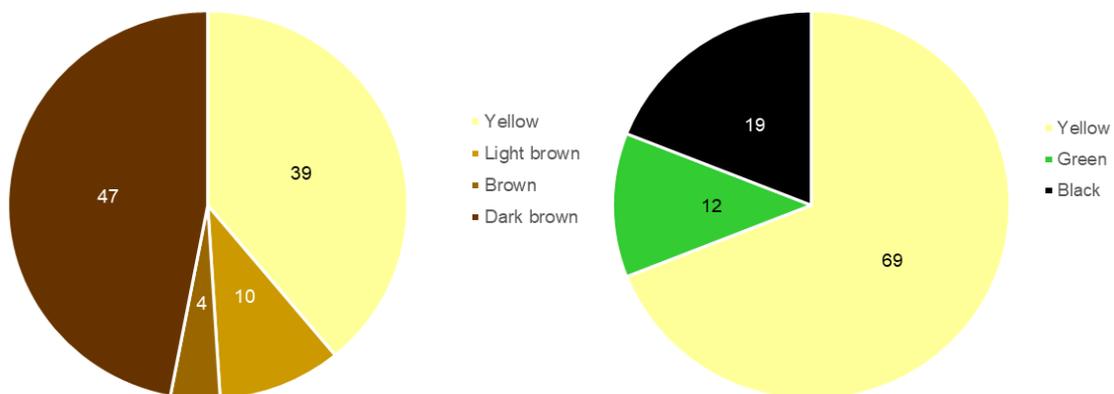
Figure 3. Variability of the pod (*left*) and seed (*right*) colors of 100 soybean genotypes

Figure 4. A. Pod color variation (Y: yellow, LB: light brown, B: brown, DB: dark brown), B. Seed color variation (Y: yellow, G: green, B: black)

Figure 5. Example of variation in the pod shattering on the different seed and pod colors

Based on the classification of resistance, it was obtained 20 very resistant genotypes, 17 genotypes were classified as resistant, 15 genotypes were moderate, nine genotypes were susceptible, and 36 genotypes were classified as very susceptible. The shattering resistance of check cultivar Dega 1 was very susceptible, whereas the other checks (Derap 1 and Detap 1) were very resistant to pod shattering. A previous study by Krisnawati and Adie (2017) obtained 13 resistant genotypes of 30 tested genotypes derived from crossing with Anjasmoro variety as one of the parentals. In India, an evaluation for pod shattering resistance of 69 soybean genotypes showed the range of shattering from 0.67-67.05% and it has obtained three resistant genotypes (Bara et al. 2013). Another study has successfully obtained nine resistant and 41 intermediate genotypes to pod shattering (Barate et al. 2018). In Nigeria, Umar et al. (2017) reported that soybean genotypes TGX1955-10E, NG/AD/11/08/023, and NG/SA/07/100 were found to be good general combiners for resistance to pod shattering. The very resistant and resistant genotypes obtained from this study would provide the chance for saving the yield losses due to pod shattering.

Characteristics of very resistant genotypes

In this study, twenty soybean genotypes with very resistant levels showed variability in the pod and seed color

(Figure 6). The pod color variation consists of seven genotypes with a yellow pod, three genotypes with a light brown pod, a genotype with a brown pod, and nine genotypes with a dark brown pod. Meanwhile, the seed color varies, i.e. 14 genotypes with yellow pod and three genotypes with green and black color, respectively.

The study to find out the effect of the pod and seed color traits in the pod shattering in soybean has never been performed. So far, the identification for the determinant for pod shattering resistance have been conducted from the aspects of morphology (Bara et al. 2013), anatomy (Tiwari and Bhatia, 1995; Zhang et al. 2018), and biochemical factors (Agrawal et al. 2002; Romkaew et al. 2008; Gaikwad and Bharud 2018). Several studies on the pod and seed characteristics related to pod shattering have been conducted.

Table 3. Pod shattering resistance of 14 pedigree (97 genotypes) and three check cultivars

Pedigree	Number of genotypes	The resistance classification and the number of genotypes				
		HR	R	M	S	VS
Anjasmoro/Dg	5	0	1	1	1	2
Dega 1/Dg	4	1	0	0	1	2
Dg/Anjasmoro	4	0	1	0	0	3
Dg/Grobogan	2	0	0	0	0	2
Dg/IAC 100	1	0	0	0	0	1
Dg/Mahameru	1	1	0	0	0	0
G2/PR15	1	0	0	1	0	0
Grobogan/Dg	20	5	4	1	0	10
Grobogan/G100H	7	1	1	0	0	5
IAC 100/Anjasmoro	6	1	2	1	0	2
JP15/Anjasmoro	39	9	7	10	7	6
Khl/Anjasmoro	3	1	1	1	0	0
Mahameru/Dg	3	0	0	0	0	3
Mahameru/IAC 100	1	1	0	0	0	0
Check varieties:						
Dega 1	1	0	0	0	0	1
Derap 1	1	1	0	0	0	0
Detap 1	1	1	0	0	0	0
Total	100	22	17	15	9	37

Note: VR: very resistant (0%), R: resistant (1-10%), M: moderate (11-25%), S: susceptible (26-50%), VS: very susceptible (>50%)
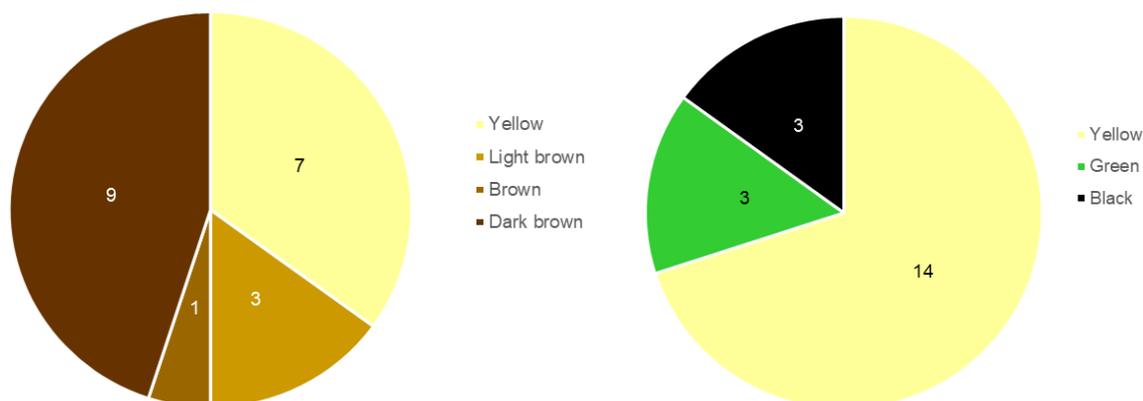
Figure 6. Variability of pod (*left*) and seed (*right*) colors of 20 very resistant genotypes to pod shattering

Thompson and Hughes (1986) reported that pod-shattering was affected by pod attributes such as pod angles, length, and width. Furthermore, Bara et al. (2013) found a higher shattering resistance of a genotype with a small pod, less width, and low volume/weight of seed. Girase et al. (2018) revealed that a lower pod setting height, a smaller number of seeds in a pod, and a thicker pod were less shattered. In a recent study, Krisnawati et al. (2020) revealed that the length of the dorsal and ventral side of the pod, a higher total pod weight, and a larger seed size would increase the degree of the pod shattering susceptibility.

In this study, the effect of the pod and seed color traits in the pod shattering was investigated by identifying the difference in the pod shattering percentage among various seed and pod colors based on Welch's t-test. Based on Table 4, the pod shattering among pod colors was not significantly different. There was no tendency that certain pod colors determine the resistance. A study in common bean also found a non-significant correlation between pod-shattering with pod color (Murgia et al. 2017). The identification in the difference of pod shattering percentage among various seed color showed that pod-shattering with different seed coat, i.e., between a light color (green or yellow) and dark color (black) was not significantly different (Table 5). However, the pod shattering between green and yellow seed color was significantly different. The yellow seeds tended to have a high shattering percentage than the green seeds. A study by Wang et al. (2007) also found the difference in shattering resistance between different seed colors in Brassica species, but further research showed that the shatter resistance was independent of seed color genes. Thus, it was suggested that the resistance to pod shattering appears to be attributed to their breeding background and selections (Wang et al. 2007), and seed morphological traits, such as seed size (Bara et al. 2013; Krisnawati and Adie 2017; Krisnawati et al. 2020).

Simultaneous selection

Based on the previous screening for shattering resistance (Table 3), twenty very resistant genotypes were obtained. The seed yield of those selected genotypes ranged from 0.52-3.09 t/ha with an average of 1.92 t/ha (Figure 7). The seed yield of shatter-resistant check cultivar of Derap 1 and Detap 1 was 2.53 t/ha and 1.39 t/ha, respectively.

Table 4. The Welch's t-test based on the pod color in the pod shattering

Pod color	N	Mean	STD	SE Mean	t value
Yellow	39	40.02	3.81	0.61	1.10^{ns}
Light brown	10	61.10	4.22	1.3	
Yellow	39	40.02	3.81	0.61	0.91^{ns}
Brown	4	66.75	4.44	2.2	
Yellow	39	40.02	3.81	0.61	-0.41^{ns}
Dark brown	47	33.36	3.30	0.48	
Light brown	10	61.10	4.22	1.3	0.19^{ns}
Brown	4	66.75	4.44	2.2	
Light brown	10	61.10	4.22	1.3	1.36^{ns}
Dark brown	47	33.36	3.30	0.48	
Brown	4	66.75	4.44	2.2	1.07^{ns}
Dark brown	47	33.36	3.30	0.48	

Note: N: number of genotypes, STD: standard deviation, SE: standard error, ns: not significant ($p > 0.05$)

Table 5. The Welch's t-test based on the seed color in the pod shattering

Seed color	N	Mean	STD	SE Mean	t value
Green	12	13.50	2.02	0.58	-3.53**
Yellow	69	48.62	3.90	0.47	
Green	12	13.50	2.02	0.58	-1.24^{ns}
Black	19	25.78	2.88	0.66	
Yellow	69	48.62	3.90	0.47	-1.92^{ns}
Black	19	25.78	2.88	0.66	

Note: N: number of genotypes, STD: standard deviation, SE: standard error, **: significant ($p < 0.01$), ns: not significant ($p > 0.05$)
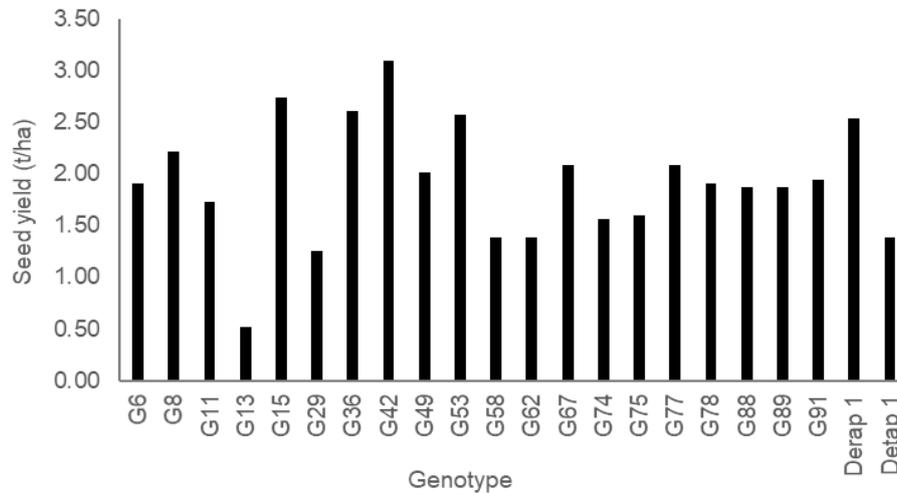
Figure 7. Seed yield of 20 very resistant genotype

If the simultaneous selection was performed based on the seed yield (of the highest yield of check cultivar, Derap 1) and the shattering resistance, then two genotypes were selected with a higher yield than Derap 1, but with similar shattering resistance, namely G42 (3.09 t/ha) and G15 (2.74 t/ha). Those genotypes have medium maturity (80 and 81 days, respectively). The days to maturity could be one of the important factors related to pod shattering. Fatima et al. (2020) found a positive correlation (r = 0.346*) between pod shattering and days to maturity. It means that shattering may occur in late-maturing genotypes than in early maturing genotypes. Similarly, Bara et al. (2013) found that the plant age could aggravate the pod shattering. On the contrary, Kataliko et al. (2019) did not found a significant correlation between pod-shattering with days to maturity.

The present finding of this study, i.e., the very resistant genotypes with high yield, could be recommended to be developed as new cultivars; meanwhile, the other very resistant genotypes can be effectively used in soybean breeding programs as gene donors to develop shattering resistant genotypes combined with certain desirable traits. From the research that has been done, it can be concluded that the pod color did not affect the pod shattering resistance of soybean genotypes. Among 100 genotypes, twenty genotypes were classified as very resistant to pod shattering. Two very resistant genotypes (G42 and G15) produce high yield and have medium maturity. Those genotypes were suggested to be developed as new improved cultivars. The other very resistant genotypes could be used as gene donors in the breeding program.

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