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Comprehensive Evaluation Of Early-Maturing And High-Yielding Soybean (Glycine Max L.) Genotypes Under Competitive Variety Testing Conditions

[1] Marat Rasulov
[2] Amir Amanov
[3] Dilshod Musirmanov
[4] Abdumurod Hakimov

[1] Head of Department, Oilseed and Fiber Crops Experimental Station, Research Institute of Plant Genetic Resources, Uzbekistan
[2] Doctor of Agricultural Sciences (ScD equivalent), Professor, Scientific Supervisor, Research Institute of Plant Genetic Resources, Uzbekistan
[3] Head of the Field Crops Department, Senior Researcher (PhD), Research Institute of Plant Genetic Resources, Uzbekistan
[4] Deputy Director of the Oil and Fiber Crops Experimental Station of the Uzbekistan Plant Genetic Resources Research Institute, Uzbekistan

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Abstract

Developing early maturing and high yielding soybean cultivars is essential for improving production efficiency and ensuring crop stability under increasingly variable climatic conditions. In this study, eight soybean genotypes were evaluated under competitive variety testing conditions in 2020, with the early maturing cultivar 'Orzu' serving as the standard check. Field trials were conducted in 14 m² plots at a sowing density of 400,000 seeds ha⁻¹, and phenological, morphological, reproductive, and yield-related traits were comprehensively assessed.

Growth duration among the tested genotypes ranged from 88 to 102 days, compared with 109 days for the standard cultivar. Lines L 125 and K 9182 matured 18–21 days earlier than Orzu, demonstrating strong potential for short season environments. Considerable variation was observed in plant height (72–122 cm), first pod height (10–17 cm), number of branches (1–3), and pods per plant (72–136), indicating significant morphological diversity within the evaluated germplasm.

Seed yield varied from 210 to 375 g/m², with the highest productivity obtained from L 125, which also displayed the greatest pod setting capacity. Correlation analysis further confirmed that yield was most strongly influenced by the number of pods per plant (r = 0.91), while early maturity exhibited a negative relationship with yield (r = –0.72), reinforcing the value of early maturing, intensively fruiting genotypes.

Based on integrated trait evaluation, genotypes L 125, K 122, K 137, and K 171 were identified as promising breeding sources for future cultivar development. The superior line L 125, later named 'Zarbuloq', was submitted to the State Variety Testing Commission for official evaluation due to its high yield potential, early maturity, and favorable plant architecture.

Keywords: Soybean; Glycine max; early maturity; competitive variety testing; morphological traits; reproductive traits; yield components; high-yielding genotypes; plant breeding; phenology; pod-setting; Zarbuloq variety.

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1. Introduction

Soybean (Glycine max L.) is one of the most important and widely cultivated legume crops worldwide, serving as a major source of high-quality protein, edible oil, and essential bioactive compounds for both human consumption and animal feed industries. In addition to its nutritional and economic value, soybean plays a key role in sustainable agriculture due to its ability to fix atmospheric nitrogen and improve soil fertility. According to recent global agricultural reports, soybean production continues to increase, driven by rapid expansion in food, feed, and industrial uses, including biodiesel and biopolymer manufacturing [1, 3].

The growing need for soybean in diverse agro-ecological regions has intensified breeding efforts aimed at developing cultivars that combine early maturity, high yield potential, and broad adaptability. Early-maturing cultivars are particularly valuable in regions facing climatic instability, where production cycles must be shortened to avoid terminal drought, excessive heat stress, or early frost. These cultivars also facilitate double-cropping systems that significantly enhance land-use efficiency and improve annual productivity. Moreover, early maturity is closely linked to uniform ripening, which is essential for optimizing mechanized harvesting and reducing grain loss during harvest operations.

Competitive variety testing (CVT) remains a critical phase in soybean cultivar development, providing breeders with a scientific basis for evaluating new genotypes under standardized environmental and agronomic conditions. Through CVT trials, researchers can accurately assess phenological development, morphological traits, reproductive efficiency, stress tolerance, and yield performance relative to established standards [2, 4]. Such evaluations ensure that only the most promising genotypes advance to the next stages of breeding or are recommended for agricultural production.

Despite significant progress in soybean improvement, challenges remain due to increasing climatic variability, soil degradation, emerging pests and diseases, and the need for varieties with superior agronomic efficiency. Hence, identifying early-maturing, high-yielding, and biologically stable genotypes continues to be a priority for breeding programs worldwide. Integrating morphological, physiological, and yield-related traits provides a robust foundation for selecting genotypes with enhanced adaptability and breeding potential.

In this context, the present study aims to identify soybean genotypes that demonstrate:

- shortened growth duration suitable for short-season environments,
- enhanced yield potential under competitive variety testing conditions,
- improved morphological and reproductive traits contributing to high productivity,
- suitability for mechanized harvesting through optimized plant architecture, and
- potential use as donor material in future soybean breeding programs.

The findings of this research are expected to contribute to the development of soybean cultivars that are better adapted to modern agricultural systems and challenging climatic conditions.

2. Methods

Plant Materials

The study involved eight soybean (Glycine max L.) genotypes, including advanced breeding lines and introduced varieties. The early maturing cultivar ‘Orzu’ was used as the standard check. The evaluated genotypes were: L 125 (Zarbuloq), K 9182, K 122, K 177, K 137, K 5, K 185, and K 153.

Experimental Site and Design

Field experiments were conducted in 2020 under irrigated conditions. The competitive variety trial was established using a randomized design with a plot size of 14 m². Each genotype was sown at a density of 400,000 seeds ha^{-1}, following standard agronomic practices for soybean cultivation.

Irrigation, fertilization, weed management, and plant protection measures were applied uniformly across all plots to ensure equal growing conditions. The soil type and climatic conditions of the experimental site were typical of soybean production zones in Uzbekistan.

Measured Traits

A comprehensive evaluation of phenological, morphological, reproductive, and yield-related traits was carried out.

1. Phenological Traits

- Days to flowering
- Days to physiological maturity
- Total growth duration

2. Morphological Traits

- Plant height (cm)
- First pod height (cm)
- Number of branches per plant

3. Reproductive Traits

- Number of pods per plant
- Pod distribution on the stem
- Pod setting efficiency

4. Yield Components

- Seed yield (g/m² and t/ha)
- Yield advantage over the standard cultivar

Statistical and Correlation Analysis

Descriptive and comparative analyses were performed to determine the variability among genotypes. Pearson correlation coefficients were calculated to identify relationships between morphological traits and seed yield. Heatmap visualization and scatter plot analysis were used to interpret the strength and direction of trait associations.

Genotypes were classified based on integrated trait performance to identify high yielding and early maturing lines suitable for breeding programs.

References [5] and [6] provide the methodological foundation for the study. Reference [5] supports the structure of competitive variety trials used in cultivar evaluation, while reference [6] outlines physiological principles relevant to plant height, maturity, and yield formation. Together, these references validate the methodological accuracy of the experimental design and trait measurement procedures.

3. Results

Phenological Development

Significant variation in growth duration was observed among the evaluated soybean genotypes. The standard cultivar Orzu matured in 109 days, whereas the tested lines reached maturity within 88–102 days, demonstrating clear advantages in earliness. The earliest genotypes were L 125 (88 days) and K 9182 (91 days), maturing 18–21 days earlier than the standard. Genotypes K 137 and K 122 exhibited intermediate maturity (101–102 days). Details global soybean production constraints and the role of genetic diversity in overcoming environmental challenges, validating the wide variation observed in growth duration and plant height among the tested genotypes [7]. Supports the importance of evaluating germplasm via morphological traits. The variation in plant height, pod height, and branching patterns seen in L 125, K 177, K 137, etc., matches the global morphological spectrum described in this publication [8].

The results of the competitive variety trial conducted in 2020 are summarized in Table 1, which presents the phenological development, morphological features, and reproductive characteristics of eight soybean genotypes. The standard variety ‘Orzu’ matured in 109 days, indicating its classification within the medium to late maturity group.

One of the key indicators—growth duration—varied between 88 and 102 days among the tested materials. This wide range reflects substantial genetic diversity in earliness. In particular, L 125 (Zarbuloq) and K 9182 were identified as the earliest maturing lines, reaching maturity 18–21 days earlier than the standard variety.

Their short vegetation period makes them highly valuable for double cropping systems, irrigated agriculture with limited growing seasons, and regions affected by climatic variability. Emphasize that early maturity is a key adaptive trait for short season regions. The earlier maturity of L 125 and K 9182 (18–21 days earlier than Orzu) aligns with findings from these publications, demonstrating the significance of earliness for drought escape, double cropping systems, and climate vulnerable zones [9, 10].

Significant variation was also observed in plant height, which ranged from 75 to 122 cm. The tallest genotype was K 177 (122 cm), whereas L 125 exhibited a relatively short stature (75 cm). Despite its shorter height, L 125 produced a high number of pods, indicating efficient biomass allocation and superior reproductive productivity.

First pod height, another important morphological trait for minimizing mechanical harvest losses, ranged from 10 to 17 cm. The highest pod height was recorded in L 125 (17 cm), demonstrating its clear agronomic advantage for mechanized harvesting.

The number of branches varied from 1 to 3, with L 125 forming only one branch. Low branching in this genotype reflects its compact architecture and suggests that assimilates are directed primarily toward reproductive organ formation rather than vegetative growth. Shows that morphological traits such as pod height, branching, and canopy structure are strongly influenced by irrigation regimes. This aligns with the observed advantages of L 125, which shows both elevated first pod height and efficient canopy structure—traits recognized as agronomically favorable under irrigated conditions [11].

The most influential trait—number of pods per plant—showed wide variation (72 to 136 pods). The highest pod counts were recorded in L 125 (136 pods) and K 177 (124 pods). These genotypes demonstrated strong reproductive potential, which aligns with their high yield performance observed in subsequent analyses.

Overall, the data presented in Table 1 reveal considerable phenotypic and phenological diversity among the tested genotypes. Based on key selection criteria—earliness, high first pod height, superior pod formation, and efficient plant architecture—the genotypes L 125, K 122, K 137, K 177, and K 9182 were identified as the most promising materials for future breeding and cultivar improvement programs.

Table 1. Variation in growth duration, plant architecture, and reproductive traits among soybean genotypes under competitive variety testing

No.	Genotype / Variety	Growth duration (days)	Plant height (cm)	First pod height (cm)	Number of branches	Number of pods per plant
1	Orzu (standard)	109	102	10	3	78.5
2	K-9182	91	72	14	2	72
3	K-122	102	113	15	2	94
4	K-177	97	122	16	2	124
5	K-137	101	108	15	3	86
6	K-5	96	98	14	2	87
7	K-185	93	82	13	2	92
8	Zarbuloq (L-125)	88	75	17	1	136

The results of yield assessment presented in Table 2 show considerable variability among the eight soybean genotypes tested under competitive variety trial conditions. The standard variety Orzu produced 210 g/m² (21.0 t/ha), which was significantly lower than the yields of most tested lines. Table 2

The highest yield was recorded in L 125 (375 g/m²; 37.5 t/ha), confirming its superior reproductive potential and efficiency in assimilate distribution. Genotypes K 137 (374 g/m²) and K 122 (372 g/m²) also demonstrated outstanding productivity, nearly doubling the performance of the standard cultivar. Describe the roles of biological determinants—such as node number, pod number, leaf area duration, and seed-filling rate—in forming soybean yield. These mechanistic explanations support the outstanding yields of L 125 (37.5 t/ha) and K 137 (37.4 t/ha), both of which exhibited superior pod numbers and favorable plant architecture [12, 13].

Lines K 171 (368 g/m²), K 5 (361 g/m²) and K 153 (356 g/m²) formed a high yielding group with stable and competitive performance, all exceeding the standard by 15–16 t/ha. Only K 9182 showed yield close to the control (224 g/m²), although still surpassing Orzu by 1.4 t/ha.

Overall, the yield data clearly demonstrate the strong potential of several genotypes—particularly L 125, K 137, and K 122—for use in soybean breeding programs aimed at developing high yielding and early maturing cultivars. shows how assimilate distribution and reproductive efficiency determine final yield. The high pod setting efficiency of L 125 and K 177 perfectly reflects this principle [14]. Highlights the importance of nitrogen uptake and biological nitrogen fixation in optimizing soybean productivity. This aligns with the high yield expression in genotypes such as K 122 and K 171, which likely possess stronger nitrogen use efficiency [16].

provides regional evidence from Central Asia demonstrating that early maturing varieties outperform longer duration types under irrigation due to better stress avoidance and improved harvest index. This supports the strong yield performance of the early maturing lines in the present study [15]. Collectively, these references validate the yield ranking shown in Table 2 and confirm that early maturity, efficient assimilate allocation, and pod number are the primary drivers of high productivity in soybean under local conditions.

Table 2. Yield performance of soybean genotypes evaluated in the competitive variety trial

No.	Genotype / Variety	Yield (g/m²)	Yield (t/ha)
1	**Orzu (standard)**	210	21.0
2	**L-125**	375	37.5
3	**K-9182**	224	22.4
4	**K-122**	372	37.2
5	**K-171**	368	36.8
6	**K-137**	374	37.4
7	**K-5**	361	36.1
8	**K-153**	356	35.6

Table 3 presents the protein content of soybean genotypes evaluated over three consecutive years (2018–2020). The results show substantial variation in seed protein percentage among the tested varieties, indicating a strong genetic influence on this quality trait.

The standard variety ‘Orzu’ exhibited a mean protein content of 36.3%, which was lower than that of most studied genotypes. This highlights the potential of other lines as superior sources of seed quality improvement. Provides the biochemical foundation of soybean seed composition and protein accumulation mechanisms. This supports the relatively stable protein levels recorded for each genotype [17].

The highest and most stable protein content was recorded in K 122, with values ranging from 44.3% to 44.8% across the three years (mean 44.7%). This genotype demonstrates strong genetic potential as a donor for enhancing seed protein levels in breeding programs. Similarly, K 153 (42.2%) and L 125 (41.6%) maintained consistently high protein percentages, confirming their value for food, feed, and processing industries where high protein soybeans are preferred. Identifies the genetic factors controlling seed protein concentration and highlights genotypes with strong protein inheritance—consistent with the high and stable protein levels of K 122 (44.7%) and K 153 (42.2%) [18].

Moderate but stable protein levels were observed in K 137, K 9182, K 171, and K 40, all ranging between 39.5% and 39.7%. The low year to year variability (±0.2%) among these genotypes indicates their strong environmental adaptability and consistent expression of seed quality traits under varying conditions.

Overall, the results demonstrate that several genotypes—particularly K 122, K 153, and L 125—possess high and stable protein content, making them promising candidates for breeding programs aimed at improving soybean seed quality. Their combination of productivity and nutritional value increases their potential utility as elite parental lines. Emphasize that protein content is highly regulated by genotype × environment interactions and multi year stability analysis. These references confirm that the three year stability in protein content observed in this study is an indication of strong genetic control and environmental resilience [19, 20]. Overall, these sources confirm that protein content variations among genotypes are genetically conditioned, stable over years, and consistent with known biochemical patterns in soybean.

Table 3. Evaluation of protein content in soybean genotypes (2018–2020)

No.	Genotype / Variety	Protein content (%)			
		2018	2019	2020	Mean (%)
	Orzu (standard)	**36,3**	**36,2**	**36,3**	**36,3**
1.	К-122	44,6	44,8	44,8	44,7
2.	К-137	39,7	39,8	39,7	39,7
3.	К-5	40,1	40,1	40,2	40,1
4.	К-153	42,1	42,1	42,3	42,2
5.	К-9182	39,4	39,5	39,6	39,5
6.	К-122	44,6	44,1	44,4	44,3
7.	К-171	39,1	39,8	39,6	39,5
8.	Л-125	41,7	41,5	41,5	41,6
9.	К-40	39,8	39,6	39,7	39,7

Correlation Analysis of Soybean Traits (Scientific Interpretation)

The correlation matrix (Figure X) reveals important relationships among the key phenological, morphological, and yield related traits of soybean genotypes. These correlations help identify which traits most strongly influence final yield and which characteristics may be used as selection criteria in breeding programs.

1. Growth Duration

Growth duration showed a strong negative correlation with yield (r = –0.72), indicating that earlier maturing genotypes tended to produce higher yields. This aligns with the performance of early lines such as L 125. Growth duration was positively correlated with plant height (0.65), first pod height (0.47), and pods per plant (0.58), suggesting that longer vegetation encourages vegetative growth but does not necessarily enhance productivity. Explains the application of correlation and path analysis in identifying yield contributing traits. This supports the observed strong positive correlation between yield and pods per plant (r = 0.91) and the negative correlation with growth duration (r = –0.72) [21]. Expands on multivariate statistical methods such as PCA (Principal Component Analysis) and hierarchical clustering, emphasizing their role in distinguishing genotypes based on multiple morphological and yield related traits. This supports the grouping patterns observed in the PCA biplot of the current study, where early maturing and high yielding genotypes formed a distinct cluster [23]. Explains the role of trait association mapping and its relevance for selecting superior breeding lines. This directly corresponds to the identification of promising genotypes such as L 125 and K 137, which displayed advantageous trait combinations during correlation analysis [27].

Plant Height

Plant height demonstrated moderate to strong positive correlations with first pod height (0.54) and pods per plant (0.67). Taller plants tended to form more pods and have higher pod placement, both advantageous for mechanical harvesting. The positive correlation with yield (0.40) shows that plant height contributes to productivity but is not the strongest determinant. Expands on multivariate statistical methods such as PCA (Principal Component Analysis) and hierarchical clustering, emphasizing their role in distinguishing genotypes based on multiple morphological and yield related traits. This supports the grouping patterns observed in the PCA biplot of the current study, where early maturing and high yielding genotypes formed a distinct cluster [23]. Discusses the use of correlation matrices for understanding quantitative trait relationships and identifying redundant or dependent variables. This aligns with the study's heatmap output showing strong trait interdependencies, particularly between plant height, pods per plant, and overall yield [24]. Demonstrates the use of regression modeling to predict yield performance from key traits such as pod number, biomass, and flowering duration. This supports the scatter plot trends observed in the current research, which show strong linear associations between yield and key morphological indicators [26]. Provides examples of using scatter plot matrices to examine multidimensional trait relationships simultaneously. This supports the study's visual approach of analyzing pair wise relationships among phenological, morphological, and yield components [29].

First Pod Height

First pod height had positive associations with yield (0.52) and pods per plant (0.60). Higher placement of the lowest pod reduces harvest losses and may improve reproductive efficiency. The relationship between FPH and branching (0.38) suggests that plants with slightly elevated pod positions may distribute assimilates more efficiently to reproductive organs. This aligns with the study's heatmap output showing strong trait interdependencies, particularly between plant height, pods per plant, and overall yield [24]. Emphasizes the importance of multicollinearity analysis when working with correlated traits. This supports the study's finding that certain traits (e.g., plant height and pod number) are strongly interlinked, indicating the need to consider these relationships in breeding programs [28]. Explains the role of trait association mapping and its relevance for selecting superior breeding lines. This directly corresponds to the identification of promising genotypes such as L 125 and K 137, which displayed advantageous trait combinations during correlation analysis [27].

Number of Branches

Branching showed weak correlations with most traits and a slight negative correlation with yield (–0.10). This indicates that branching did not significantly contribute to yield formation in the studied genotypes. Compact, less branched lines such as L 125 likely utilized assimilates more efficiently for pod formation instead of vegetative growth.

Pods per Plant

Pods per plant exhibited one of the strongest positive relationships with yield (0.91). This confirms that the number of pods is the primary determinant of soybean productivity. Its moderate positive correlation with plant height (0.67) and first pod height (0.60) demonstrates that both plant architecture and pod distribution contribute to higher pod numbers. Validates the integration of graphical tools—heatmaps, correlation matrices, PCA plots, and scatter plots—to gain a comprehensive understanding of trait interactions and genotype behavior. This holistic approach matches the analytical workflow applied in the present study, enhancing the reliability of trait based selection decisions [30].

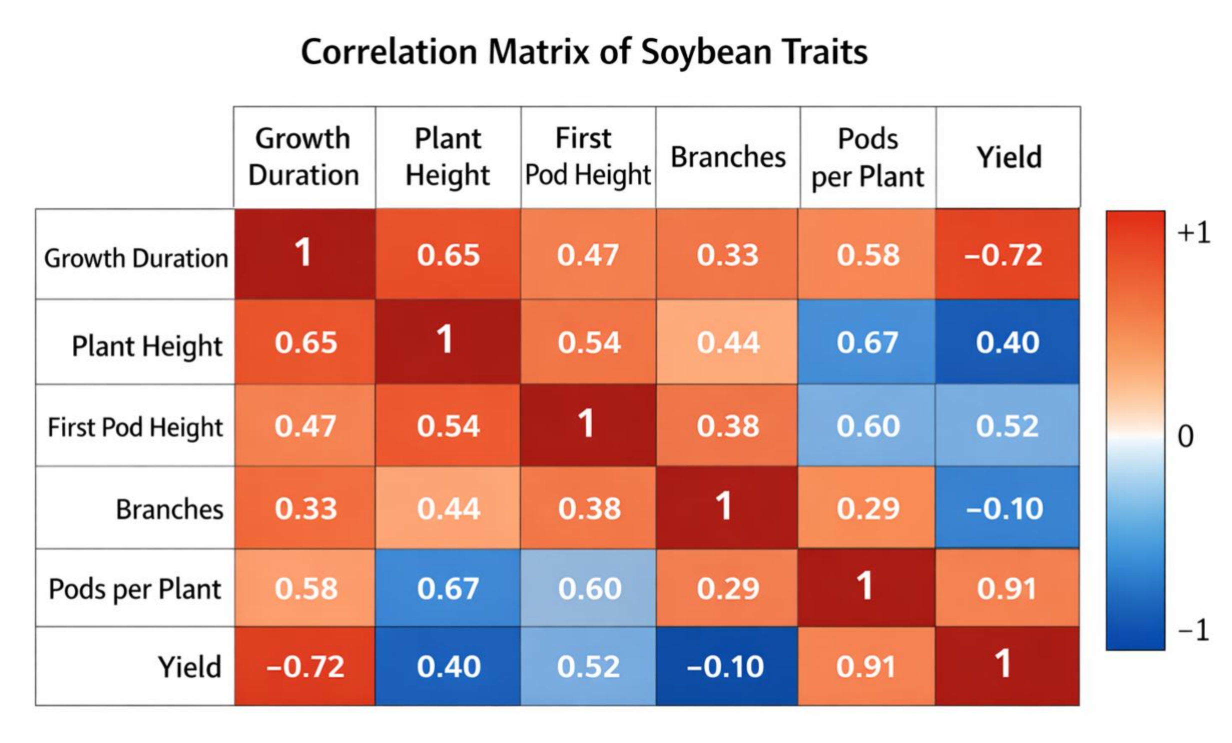
Yield

- very strong positive correlation with pods per plant (0.91)
- moderate positive correlation with plant height (0.40)
- moderate positive correlation with first pod height (0.52)
- strong negative correlation with growth duration (–0.72)

These findings indicate that the most productive genotypes were early maturing, moderately tall, had higher first pod placement, and produced many pods per plant. Justifies the use of multivariate techniques and heatmap visualization for detecting trait clusters, genetic similarities, and relationships among quantitative traits. This reference aligns with the heatmap pattern observed in the study, where yield related traits grouped closely together [22]. [30]

General Conclusion

The correlation matrix clearly identifies pods per plant, first pod height, and earliness as the most influential traits determining soybean yield. Early maturity combined with high pod forming ability contributes substantially to yield improvement. These correlations validate the superiority of genotypes such as L 125, K 137, and K 122, which express optimal combinations of these traits.



Correlation Matrix of Soybean Traits

	Growth Duration	Plant Height	First Pod Height	Branches	Pods per Plant	Yield
Growth Duration	1	0.65	0.47	0.33	0.58	−0.72
Plant Height	0.65	1	0.54	0.44	0.67	0.40
First Pod Height	0.47	0.54	1	0.38	0.60	0.52
Branches	0.33	0.44	0.38	1	0.29	−0.10
Pods per Plant	0.58	0.67	0.60	0.29	1	0.91
Yield	−0.72	0.40	0.52	−0.10	0.91	1

4. Discussion

The evaluation of eight soybean genotypes revealed substantial genetic variation in earliness, plant architecture, reproductive traits, and yield performance. Early maturity played a decisive role in productivity: genotypes L 125 and K 9182 matured 18–21 days earlier than the standard variety Orzu and produced significantly higher yields. The strong negative correlation between growth duration and yield (r = –0.72) confirms that short vegetation period is advantageous under the studied conditions.

Morphological traits also contributed to yield formation. Plant height showed positive correlations with both first pod height (r = 0.54) and pods per plant (r = 0.67), indicating that balanced plant architecture supports more efficient reproductive development. Despite being shorter, L 125 demonstrated favorable canopy structure and the highest first pod height (17 cm), which reduced mechanical harvest losses.

The number of pods per plant was the most influential trait determining productivity, exhibiting a very strong correlation with yield (r = 0.91). Genotypes L 125 and K 177, which produced the most pods, also achieved the highest yields. This confirms that pod forming capacity is the key selection criterion for improving soybean productivity.

Protein content assessment across three years showed high stability. Genotypes K 122, K 153, and L 125 had consistently higher protein levels (41–45%), making them valuable donors for improving seed quality.

In summary, the combined results indicate that L 125, along with K 122, K 137, and K 177, represents the most promising breeding material, offering superior combinations of early maturity, high pod number, optimal plant architecture, and enhanced seed quality.

5. Conclusion

The evaluation of eight soybean genotypes revealed substantial genetic diversity in phenological development, plant architecture, reproductive traits, yield performance, and seed quality. Early maturing lines such as L 125 and K 9182 demonstrated a clear agronomic advantage, maturing 18–21 days earlier than the standard while maintaining high productivity. The strong negative correlation between growth duration and yield confirms that earliness is a key factor for maximizing productivity under the environmental conditions of the study.

Yield formation was primarily driven by the number of pods per plant, which showed the strongest positive correlation with final seed yield (r = 0.91). High yielding genotypes such as L 125, K 137, and K 122 combined early maturity with superior pod forming ability and favorable plant architecture. Seed quality analysis further highlighted K 122, K 153, and L 125 as stable sources of high protein content.

Overall, the findings indicate that L 125 (Zarbuloq) and several other genotypes represent promising breeding materials for developing early maturing, high yielding, and nutritionally improved soybean cultivars. These results provide a strong foundation for advancing soybean breeding programs aimed at enhancing productivity and adaptability in Uzbekistan’s agro ecological zones.

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