



Evaluating the Effects of Seeding Rate on Agronomic Traits of 'Katran' Chickpea (*Cicer arietinum* L.) Using Principal Component Analysis

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Abstract

Establishing an optimal plant population is a critical factor for maximizing seed yield in chickpea (*Cicer arietinum* L.). This study was conducted to determine the influence of six seeding rates (100 to 350 kg ha⁻¹) on yield and its components in the 'Katran' chickpea cultivar and their correlation. A field experiment was carried out during the 2023-2024 growing season in Kahramanmaraş, Türkiye, using a randomized complete block design. Principal Component Analysis (PCA) of seven key agronomic traits revealed that the first three principal components (PCs) accounted for 80.14% of the total variation. PC1, termed "Plant Vigor and Architecture," identified a clear trade-off between vegetative growth (e.g., plant height) and seed size (100-seed weight). PC2, "Pod Set Strategy," was primarily driven by the number of pods per plant. Crucially, PC3, "Yield Realization," was strongly and positively correlated with seed yield, indicated that yield was a distinct trait independent of plant size or pod count. The findings concluded that high seeding rates promoted vegetative growth at the expense of seed size. That optimal yield in 'Katran' chickpea was achieved not by maximizing number of pods per plant, but by balancing plant competition to support a moderate number of well-filled pods per plant.

Research Article

Article History

Received :17.08.2025
Accepted :30.09.2025

Keywords

Cicer arietinum L.
plant density
yield components
multivariate analysis
biplot

1. Introduction

Chickpea (*Cicer arietinum* L.) is a cornerstone of global food security, ranking among the world's most crucial seed legume crops. It provides an affordable, high-quality source of dietary protein, essential minerals, and fiber for millions of people, particularly in the semi-arid regions of Asia and Africa (Gaur et al., 2012). Beyond its nutritional value, chickpea plays a vital role in sustainable agricultural systems through its symbiotic nitrogen fixation, which enhances soil fertility and reduces the need for synthetic fertilizers, making it an ideal component in crop rotation systems (Stagnari et al., 2017). To meet the demands of a growing global population, enhancing chickpea productivity is a primary agricultural goal. Seed yield is a complex quantitative trait resulting from the interaction between the plant's genetic potential and the production environment, which is heavily influenced by agronomic management practices. Among these practices, establishing an optimal plant population density through an appropriate seeding rate is paramount for maximizing yield (Seyedi and Hamzei, 2022). Sub-optimal plant densities fail to efficiently exploit available resources, leading to lower yields and increased weed pressure. Conversely, excessive plant densities can trigger intense intraspecific competition for light, water, and nutrients, often resulting in increased lodging, reduced branching and pod set, and a lower harvest index, thereby negating the potential benefits of a higher plant count (Nleya and Rickertsen, 2013). Consequently, identifying the optimum seeding rate for specific cultivars in their target environments remains a critical research objective. The final seed yield in chickpea is determined by the cumulative effect and interplay of several yield components, including plant height, the number of branches per plant, pods per plant, and seed weight.

Understanding the complex interrelationships among these traits is essential for developing effective management strategies. Principal Component Analysis (PCA) is a powerful multivariate statistical technique that can effectively dissect these complex relationships. By transforming a set of correlated variables into a smaller set of uncorrelated principal components, PCA helps identify the key traits that account for the majority of the variation in a dataset, providing valuable insights into the data's underlying structure (Mohammadi and Prasanna, 2003). This method has been successfully employed in chickpea and other crops to evaluate genetic diversity and identify key selection criteria for yield improvement (Farshadfar and Farshadfar, 2008; Traoré et al., 2022). This study was, therefore, undertaken to (i) determine the effects of six different seeding rates on the seed yield and major yield components of the 'Katran' chickpea cultivar, and (ii) to utilize principal component analysis to elucidate the correlation among these agronomic traits and identify the primary sources of variation influenced by plant population density.

2. Material and Methods

2.1. Experimental site, plant material, and growing conditions

The field experiment was conducted during the 2023-2024 growing season (Chickpeas Planting December 27, 2023 - Harvest June 20, 2024) at the experimental field of the Faculty of Agriculture, Kahramanmaraş Sutcu Imam University, Kahramanmaraş, Türkiye. The chickpea cultivar 'Katran', a registered and commonly cultivated local variety, was used as the plant material. Meteorological data and soil properties of the experimental site were shown in Tables 1 and 2.

Table 1. Soil properties

Variables	OM	PR	AW	FC	BD	Lime	Mn	Zn	Fe	P
Unit	%	MPa	%	%	g/cm ³	%	ppm	ppm	ppm	ppm
Average	2.32	1.58	11.77	28.40	1.38	14.20	5.50	0.60	9.60	7.20

*OM: Organic matter, PR: Penetration resistance, AW: Available water, FC: Field capacity, BD: Bulk density

Table 2. Meteorological Data of Kahramanmaraş (Long-term 1930-2024) (Anonymous, 2025)

Data Type	December	January	February	March	April	May	June
Average Temp. (°C)	6.70	4.80	6.30	10.40	15.20	20.10	25.00
Average Sunshine Dur. (hours)	3.20	3.30	4.00	5.30	6.60	8.10	10.00
Average Number of Rainy Days	9.88	10.15	10.31	10.11	9.08	6.76	2.03
Monthly Total Precip. (mm)	130.60	124.00	112.20	95.10	73.00	38.80	8.60

2.2. Experimental design and treatments

The experiment was laid out in a randomized complete block design (RCBD) with three replications. The treatments consisted of six seeding rates: 10, 15, 20, 25, 30, and 35 kg da⁻¹ (equivalent to 100, 150, 200, 250, 300, and 350 kg ha⁻¹). Each plot consisted of four rows, each 5 m long, with an inter-row spacing of 50 cm, resulting in a plot area of 10 m². Seed sowing was performed manually. Standard regional agronomic practices for weed and pest management were applied uniformly across all treatments.

2.3. Data collection

At physiological maturity, five plants were randomly selected from the two central rows of each plot to measure the following traits: plant height (cm), first pod height (cm), number of branches per plant, and number of pods per plant. For seed yield determination, the two central rows of each plot were harvested manually to avoid border effects. The harvested material was threshed, and the seed was cleaned and weighed. The final seed yield was calculated and adjusted to kilograms per hectare (kg ha⁻¹). The 100-seed weight (g) was determined by weighing 100 randomly sampled seeds from each plot's harvest.

2.4. Statistical analysis

A Principal Component Analysis (PCA) was performed on the collected data (SPSS 20 software package). The analysis was based on a pearson correlation matrix generated from

standardized data for the effects of different measurement units. The objective of the PCA was to identify the principal components contributing most significantly to the total variance and to visualize the interrelationships between seeding rates and the measured agronomic traits (Mohammadi and Prasanna, 2003).

3. Findings and Discussion

3.1. Principal component analysis (PCA)

Principal Component Analysis was performed to identify the patterns of variation and determine the traits that contributed most to the dataset's variability. The analysis extracted seven principal components (PCs). Based on the Kaiser criterion (eigenvalue >1.0), the first three PCs were deemed significant for interpretation. The eigenvalues, percentage of variance explained, and cumulative variance for these first three principal components are presented in Table 3. The first principal component (PC1) had an eigenvalue of 2.45 and accounted for 35.03% of the total variation. The second principal component (PC2) had an eigenvalue of 2.16, explaining an additional 30.79%. The third principal component (PC3) had an eigenvalue of 1.00 and explained a further 14.31% of the variation. Together, these three components accounted for 80.14% of the total variation, confirming that they effectively summarized the vast majority of the information in the original dataset.

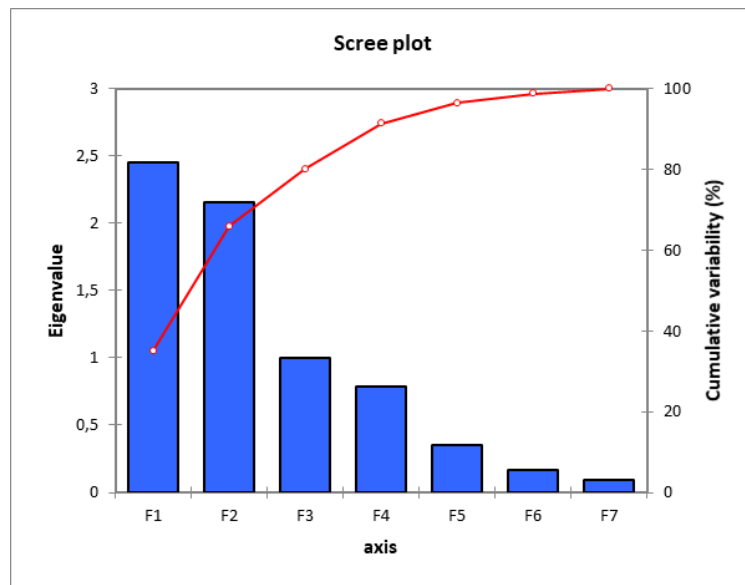


Figure 1. Scree plot of the eigenvalues for the seven principal components. The plot shows a apparent "elbow" after the third component, and only the first three components have an eigenvalue greater than 1.0 (Kaiser criterion), justifying their retention for analysis.

As shown in Figure 1, only the first three components have an eigenvalue greater than 1.0, and a apparent "elbow" in the plot is observed at the third component, after which

the explained variance by subsequent components diminishes sharply. Therefore, these three components were retained for further analysis.

Table 3. Eigenvalues, variability, and cumulative variance explained by the first three principal components

Component	Eigenvalue	% of Variance	Cumulative %
PC1	2.45	35.03	35.03
PC2	2.16	30.79	65.82
PC3	1.00	14.31	80.14

The loadings of the original variables on the first three principal components are shown in Table 4. These loadings represent the correlation between the variables and the components and are crucial for interpreting the components. PC1 was strongly and positively correlated with Plant Height (0.84), First Pod Height (0.78), and Stem Diameter (0.67), while showing a strong negative correlation with 100-Seed Weight (-0.77). Therefore, PC1 can be interpreted as a "Plant Vigor and Architecture" component, representing a trade-off between vegetative growth and seed size. PC2 was dominated by a robust positive correlation with Pod Number per Plant (0.90).

It also showed a moderate positive correlation with Stem Diameter (0.54) and negative correlations with Pod Diameter (-0.63) and First Pod Height (-0.52). This component can be defined as a "Pod Set Strategy" component, highlighting the plant's allocation of resources towards the quantity of reproductive structures. PC3 was most strongly associated with Seed Yield (0.79). It also had a moderate positive correlation with Stem Diameter (0.39) and 100-Seed Weight (0.35). This component can be clearly interpreted as the "Yield Realization" component, directly representing the factors that translate into the final harvested yield.

Table 4. Variable loadings (correlations) on the first three principal components

Variable	PC1	PC2	PC3
Plant Height (cm)	0.84	-0.36	0.20
First Pod Height (cm)	0.78	-0.52	-0.09
Pod Diameter (mm)	-0.29	-0.63	-0.05
Stem Diameter (mm)	0.67	0.54	0.39
Pod Number per Plant	0.09	0.90	0.22
100-Seed Weight (g)	-0.77	0.01	0.35
Seed Yield (kg da ⁻¹)	-0.16	-0.52	0.79

The biplot in Figure 2 provided a clear visualization of the relationships described by the first two principal components, which account for 65.82% of the total variance. The first component, PC1 (the horizontal axis), clearly separates traits related to plant architecture from those related to seed size. The vectors for Plant Height, First Pod Height, and Stem Diameter were clustered together on the positive side of PC1, and the acute angles between them confirm their strong positive correlations. In direct opposition, the vector for 100-Seed Weight was located on the negative side, visually representing the trade-off

between vegetative vigor and seed filling. The second component, PC2 (the vertical axis), was dominated by the Pod Number per Plant vector, indicating that this trait lies on a different axis of variation from plant size. The nearly perpendicular (90-degree) angle between the Pod Number and Plant Height vectors indicates that these two traits were largely uncorrelated in this dataset. This visual evidence strongly supports our interpretation that maximizing yield in 'Katan' chickpea is not a simple function of plant size or pod count alone, but a more complex interplay of the factors revealed in the analysis.

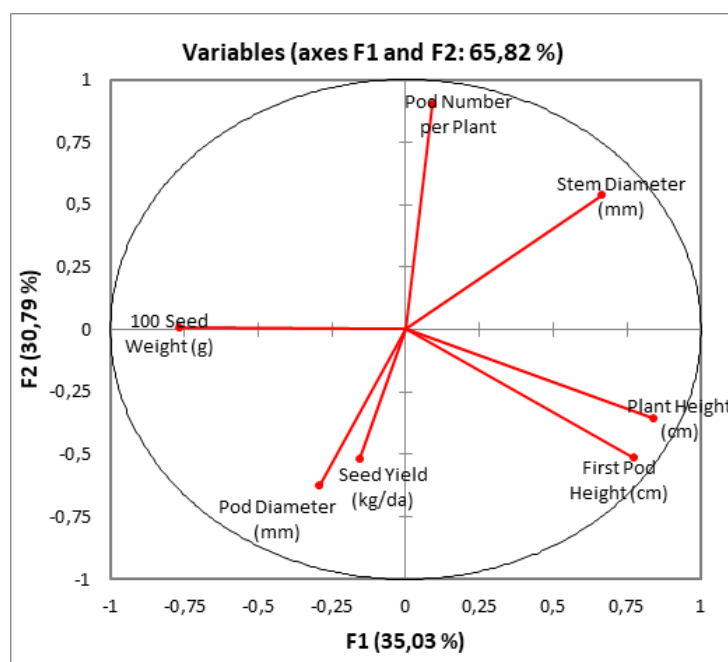


Figure 2. Principal Component Analysis (PCA) biplot of seven agronomic traits based on the first two principal components (PC1 and PC2), which collectively explain 65.82% of the total variation. The vectors represent the variable loadings. The plot illustrates the strong positive correlation between Plant Height, First Pod Height, and Stem Diameter, and their opposition to 100-Seed Weight along the PC1 axis. PC2 is primarily driven by Pod Number per Plant, showing its distinct role in the dataset.

3.2. Discussion

The results of the Principal Component Analysis provide a comprehensive view of the complex interrelationships among agronomic traits in the 'Katran' chickpea cultivar. The fact that the first three PCs accounted for over 80% of the total variation confirms that PCA was an effective tool for data reduction and interpretation (Yücel et al., 2006; Upadhyaya et al., 2007; Kushwah et al., 2022). The first component (PC1), "Plant Vigor and Architecture," reveals a fundamental trade-off in resource allocation. The strong positive association among plant height, stem diameter, and first pod height indicates a unified vegetative growth strategy. However, the strong inverse relationship with 100-seed weight on this same axis is particularly revealing. It suggests that conditions promoting vigorous vegetative growth may come at the cost of seed filling, resulting in smaller seeds. This phenomenon, in which increased competition can lead to taller plants and smaller seeds due to resource limitation, is a well-documented trade-off in legumes, governed by principles of resource allocation between vegetative and reproductive structures (Weiner et al., 2009). For instance, studies on soybeans have shown that increased plant density enhances competition for light, resulting in taller plants but a significant reduction in individual seed weight as resources are diverted (Board et al., 1992). This highlights a classic source-sink competition within the plant. This highlights a classic source-sink competition within the plant (Borrás et al., 2004). The second component (PC2), "Pod Set Strategy," is almost entirely driven by the number of pods per plant. While many studies on chickpea establish that the number of pods per plant is often the most critical determinant of final seed yield (Farshadfar and Farshadfar, 2008; Nikita and Lal, 2022), our analysis suggests a more nuanced relationship for the 'Katran' cultivar. In our findings, PC2, which is dominated by pod number, is negatively correlated with seed yield (-0.52). This indicates that simply maximizing the number of pods may not lead to higher yields and could even be detrimental.

The positive association between PC2 and stem diameter suggests that a robust stem is a prerequisite for supporting a large number of pods, but this high pod load appears to create an excessive sink strength that the plant cannot adequately supply, ultimately reducing the overall harvested yield (Leport et al., 1999). Most critically, the third component (PC3), "Yield Realization," isolates seed yield as a distinct factor. The fact that seed yield has its highest loading (0.79) on this separate component is a key finding. It implies that final yield is not a simple function of being a large plant (PC1) or having many pods (PC2) (Sinclair, 1999). Instead, it is a more complex trait influenced by a different combination of factors. The positive loadings of stem diameter and 100-seed weight on this component suggest that a sturdy plant structure capable of supporting development and the ability to produce heavier, well-filled seeds are the more direct contributors to realizing a high final yield.

4. Conclusion

This study successfully employed Principal Component Analysis to deconstruct the complex agronomic traits of the 'Katran' chickpea cultivar. The analysis effectively reduced the data's complexity into three significant, interpretable components "Plant Vigor and Architecture," "Pod Set Strategy," and "Yield Realization" which collectively explained 80.14% of the total observed variation. The findings revealed distinct and sometimes competing biological strategies. A clear trade-off was identified between vegetative growth and seed size (PC1). Furthermore, the strategy of producing a high number of pods (PC2) was found to be separate from, and even negatively correlated with, the final seed yield. The most crucial conclusion is that seed yield in 'Katran' chickpea is a distinct trait (PC3), not merely a direct outcome of plant size or pod quantity. While a robust stem and good seed-filling capacity (100-seed weight) are beneficial, an excessive number of pods appears to be counterproductive, likely due to intraspecific competition that hinders

the development of all seeds to their full potential. Therefore, the optimal strategy for maximizing yield is not simply selecting for the highest pod count, but rather achieving a balance between a healthy plant architecture and a moderate number of pods that the plant can adequately support and fill.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

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To Cite

Kara, Z., Yürürdurmaz, C., Çokkızgın, A., 2025. Evaluating the Effects of Seeding Rate on Agronomic Traits of 'Katran' Chickpea (*Cicer arietinum* L.) Using Principal Component Analysis. *ISPEC Journal of Agricultural Sciences*, 9(4): 1106-1113.
DOI: <https://doi.org/10.5281/zenodo.17885934>.
