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Original Article

Historical trends in pod shattering resistance and agronomic traits of Indonesian soybean varieties released from 1919 to 2021

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Abstract

Pod shattering has become one of the causes for significant yield losses in soybean production in the tropics. This study aimed to evaluate the changes in agronomic traits and pod shattering resistance, to identify the historical trends, and to assess the relationships among yield and yield components. This research was conducted in the field and laboratory. A field experiment was carried out in Malang, East Java, Indonesia during the dry season 2024, and the laboratory experiment was done to evaluate the pod shattering resistance. Genetic variation was found among varieties. Based on the trend analysis, there is a gradual decrease in pod shattering susceptibility (0.265%) in recent released varieties, indicates a consistent increase in pod shattering resistance. Modern cultivars tend to flower earlier and have a more compact plant architecture, with larger seeds but fewer full pods. Based on correlation analysis, the characters of plant height, number of nodes, and number of branches can be utilized as selection indicator to obtain high yielding soybean genotypes. Overall, the results indicate the achievement of soybean breeding in Indonesia in reducing yield losses and give useful traits for selecting high-yielding and shattering-resistant varieties.

Keywords: Genetic variation, Modern cultivar, Selection, Trend analysis, Yield loss

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Introduction

Soybean is the third most significant food crop in Indonesia after rice and maize, especially as a good source of protein and used in the industry as well (Harsono et al., 2021). For over a century, soybean breeding has been actively engaged, which has resulted in several improved varieties that are suited to various agroecosystems. Soybean breeding in Indonesia has focused on the yield improvement, which also supported by other important agronomic traits, such as early days to maturity, large seed size, and resilience to biotic and abiotic stressors (Mastur et al., 2020; Harsono et al., 2021).

Pod shattering is one of the most major constraints affecting soybean yield**,** especially under hot and dry weather prior to harvest (Tukamuhabwa et al., 2002). The extent of yield loss due to pod shattering varies widely, ranging from negligible to severe, depending on plant attributes, management practices, environmental conditions and varietal susceptibility (Maity et al., 2021; Seo et al., 2022). Breeding for resistance to pod shattering has therefore become a key objective in soybean improvement programs. In addition, agronomic traits such as plant height, number of pods per plant, and seed size are essential indicators of varietal performance and breeding progress. The main keys for genetic improvement of shattering resistant soybean varieties rely on the availability of the gene source, understanding of the genetic basis of inheritance, and a reliable selection technique for pod shattering (Parker et al., 2021; Krisnawati et al., 2022). The genetic control of pod shattering in soybean has been extensively studied with different findings (Ogutcen et al., 2018; Nevhudzholi et al., 2020). Soybean-producing countries continue to improve soybean resistance to pod shattering. In Japan, the cultivars *Hayahikari* and *Yukihomore* were released in 2010, using *SJ2* as the resistant gene source (Yamada et al., 2009). In Korea, the soybean cultivar Saegeum has been released with characteristics of high yield and high shattering resistance (Kim et al., 2019). Several methods have been developed to evaluate pod shattering resistance, including field evaluation and the oven-dry method (Tukamuhabwa et al., 2002; Seo et al., 2020), both of which produce consistent results (Agrawal et al., 2000; Krisnawati et al., 2022).

Several soybean varieties have been released in Indonesia since the early 1900s, however, there has been no comprehensive examination of their pod shattering resistance and agronomic performance during a century of breeding. Most previous studies concentrated on a restricted number of types or on short-term selection cycles, without addressing the long-term genetic improvement obtained by regular breeding activities (Adie et al., 2022; Krisnawati and Adie, 2024). The analysis in this study will reveal the past patterns related to the development of soybean breeding by connecting agronomic performance and pod shattering resistance with the year of variety release. Therefore, the expected results are how long-term breeding efforts have altered characteristics associated with shattering resistance and agronomic traits.

The objectives of this study were to evaluate the pod shattering resistance and agronomic traits, identify historical trends in these attributes throughout breeding periods, and to assess the relationship between yield and yield components of 87 soybean varieties released in Indonesia from 1918 to 2021.

Material and Methods

Plant material

The study used 87 Indonesian soybean varieties released between 1919 and 2021 (Table 1). These varieties originated from various sources, including hybridization, local varieties, introductions, and mutations. The breeding programs were carried out by government institutions (Ministry of Agriculture), universities, the National Nuclear Energy Agency, and local government agencies at the district level. The data of the year of release (YOR) and origin for each variety was obtained from official variety release records.

Table-1. Indonesian soybean varieties evaluated in this study, released between 1919 and 2021.

No	Variety	YOR	Origin
1	No 27	1919	Introduction from Taiwan
2	No 29	1924	Introduction from Taiwan
3	Ringgit	1935	Selection from biparental crosses

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4	Sumbing	1937	Selection from biparental crosses
5	Merapi	1938	Local variety
6	Orba	1974	Selection from biparental crosses
7	Galunggung	1981	Selection from biparental crosses
8	Guntur	1982	Selection from biparental crosses
9	Lokon	1982	Selection from biparental crosses
10	Wilis	1983	Selection from biparental crosses
11	Raung	1986	Selection from biparental crosses
12	Merbabu	1986	Selection from biparental crosses
13	Muria	1987	Mutation selection
14	Tidar	1987	Mutation selection
15	Petek	1988	Local variety
16	Lompobatang	1989	Selection from biparental crosses
17	Lumajang Bewok	1989	Local variety
18	Rinjani	1989	Selection from biparental crosses
19	Tengger	1991	Mutation selection
20	Jayawijaya	1991	Selection from biparental crosses
21	Dieng	1991	Selection from biparental crosses
22	Krakatau	1992	Introduction from Taiwan
23	Malabar	1992	Selection from biparental crosses
24	Kipas Putih	1992	Local variety
25	Singgalang	1992	Introduction from Nigeria
26	Cikuray	1992	Selection from biparental crosses
27	Sinduro	1995	Selection from biparental crosses
28	Slamet	1995	Selection from biparental crosses
29	Pangrango	1995	Selection from biparental crosses
30	Kawi	1998	Selection from biparental crosses
31	Bromo	1998	Introduction from Philippine
32	Argomulyo	1998	Introduction from Thailand
33	Meratus	1998	Mutation selection
34	Leuser	1998	Selection from biparental crosses
35	Burangrang	1999	Selection from biparental crosses
36	Manglayang	1999	Selection from biparental crosses
37	Tanggamus	2001	Selection from biparental crosses
38	Nanti	2001	Selection from biparental crosses
39	Anjasmoro	2001	Introduction from Manchuria
40	Sinabung	2001	Multiparent crosses of 16 parental
41	Kaba	2001	Multiparent crosses of 16 parental
42	Mahameru	2001	Introduction from Manchuria
43	Sibayak	2001	Selection from biparental crosses
44	Lawit	2001	Selection from biparental crosses
45	Menyapa	2001	Selection from biparental crosses
46	Baluran	2002	Introduction from Taiwan
47	Ijen	2003	Backcross selection

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48	Seulawah	2004	Selection from biparental crosses
49	Rajabasa	2004	Mutation selection
50	Ratai	2004	Selection from biparental crosses
51	Gumitir	2005	Introduction from Taiwan
52	Argopuro	2005	Introduction from Taiwan
53	Mallika	2007	Local variety
54	Mitani	2008	Mutation selection
55	Gepak Ijo	2008	Local variety
56	Grobogan	2008	Local variety
57	Gepak Kuning	2008	Local variety
58	Detam 2	2008	Selection from biparental crosses
59	Detam 1	2008	Selection from biparental crosses
60	Mutiara 1	2010	Mutation selection
61	Gema	2011	Selection from biparental crosses
62	Dering 1	2012	Selection from biparental crosses
63	Detam 4 Prida	2013	Selection from biparental crosses
64	Gamasugen 2	2013	Mutation selection
65	Gamasugen 1	2013	Mutation selection
66	Detam 3 Prida	2013	Selection from biparental crosses
67	Mutiara 2	2014	Mutation selection
68	Dena 2	2014	Selection from biparental crosses
69	Demas 1	2014	Selection from biparental crosses
70	Mutiara 3	2014	Mutation selection
71	Dena 1	2014	Selection from biparental crosses
72	Devon 1	2015	Selection from biparental crosses
73	Dega 1	2016	Selection from biparental crosses
74	Deja 1	2017	Selection from biparental crosses
75	Deja 2	2017	Selection from biparental crosses
76	Devon 2	2017	Selection from biparental crosses
77	Nusa Sanggabuana	2018	Introduction from Thailand
78	Detap 1	2018	Backcross selection
79	Derap 1	2019	Backcross selection
80	Devatra 1	2020	Selection from biparental crosses
81	Dering 2	2020	Selection from biparental crosses
82	Demas 3	2020	Backcross selection
83	Devatra 2	2020	Selection from biparental crosses
84	Demas 2	2020	Selection from biparental crosses
85	Dering 3	2020	Selection from biparental crosses
86	Depas 1	2021	Selection from biparental crosses
87	Derek 1	2021	Selection from biparental crosses

Field experiment

All soybean varieties were evaluated in a field experiment conducted at Malang, East Java, Indonesia, from April to July 2024. The field experiment was carried out in a tropical environment located at 8° 2′ 56.4″ S and 112° 37′ 30″ E, at an elevation of 445 m above sea level. The climate at the experimental site is classified as type C2 according to the Oldeman system, with an average relative humidity of approximately 90%. The field experiment followed a randomized block design with three replications. Each variety was planted at a spacing of 40 cm × 15 cm, with two plants per hill. NPK fertilizer (15-15-15) was applied at a rate of 150 kg ha^{-1}. Pests and diseases were effectively controlled beginning at eight days after planting. Standard agronomic practices, including weed control and irrigation, were optimally maintained throughout the experiment.

Laboratory study for pod shattering evaluation

Pod shattering evaluation was conducted in the Laboratory of Purwodadi Botanical Garden, Pasuruan, East Java, Indonesia. Plant materials for the pod shattering evaluation were collected at the R8 stage (full maturity, when approximately 95% of the pods had reached their mature color). Three plants were randomly selected from each variety and replication, then air-dried for three days at room temperature. Thirty pods were randomly detached from each sample plant, placed in a petri dish (Ø = 15 cm), and subjected to oven drying. The evaluation of pod shattering resistance was conducted under laboratory conditions using the oven-dry method described by Krisnawati and Adie (2017).

Data collection and analysis

Pod shattering percentage was calculated based on the number of shattered pods divided by the number of sample pods (thirty pods). The classification of the pod shattering resistance (AVRDC, 1979) was based on the percentage of shattering: very resistant (0%), resistant (1 to 10%), moderately resistant (11 to 25%), susceptible (26 to 50%), and very susceptible (>50%) The agronomic data collected included length of vegetative phase (days), length of generative phase (days), G/V ratio, days to maturity (days), plant height (cm), number of branches, number of nodes, number of filled pods, number of empty pods, internode length (cm), stem diameter (cm), 100-seed weight (g), and seed yield per plant (g). The data was subjected to ANOVA analysis. The relationships among agronomic traits and yield components as well as among pod morphological traits and pod shattering were performed using Pearson's correlation analysis. All the correlation coefficients were visualized using a correlation matrix generated in RStudio using the *corrplot* and Hmisc packages (Rstudio, 2020).

Temporal trend analysis based on year of release

Temporal trends in pod shattering resistance (percentage of shattering) and agronomic traits among soybean varieties released between 1919 and 2021 were analyzed using linear regression analysis, in which the mean trait value of each variety was regressed against its year of release (Tadesse et al., 2018). This approach was used to estimate the rate of genetic change across breeding periods, and the slope of the regression line was used as an indicator of the direction and magnitude of change over time. The mean absolute deviation (MAD), mean absolute percentage error (MAPE), and mean square deviation (MSD) were used for detecting the accuracy of the regression model (Okoro, 2024). These indices were used to quantify the deviation between observed values and predicted values generated from the regression model.

Results

Pod shattering screening

A total of 87 soybean varieties released in Indonesia over a 102-year period (1919–2021) showed significant variation in agronomic traits pod shattering resistance (Table 2). The average pod shattering of 87 soybean varieties on various oven-dry temperatures showed that none of the varieties exhibited pod shattering after being subjected to 30°C for three days. When the temperature was raised to 40°C, the average pod shattering across all varieties reached 12%. The shattering percentage then increased sharply, reaching an average of 81% and 92% at 50 °C and 60 °C, respectively.

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Table-2. Analysis of variance for pod shattering, pod attributes, and agronomic traits of 87 soybean genotypes.

Traits	Symbol	Mean Square	
		Replication	Genotype
Pod shattering at 40°C	PS40	73.6235*	2483.7843**
Pod shattering at 50°C	PS50	40.4051ns	5888.7067**
Pod shattering at 60°C	PS60	37.7401ns	1939.7532**
Pod width (mm)	PDW	11.5805 ns	27.76026**
Pod length (mm)	PDL	84.1552**	383.4753**
Pod thickness (mm)	PDT	0.7504 ns	5.3587**
Days to flowering	DTF	0.1034ns	52.6786**
Days to maturity (days)	DTM	12.6551**	121.5338**
Ratio of generative/vegetative phase	G/V	0.0028ns	0.13660*
Plant height (cm)	PHG	203.5670*	774.3318**
Number of branches	NOB	0.1877ns	4.4946**
Number of nodes	NON	235.7356ns	538.7981*
Number of filled pods	NFP	54.4981ns	1210.8659**
Number of empty pods	NEP	4.9003*	15.0965**
Nodes distance (cm)	NDT	0.0428ns	5.2063**
Stem diameter (cm)	SDM	0.0848*	0.6179**
100 seed weight (g)	HSW	2.0948**	38.7054**
Seed weight per plant (g)	SDY	19.3218**	36.1822**

Note: ns = not significant, * = significant at 5 % probability level (p < 0.05), ** = significant at 1 % probability level (p < 0.01)

The classification of pod shattering resistance among 87 soybean varieties subjected to different oven-drying temperatures is presented in Figure 1. At 30°C, all varieties exhibited very high resistance, with pods remaining largely intact and structurally stable. However, distinct differences in resistance levels became apparent as the oven temperature increased. By the end of the observation period, after exposure to 60 °C, no varieties were classified as very resistant; six varieties were categorized as resistant, two as moderately resistant, none as susceptible, and the remaining 83 as very susceptible to pod shattering.

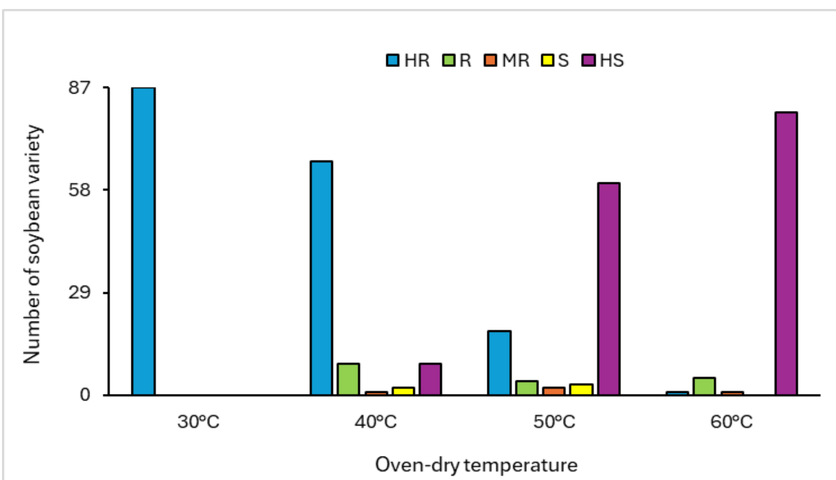

Figure-1. The resistance classification of 87 soybean varieties to pod shattering. HR = highly resistant, R = resistant, MR = moderately resistant, S = susceptible, HS = highly susceptible.

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Variation and temporal trends in pod shattering resistance

The percentage of pod shattering among soybean varieties released from 1919 to 2021 showed substantial variation (Figure 2). Most of varieties generally showed very high pod shattering levels, nearly 100%, suggesting that susceptibility to pod dehiscence has been a persistent problem in Indonesian soybean variety. However, a few varieties released after 2000 showed exceptionally low shattering percentages, indicating the presence of genetic improvement for resistance. In 2001, the Anjasmoro variety was the first pod-shatter-resistant variety released from soybean breeding programs in Indonesia, and the Gumitir soybean variety was released in 2015, which is also pod-shatter-resistant. Before 2000, nearly all varieties were highly susceptible, reflecting that resistance to pod shattering was not yet a priority in soybean breeding programs. Breeding for shattering resistance showed a significant advancement, as seen by the increased number of cultivars with low shattering resistance level in the 2000s and onward.

The trend analysis was shown in Figure 3. The result showed a slow but steady improvement in genetic resistance over time, as indicated by the regression equation ($Y_t = 103.38 - 0.265t$). However, the fitted model's accuracy measurements show inconsistent progress, potentially because of variations in genetic backgrounds, selection intensity, and environmental factors influencing pod drying and maturity.

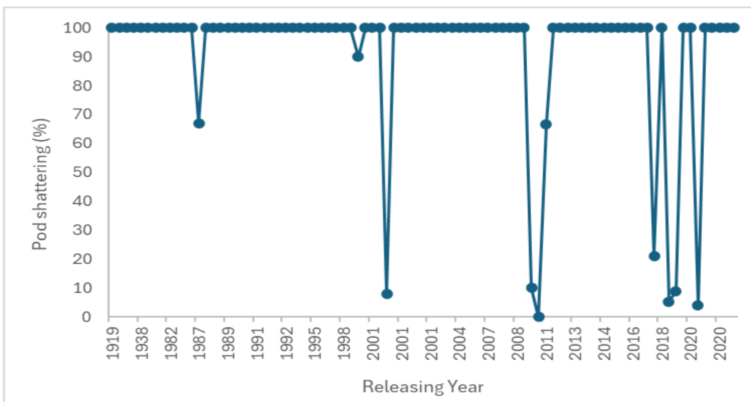

Figure-2. Distribution of pod shattering percentage among 87 Indonesian soybean varieties released from 1919 to 2021. Each point represents the mean of pod shattering percentage of a variety as listed in the varietal dataset (Table 1).

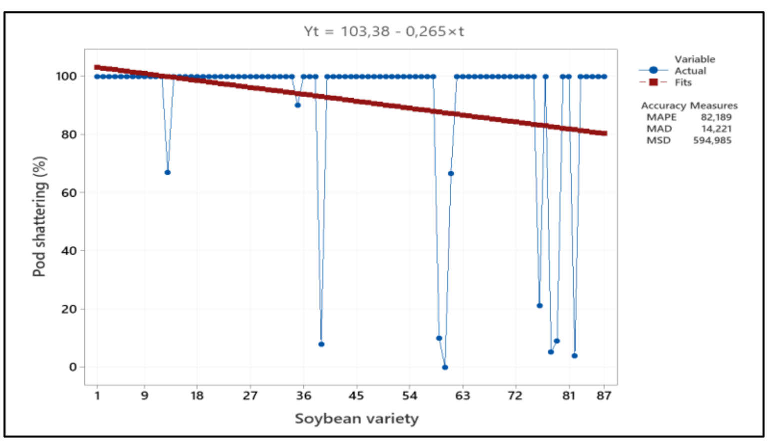

Figure-3. Trend analysis of pod shattering resistance in 87 Indonesian soybean varieties released between 1919 and 2021, as listed in the varietal dataset (Table 1).

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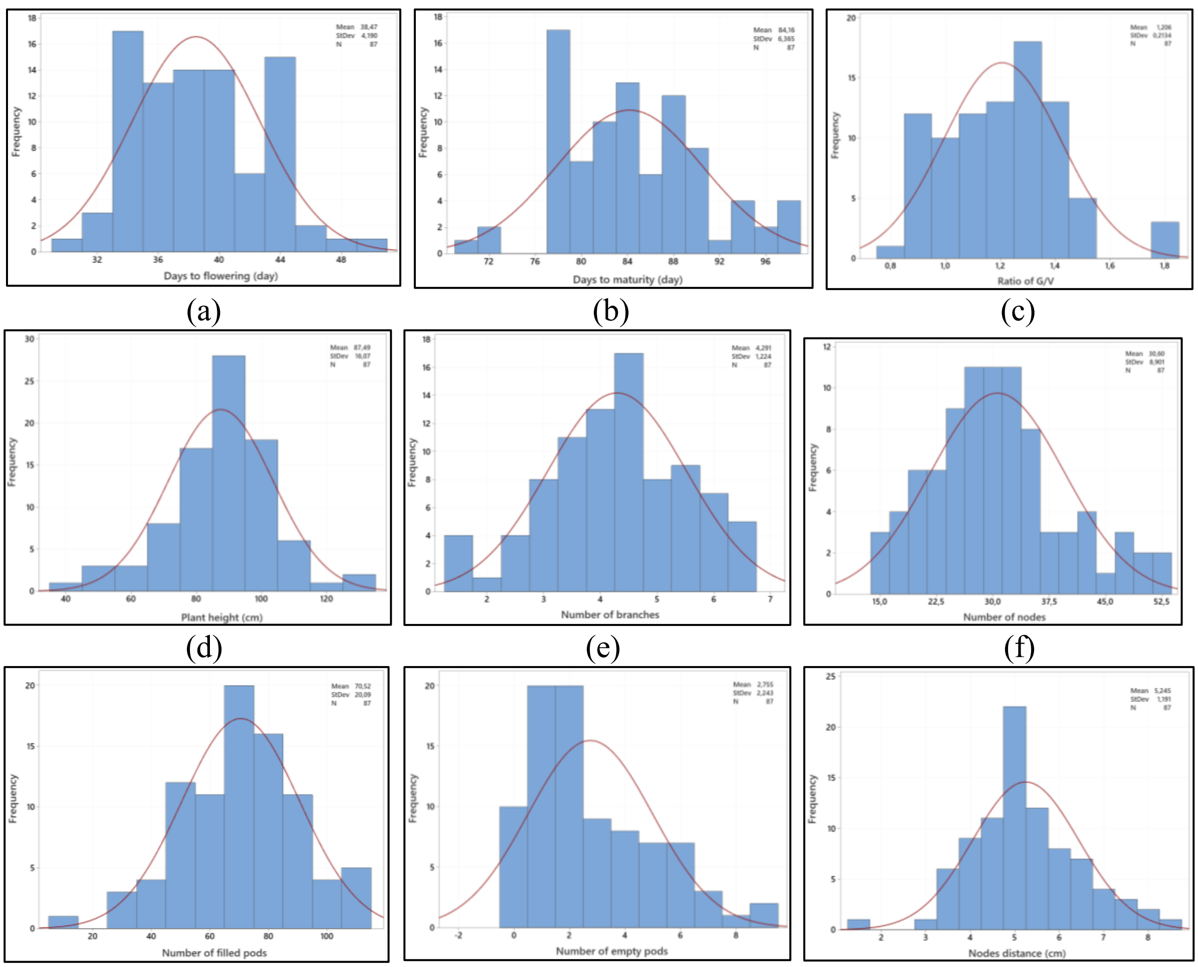
Agronomic traits and temporal trends

Soybean varieties released in Indonesia during the period 1919–2021 exhibit significant variation in agronomic traits. This diversity is observed in phenological traits (length of the vegetative phase, length of the generative phase, the ratio between generative and vegetative phases, and maturity duration), growth traits (plant height, number of branches, number of nodes, number of filled and empty pods, stem diameter, and node spacing), as well as yield traits (seed size and seed yield) (Figure 4). The average vegetative phase lasted 38 days (range 30–50 days), the generative phase averaged 46 days (range 36–62 days), the mean G/V ratio was 1.23 (range 0.77–1.81), and the average days to maturity was 85 days (range 70–99 days) (Figures 4a-4c). The performance of growth traits ware presented in Figures 4d-4j. The average of plant height was 87.45 cm (range 36.33–132.67 cm), number of branches average was 4.29 branches/plant (range 1.33–6.67), number of nodes average was 31.78 nodes/plant, (range 14.67–124.33), number of filled pods average was 70.60 pods/plant (range 14.67–112.33), and number of empty pods average was 2.76 pods/plant (range 0–9). The average internode length was 5.32 cm, with a range of 3.17–8.43 cm, and stem diameter had an average of 2.26 cm, with a range of 1.2–3.33 cm. Furthermore, for yield traits, 100-seed weight ranged from 5.42 to 21.95 g (average 10.79 g/100 seeds), and seed yield per plant ranged from 6.86 to 24.61 g (average 17.03 g) (Figure 4k, 4l).



(a) (b) (c)
(d) (e) (f)
(g) (h) (i)

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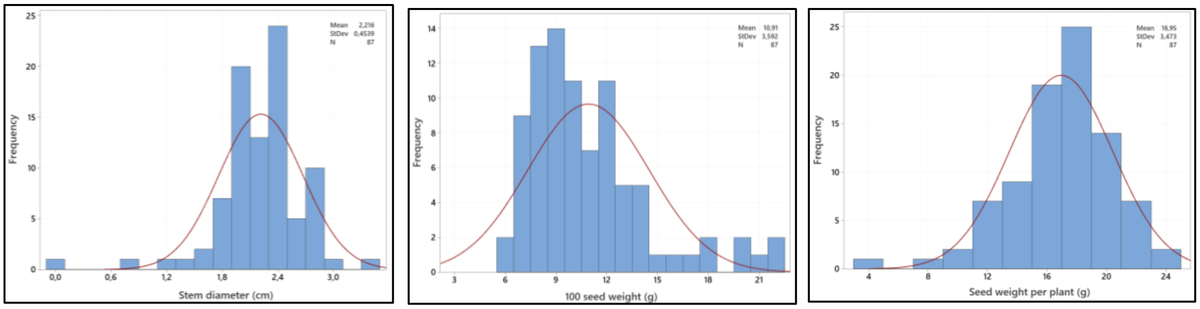


(j) (k) (l)

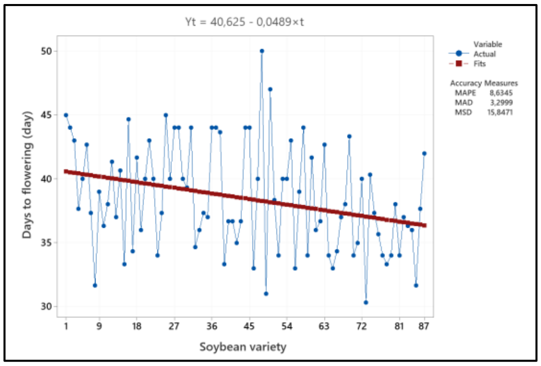
Figure-4. Histogram of twelve agronomic traits across 87 soybean varieties.

The trend analysis of days to flowering (DTF) for 87 soybean varieties released from 1919 to 2021 showed a gradual decline over time, indicating a reduction of about 0.05 days per year (Figure 5a), following the fitted regression line $Y_t = 40.625 - 0.0489t$. For the days to maturity (Figure 5b), the trend analysis of 87 soybean varieties released from 1919 to 2021 showed a gradual reduction in days to maturity (DTM). The fitted regression line ($\hat{Y} = 86.19 - 0.0464t$) indicates a decline of approximately 0.046 days per year (0.46 days per decade). The generative-to-vegetative (G/V) ratio of 87 soybean varieties released between 1919 and 2021 showed a slight but consistent upward trend (Figure 5c). The regression equation ($\hat{Y} = 1.1342 + 0.001639t$) indicates a gradual annual increase in the proportion of the growth period allocated to the generative phase. The trend analysis of plant height showed a gradual declining pattern over time.

In this study, plant height showed a decrease by approximately 0.15 cm per year, as seen in the fitted linear regression model ($\hat{Y} = 94.29 - 0.1546t$), indicates that newer or modern soybean varieties tend to be shorter than older ones. In the characters of branches and nodes number, it shows a minor but consistent decreasing trend (Figure 5e-5f). A decrease in the node numbers generally indicates more compact growth habits or a shorter vegetative phase.

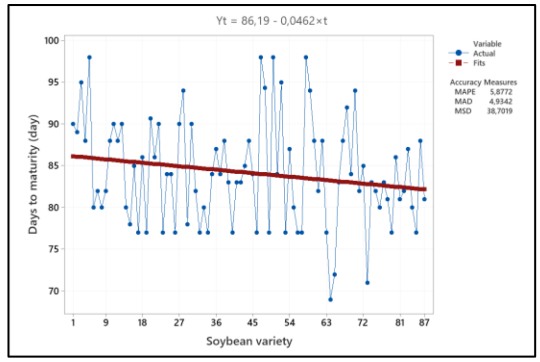
For the node distance and stem diameter (Figure 5g–5h), they were gradually increased with positive regression slopes suggesting that more recent cultivars often had thicker stems, and a slightly longer internode. This change of characteristics might facilitate more effective plant growth by increasing light penetration within the canopy. And the gradual increase of stem diameter (0.001 cm per year), indicating enhanced stem robustness that could support more plant stability and lower lodging risk

Seed weight per plant remained relatively stable across release years (Figure 5k), but clear changes were observed in its component traits. The number of filled pods showed a decreasing trend (Fig. 5i), whereas 100-seed weight exhibited a clear increasing trend, by approximately 0.07 g per year (Figure 5j), indicating that more recent cultivars tend to produce larger and heavier seeds. The trend analysis of seed weight per plant exhibited a slight increasing pattern over time (Figure 5k). The fitted linear regression mode was $\hat{Y} = 16.529 - 0.0095t$.



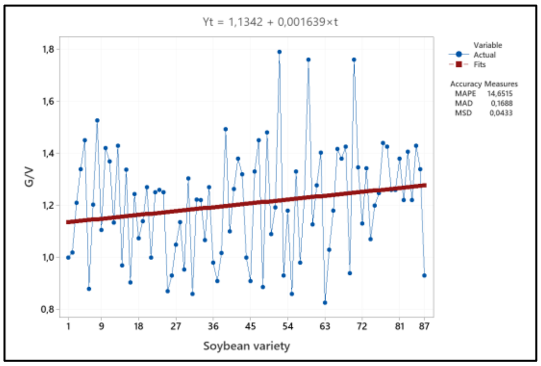
Yt = 40,625 - 0,0489×t
Days to flowering (day)
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 8,6345
MAD 3,2999
MSD 15,8471

(a)



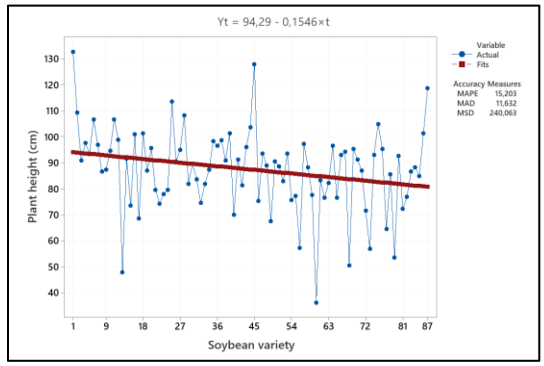
Yt = 86,19 - 0,0462×t
Days to maturity (day)
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 5,8772
MAD 4,9342
MSD 38,7019

(b)



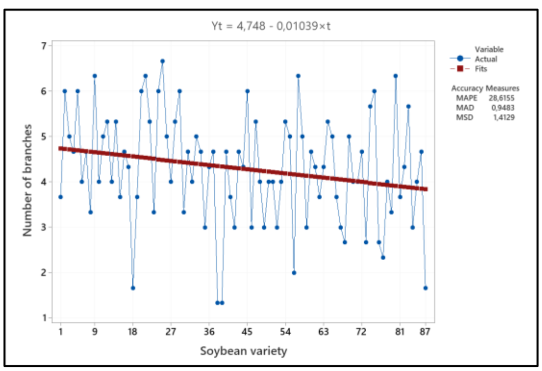
Yt = 1,1342 + 0,001639×t
G/V
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 14,6515
MAD 0,1688
MSD 0,0433

(c)



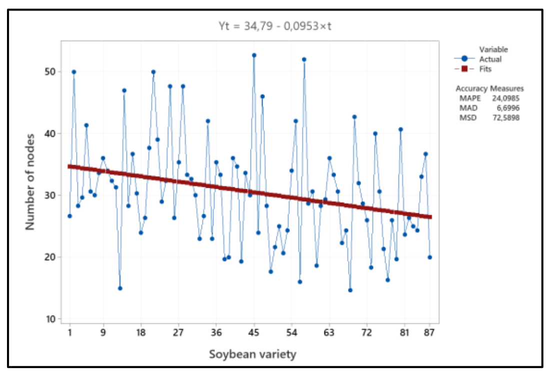
Yt = 94,29 - 0,1546×t
Plant height (cm)
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 15,203
MAD 11,632
MSD 240,063

(d)



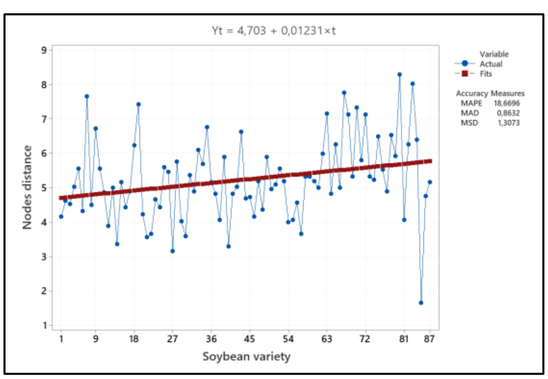
Yt = 4,748 - 0,01039×t
Number of branches
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 28,6155
MAD 0,9483
MSD 1,4129

(e)



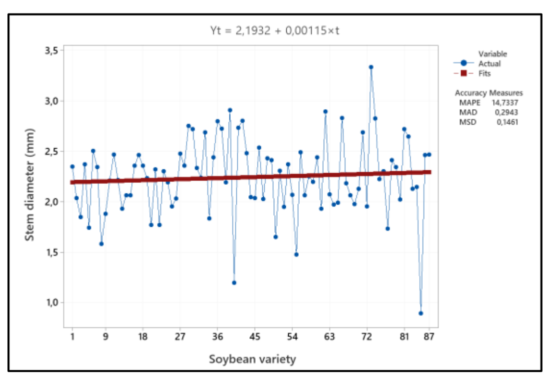
Yt = 34,79 - 0,0953×t
Number of nodes
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 24,0985
MAD 6,6996
MSD 72,5898

(f)



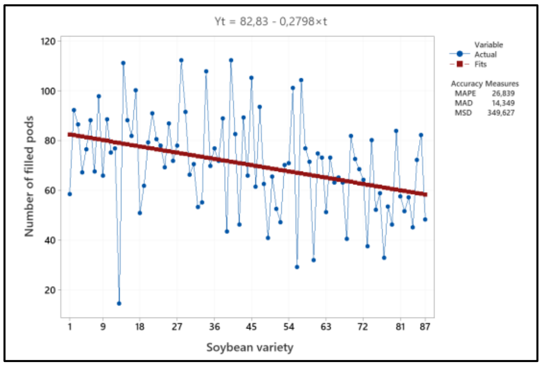
Yt = 4,703 + 0,01231×t
Nodes distance
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 18,6696
MAD 0,8632
MSD 1,3073

(g)

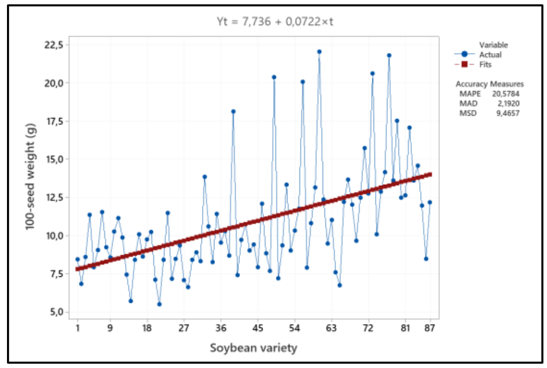


Yt = 2,1932 + 0,00115×t
Stem diameter (mm)
Soybean variety
Variable
Actual
Fits
Accuracy Measures
MAPE 14,7337
MAD 0,2943
MSD 0,1461

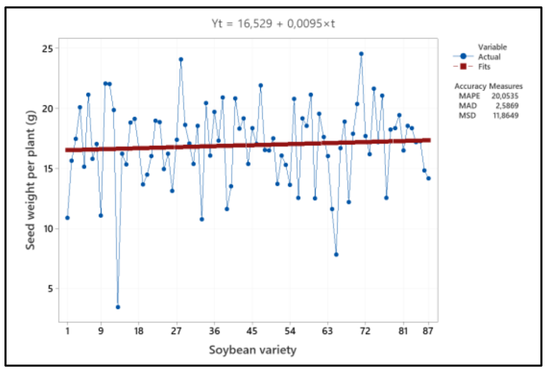
(h)



(i)



(j)



(k)

Figure-5. Trend analysis of agronomic traits in 87 Indonesian soybean varieties released between 1919 and 2021, as listed in the varietal dataset (Table 1).

Relationship between yield components and agronomic traits

The correlation analysis among yield components revealed clear relationships that are highly relevant for soybean breeding (Figure 6). Days to flowering (DTF) and days to maturity (DTM) showed a strong positive correlation (r = 0.75). Plant height (PHG) was positively correlated with the number of nodes (NON; r = 0.74) and number of branches (NOB; r = 0.51; meanwhile, the number of filled pods (NFP) also showed a positive correlation with the number of nodes (r = 0.65) and branches (r = 0.49). However, in contrast, 100-seed weight (HSW) showed a negative correlation with pod-related traits, including NFP (r = –0.02). Meanwhile, most of yield components were only correlated with stem diameter (SDM) and internode characteristics, suggesting that these characteristics may have little direct impact on seed yield.

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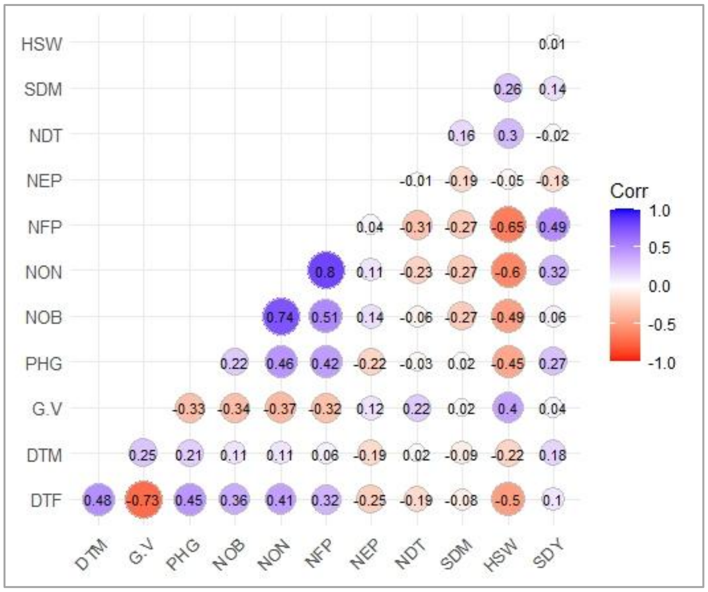

Figure-6. Correlation matrix among yield and yield components of 87 soybean varieties. Circle size and color intensity represent the strength and direction of the correlations, with purple indicates positive associations and red indicates negative associations. The code of agronomic traits was described in Table 2.

Discussion

The pod shattering resistance showed a significant variation among tested genotypes, which indicate that various genetic backgrounds and selection criteria were used in Indonesian soybean breeding projects over time. Additionally, the results indicate that pod shattering resistance is regulated by genetic factors, as seen by the observed variation is entirely genetically driven (Han et al., 2021; Shimbwambwa et al., 2024). In this study, no shattered pods were found at 30°C based on oven-dry method. Other studies also reported that at 30 °C, most pods remained intact with very low shattering (Ekom et al., 2025). A study reported that the used of 30°C temperature was for a baseline treatment to equilibrate pod moisture content, to ensure a consistent initial environment condition before exposure to higher temperature treatments (Krisnawati and Adie, 2019).

In this study, the pod shattering percentage increased as the oven temperature increased, suggesting that there were degradation of cellular structures and moisture loss (Ekom et al., 2025). Thus, the increase in the oven temperature will efficiently accelerate the loss of seed and pod moisture, enhancing genotypic variations in shattering resistance and increase internal tension that makes pods more prone to dehiscence (Ogutcen et al., 2018; Krisnawati et al., 2020). The sharp rise in shattering percentage between 40°C and 50°C highlights a critical threshold at which pod wall tension surpasses the mechanical strength of the suture, especially in the susceptible varieties (Zhang et al., 2018).

In Indonesia, the history of soybean variety development reflects the gradual integration of pod shattering resistance into breeding programs. The first soybean variety released in Indonesia was Otau in 1918, introduced from Formosa (Taiwan). However, in this study, we analyzed varieties released starting from 1919, with No. 27 as the earliest entry. The dataset consisted of 87 soybean varieties released between 1919 and 2021, representing more than a century of breeding progress. Before 2000, most soybean varieties were highly susceptible, indicating that pod shattering resistance was not a breeding priority. Since the 2000s, the emergence of low-shattering varieties reflects significant breeding progress. This improvement may be attributed to the introduction of resistant parental lines and the adoption of more effective selection environments. Previous studies have reported that breeding for pod shattering resistance is achievable through targeted hybridization and evaluation under dry and high-temperature conditions (Tukamuhabwa et al., 2002; Krisnawati and Adie, 2019; Krisnawati and Adie, 2024).

Pod shattering resistance is a key breeding target in Indonesia, where dry-season conditions and delayed harvesting—often due to labor shortages—intensify seed losses in susceptible varieties (Krisnawati and Adie, 2024). In this study, trend analysis revealed a pod shattering reduction rate of 0.265% per year. This value may seem low, but it represents decades of consistent breeding advancement. More recent soybean varieties generally exhibited a higher shattering resistance, as shown by the decrease in the shattering resistance.

In the last five years, soybean varietal breeding programs have been developed in the country for pod shatter resistance and high yield. This program resulted in soybean variety of Detap 1 which was released in 2018, followed by Derap 1 in 2019, and Demas 3 in 2020. The presence of a few low-shattering varieties within a largely susceptible population highlights the success of targeted breeding and the availability of promising resistant germplasm.

In this study, significant variation in agronomic traits was found. Three agronomic characteristics that are essential for soybean development in tropical Indonesia are early maturity, large seed size, and high seed yield. Early maturity is required because soybean is commonly planted in the lowland as the final crop in the planting pattern of rice-rice-soybean. In addition, the largest use of soybean in Indonesia is for tempeh production, which demands cultivars with large seed size. For Indonesia's tropical regions, it has been suggested that the optimal maturity duration for achieving high yield is around 74 days (Adie and Krisnawati, 2017).

The trend analysis of agronomic traits for 87 soybean varieties released from 1919 to 2021 showed a variation. Trend analysis showed a gradual decline in days to flowering as well as the days to maturity. The downward trend suggests that newer soybean varieties tend to flower and be harvested earlier than older ones. Although the annual change is small, the long-term trend reflects a meaningful shift toward earlier-maturing cultivar. This pattern is likely to reflect breeding for early-maturing varieties suited to existing cropping systems. In Indonesia, early days to maturity has become an important trait, since one of the cropping patterns is a rice–rice–soybean, which allows soybean to complete its growth cycle within the limited planting window after the second rice crop, furthermore, will also help plants escape form drought stress which often occur near the end of the growing season (Susanto et al., 2025).

In this study, the was a slight but consistent upward trend in the character of G/V ratio. The individual varieties showed variation, but the positive slope suggests a long-term shift toward a comparatively longer reproductive phase. This study result indicates that that Indonesian modern soybean varieties reach flowering earlier and complete their life cycle faster yet maintain a relatively longer reproductive phase. In Brazil, modern cultivars tend to have a shorter vegetative growth period compared to older cultivars (Umburanas et al., 2022). According to research by Adie and Krisnawati (2021), the G/V ratio affects seed yield in soybeans with medium to large seeds, while it has less impact on production in cultivars with medium seeds.

The newest Indonesian varieties showed changing in the plant architecture, namely the decrease plant height, a fewer number of nodes, and a longer node distance, which is similar with earlier study in South Brazil (Todeschini et al., 2019). According to a study by Li et al. (2025), fewer branches will contribute to a more uniform canopy structure, and less intraplant competition. A further study in Northeast China found that improvements in the canopy design and seed characters have been linked to increased yield (Waqar et al., 2025).

In the character of seed weight per plant, the result of the trend analysis in this study showed a gradual increase. The positive trend indicates a gradual improvement in yield potential at the individual plant level, despite the slope in a small size. Other studies also found a yield increase across various historical cultivars and maturity groups (de Felipe et al., 2016; Todeschini et al., 2019; Umburanas et al., 2022).

Meanwhile, based on the correlation study, showed that genotypes with later flowering also tended to mature later. This is consistent with Truong et al. (2006). Furthermore, taller plants tend to have more nodes and branches, which provide additional sites for pod formation. A similar study also reported that these characteristics could be used as selection indicator for high yield (Li et al., 2020). However, a negative correlation was found with other pod traits, indicates a trade-off between seed size and pod number (Kumagai et al., 2022).

Conclusion

The significant variation was found in the pod shattering resistance of 87 soybean varieties. The trend analysis showed a gradual decrease in pod shattering

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susceptibility (0.265%) in the recent varieties (modern cultivars). Characteristics of modern cultivars are having earlier flowering, reduced plant height, fewer branches, fewer nodes, larger seed size but a smaller number of pods. Characters of plant height, number of nodes, and number of branches could be used as selection indicators for obtain high yield potential in soybean.

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