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***Research Article***

# Genotype and Environment Interaction Identifies Stable High-Yielding and Pod Borer-Resistant Chickpea Genotypes for Sustainable Production

Sarbaz Khan[1,2], Rozina Gul[2*], Hamayoon Khan[3], Husnain Arif[2], Furqan Alam[2], Sada Bahar[4], Sheryar Khan[5], Asfandyar Khan[6]

[1]School of Tropical Agriculture and Forestry, Sanya Institute of Breeding and Multiplication, Hainan University, Sanya 572025, China.
[2]Department of Plant Breeding and Genetics, Faculty of Crop Production, The University of Agriculture, Peshawar 25130, Pakistan.
[3]Department of Climate Change Sciences, The University of Agriculture, Peshawar 25130, Pakistan.
[4]Directorate of Outreach, Agriculture Research System, Peshawar, Khyber Pakhtunkhwa 25000, Pakistan.
[5]Department of Plant Breeding and Genetics, Faculty of Biological and Health Sciences, Hazara University, Dhodial, Mansehra 21120, Pakistan.
[6]Department of Horticulture, Faculty of Crop Production, The University of Agriculture 25130, Peshawar, Pakistan.

[*]Correspondence: (Rozina Gul), rozinagul@aup.edu.pk

**Abstract**

Chickpea (*Cicer arietinum* L.) is an important legume crop valued for its nutritional quality and adoption to diverse agroecological conditions. The present study evaluated 44 chickpea genotypes, comprising 40 advanced lines and four local check cultivars, under insecticide-treated and untreated pod-borer management conditions, during the 2022–23 cropping season. The experiment was conducted using a randomized complete block design with three replications. Analysis of variance revealed highly significant ($P \leq 0.01$) genotypic and genotype × pest-management interactions for most studied traits, indicating differential genotype responses to pod-borer management conditions. Pest-management effects were significant for days to 50% flowering, days to 90% maturity, and plant height, while pod damage and seed yield also differed markedly between treated and untreated conditions. D-15005 showed the earliest flowering (105.5 days), D-14014 reached maturity earliest (164.8 days), and K-11051 recorded the greatest plant height (73.3 cm). D-14005 exhibited the lowest pod damage (5.08%), indicating strong pod-borer resistance. D-11030 showed the highest biological yield (5903.7 kg $ha^{-1}$) and seed yield (2518.5 kg $ha^{-1}$) and maintained superior performance across both management conditions, particularly for productive branches, pods per plant, and seed yield. Insecticide-treated conditions reduced mean pod damage from 19.27% to 7.00% and increased mean seed yield to 1865.4 kg $ha^{-1}$. High heritability was observed for days to 50% flowering, pods per plant, and plant height under both management conditions, whereas high genetic advance was recorded for biological and seed yield. Based on yield performance, stability across contrasting pest-management conditions, and pod-borer resistance, D-11030, D-14005, K-01153, K-01213, and K-70009 were identified as promising genotypes for chickpea improvement and sustainable production.

**Keywords:** Chickpea, Genotype x environment interaction, *Helicoverpa armigera*, pod-borer resistance, Seed yield, Genetic Stability.

## 1. Introduction

*Cicer arietinum* L. (chickpea) is an annual diploid species ($2n = 2x = 16$) belonging to the family Fabaceae and subfamily Faboideae. It is also known as garbanzo bean, gram, Bengal gram, or chana and is one of the oldest and most widely cultivated food legumes worldwide. Chickpea is predominantly self-pollinated, with natural outcrossing occurring at low frequencies under field conditions, mainly through insect-mediated pollination [1]. According to the Food and Agriculture Organization of the United Nations (FAO) [2], chickpea ranks as the third most important pulse crop globally, after dry beans and peas. The crop was domesticated in the Fertile Crescent, particularly in southeastern Türkiye and northern Syria, with archaeological evidence dating back to approximately 7500–6800 BCE [3]. It subsequently spread to the Mediterranean region, South Asia, Central Asia, Africa, and other regions. In 2023, chickpea was cultivated on approximately 14.1 million hectares worldwide, producing about 16.5 million tonnes at an average productivity of 1.17 t $ha^{-1}$ [4]. FAOSTAT provides global crop production, harvested-area, and yield statistics. India is the leading chickpea-producing country, followed by Australia, Türkiye, the Russian Federation, Myanmar, Ethiopia, and Pakistan. Chickpea production is therefore concentrated mainly in South Asia and other semi-arid production regions.

Chickpea is also an important pulse crop in Pakistan. During 2020–21, it was cultivated on approximately 0.94 million hectares, producing about 0.49 million tonnes at an average yield of 521 kg $ha^{-1}$ [5]. Production is concentrated in rainfed areas, particularly in Punjab and the southern districts of Khyber Pakhtunkhwa (KP). In southern KP, chickpea is commonly cultivated in Tank, Lakki Marwat, Bannu, Dera Ismail Khan, and Karak [6].

Chickpea is broadly classified into two market types, Desi and Kabuli, based mainly on seed size, shape, colour, and seed-coat characteristics [7]. Desi chickpea generally has small seeds with a thick, pigmented seed coat, whereas Kabuli chickpea has larger seeds with a thin, cream-coloured to beige seed coat. The two types also differ in flower colour; Kabuli chickpea typically produces white flowers, whereas Desi chickpea produces pink to purple flowers due to anthocyanin pigmentation [7]. Chickpea develops a relatively deep root system, which contributes to its adaptation to water-limited environments. However, its productivity is constrained by several biotic and abiotic stresses, including fungal diseases such as Fusarium wilt and Ascochy blight [8]. Chickpea is an important source of plant-based protein, carbohydrates, dietary fiber, and minerals, particularly in regions where pulses are a major component of the human diet [9–11]. Its high nutritional value and relatively low production cost make it an important food legume in Pakistan and other chickpea-producing regions. However, chickpea production is frequently limited by insect pests, among which the gram pod borer, Helicoverpa armigera (Hübner), is one of the most damaging [12]. The larvae preferentially feed on reproductive structures, including flowers and developing pods, causing direct damage to seeds and reducing yield and seed quality [13,14]. Severe infestations can cause yield losses of up to 75–90%, depending on genotype, environmental conditions, and pest pressure [15]. These substantial losses highlight the need for host-plant resistance and effective, environmentally sustainable pest-management strategies [16]. However, the expression of yield and resistance-related traits can vary across environments and management conditions because of genotype × environment (G × E) interactions [17,18]. Such interactions complicate the identification of stable and widely adapted genotypes but can also provide valuable information for selecting genotypes with specific adaptation to target environments [19].

Therefore, evaluating genotypes under contrasting pest-management conditions can help distinguish genetic performance from responses associated with pest pressure and management. Therefore, the present study was undertaken to investigate genotype × pest-management interactions in chickpea under two contrasting pod-borer management conditions. The study evaluated chickpea genotypes for pod-borer damage under untreated conditions and for yield and yield-related traits under both management conditions. The objective was to identify genotypes combining reduced pod-borer damage with high yield potential. In addition, the heritability of yield and yield-related traits was estimated under both management conditions to assess the genetic contribution to trait variation.

## 2. Materials and Methods

### 2.1. Experimental site

The experiment was conducted at the research farm of the University of Agriculture, Peshawar, Pakistan (34.01° N latitude and 71.47° E) during the 2022-2023 chickpea growing season. The experimental soil was clay-textured, with a pH of 8.2, organic matter content of 0.87%, and available phosphorous (P), and Potassium (K) contcentrations of 6.57 and121 mg kg $^{-1}$, respectively. During the growing season, mean monthly temperatures ranged from 11 to 23.7°C, and total rainfall was approximately 165mm. Chickpea was sown in October and harvested in March. Fertilizers were applied according to the recommended agronomic practices for chickpea, with approximately 25–30 kg N ha$^{-1}$ and 60 kg P ha$^{-1}$ applied. Irrigation was provided 2-3 times by flood irrigation according to crop requirements. The experiment comprised two contrasting pod-borer management environments established at the same location during the same growing season. One environment received insecticide applications for pod-borer control, whereas the other remained untreated throughout the growing season. This design enable the evaluation of genotype performance under contrasting levels of pod-borer management.

### 2.2. Experimental design

Forty-four chickpea genotypes, comprising 40 advanced lines and four check varieties, were evaluated under the two contrasting pest management conditions. The detail of genotypes are mentioned in (Table 1). The experiment was sown during the third week of October 2022 and arranged in a randomized complete block design (RCBD) with three replications. Each genotype was planted in three rows, with a row length of 3 m and row-to-row and plant-to-plant spacings of 30 and 10 cm, respectively. During the pod-development stage, one management condition received Coragen insecticide for pod-borer control, whereas the other remained untreated. All genotypes in both management conditions received identical cultural and agronomic practices, including hoeing and weeding, from sowing to harvest. Thus, the two management conditions differed only in pod-borer control, allowing genotype performance to be compared under insecticide-treated and untreated conditions at the same location and during the same growing season. These conditions therefore represent contrasting pest-management environments rather than multilocation or multiyear environments.

### 2.3. Data collection

Days to 50% emergence were recorded from the date of sowing until 50% of the seeds in each entry had emerged. Days to 50% flowering were determined by visual observation, recording the number of days from sowing until 50% of the plants in each entry produced their first flower. Days to 90% physiological maturity were recorded as the number of days from planting until approximately 90% of the plants became yellowish or brown and reached physiological maturity. Plant height (cm) was measured on five randomly selected plants from each entry before maturity by measuring the distance from the plant base to the topmost leaf using a meter stick, and the mean value was calculated for each entry. The number of productive branches plant$^{-1}$ was determined by counting the primary and secondary productive branches of the selected plants, and the average number was calculated. Similarly, the number of pods $plan^{-1}$ was determined by collecting and counting all pods from five randomly selected plants after harvesting, followed by calculation of the mean. The number of seeds $pod^{-1}$ was determined from five randomly selected plants by counting the seeds in the pods, and the average number of seeds $pod^{-1}$ was calculated for each entry. Larval count $plant^{-1}$ was determined by randomly selecting five plants from each plot and counting the larvae present on the plants on a weekly basis; the average larval population was then calculated for each entry.

**Table 1.** Chickpea genotypes evaluated during 2022-23.

| Genotypes | Source | Genotypes | Source | Genotypes | Source |
|---|---|---|---|---|---|
| D-08625 | AARI | D-15020 | AARI | K-14014 | AARI |
| D-09027 | AARI | D-15036 | AARI | K-60066 | AARI |
| D-10008 | AARI | D-93127 | AARI | K-60069 | AARI |
| D-10039 | AARI | D-97086 | AARI | K-60075 | AARI |
| D-11030 | AARI | K-01151 | AARI | K-70009 | AARI |
| D-12011 | AARI | K-01153 | AARI | K-600508 | AARI |
| D-13011 | AARI | K-01155 | AARI | K-CH-47/04 | AARI |
| D-13012 | AARI | K-01158 | AARI | K-FLIP-82-15 | AARI |
| D-13031 | AARI | K-01208 | AARI | NKC(5-5-20) | NIFA |
| D-13036 | AARI | K-01209 | AARI | NKC(10-99) | NIFA |
| D-14005 | AARI | K-01210 | AARI | KARAK-1 | ARSAK |
| D-15005 | AARI | K-01213 | AARI | KARAK-2 | ARSAK |
| D-15012 | AARI | K-08003 | AARI | KARAK-3 | ARSAK |
| D-15015 | AARI | K-08817 | AARI | NIFA-2005 | NIFA |
| D-15018 | AARI | K-08021 | AARI | | |

Pod damage (%) was assessed by randomly selecting five plants from the standing crop at physiological maturity. The percentage of damaged pods was calculated according to equation 1 [20]:

$$Pod\ damaged\ (\%) = \frac{Number\ of\ damaged\ pods}{Number\ of\ total\ pods} \times 100 \quad (1)$$

The 100-seed weight (g) was determined by randomly counting 100 seeds from the total produce of each genotype and weighing them using a digital balance. Biological yield (BY) (kg $ha^{-1}$) was determined by harvesting the entire plants, including pods, at the appropriate stage of maturity. The harvested material was sun-dried for seven consecutive days, after which the biological yield per plot was recorded and converted to kg $ha^{-1}$ according to equation (2):

$$BY(Kg\ ha^{-1}) = \frac{\text{BY per plot}}{\text{Plot area m}^{-2}} \times 100m^{-2} \quad (2)$$

Where BY indicate biological yield.

Grain yield (kg $ha^{-1}$) was calculated by converting the grain weight obtained from each plot to a hectare basis using equation (3):

$$GY(Kg\ ha^{-1}) = \frac{GY\ per\ plot}{Plot\ area\ m^{-2}} \times 100m^{-2} \quad (3)$$

Where BY indicate biological yield.

Harvest index (HI) was calculated as the ratio of grain yield to biological yield and expressed as a percentage according to equation (4):

$$HI(\%) = \frac{GY\ per\ plot}{BY\ per} \times 100 \quad (4)$$

Where HI indicate harvest index, GY indicate grain yield and BY indicate biological yield.

### 2.4 Statistical analysis

The collected data for the studied traits were analyzed across the two pest-management environments (Table 2) to assess genotype × environment (G × E) interactions. Analysis of variance (ANOVA) was performed for all traits following the procedure described by Gomez et al. [21]. Differences among genotype means for yield and yield-related traits were compared using the least significant difference (LSD) test at the 5% probability level, following Steel and Torrie [22] Broad-sense heritability was estimated by the method described by Allard et al. [23]. The $h^2$ was calculated by using equation 5.

$$h^2_{B.S} = Vg/Vp \times 100 \quad (5)$$

where Vg is the genetic variance and Vp is the phenotypic variance. The genetic variance (Vg) was estimated from the genotype mean square and error mean square obtained from the ANOVA using equation 6.

Genetic variance (Vg) = GMS-EMS/r (6)

where GMS is the genotype mean square, EMS is the error mean square, and r is the number of replications. Environmental variance (Ve) was estimated from the error mean square using equation 7.

Environmental variance (Ve) = EMS (7)

Phenotypic variance (Vp) was calculated as the sum of genetic variance (Vg) and environmental variance (Ve) using equation 8.

*Phenotypic variance (Vp) = Vg + Ve* (8)

Heritability estimates were classified as low (≤30%), moderate (>30% to <60%), and high (≥60%).

Genetic advance (GA) was estimated for each trait using the method described by Johnson et al. [24]. Genetic advance under selection was calculated using Equation (9)

$$GA = i \times \sigma p \times h^2 \quad (9)$$

Where; k = Selection Intensity, σp = Phenotypic standard deviation, $h^2$ (b.s) = Broad sense heritability

σp = phenotypic standard deviation, calculated as the square root of phenotypic variance (σp = √V )

This definition is directly consistent with the genetic advance equation $GA = i \times \sigma p \times h^2$, where σp represents the phenotypic standard deviation [25].

# 3. Results

## 3.1. Analysis of variance of studied traits

The analysis of variance revealed significant differences among chickpea genotypes for all agro-morphological, yield, and pest-related traits except for days to emergence, for which the genotype effect was non-significant (Table 2). Genotypes showed highly significant ($P \leq 0.01$) effects on days to flowering, days to maturity, plant height, productive branches plant$^{-1}$, larval count plant$^{-1}$, pods plant$^{-1}$, seeds pod$^{-1}$ pod damage,100-seed weight, biological yield, grain yield, and harvest index. The genotype × environment interaction was also highly significant ($P \leq 0.01$) for all traits except days to emergence, indicating that the performance of genotypes varied considerably across environments. Environmental effects were highly significant for productive branches, larval count, pods plant$^{-1}$, pod damage, 100-seed weight, biological yield, grain yield, and harvest index, whereas days to emergence, flowering, maturity, and plant height were not significantly affected by the environment. The replication-within-environment effect was significant only for productive branches, larval count, pods plan$^{-1}$, seeds pod$^{-1}$, pod damage, 100-seed weight, biological yield, grain yield, and harvest index.

**Table 2.** ANOVA for the agro-morphological traits, pod damage, and larval count in chickpea genotypes at Malakandhar Research farm the University of Agriculture, Peshawar, during. 2022-23.

| Traits | Envi (1) | Reps w/En (4) | Genotypes (43) | G × E (43) | Pooled error (172) | CV (%) |
|---|---|---|---|---|---|---|
| Days to emergence | 0.19$^{ns}$ | 0.84 | 1.46** | 0.44$^{ns}$ | 0.35 | 7.26 |
| Days to flowering | 0.09$^{ns}$ | 0.41 | 13.07** | 2.83** | 0.58 | 0.69 |
| Days to maturity | 2.18$^{ns}$ | 2.16 | 8.56** | 8.56** | 3.22 | 1.06 |
| Plant height | 7.2$^{ns}$ | 17.4 | 157.11** | 45.70** | 8.64 | 5.4 |
| Productive branches | 3.87** | 1.19 | 2.84** | 1.42** | 0.51 | 8.20 |
| Larval count | 535.52** | 21.23 | 17.70** | 10.91** | 3.40 | 38.39 |
| Pods plant$^{-1}$ | 15456.06** | 27.2 | 259.22** | 36.69** | 4.26 | 4.88 |
| Seeds per pod | 1.75** | 0.15 | 0.36** | 0.35** | 0.09 | 19.44 |
| Pod damage | 9834.59** | 164.03 | 182.27** | 103.69** | 18.94 | 33.20 |
| 100-seed wt | 17.1** | 2.83 | 3.99** | 0.84** | 0.39 | 2.35 |
| Biological yield | 2550163.5** | 1531807.1 | 1845014.1** | 714477.8** | 296535.7 | 12.50 |
| Grain Yield | 5550543** | 138952 | 317047** | 181702** | 38023.7 | 11.33 |
| Harvest index | 149.56** | 23.75 | 96.69** | 94.69** | 11.9 | 8.61 |

Note: ns, * and ** indicate non-significant, significant at $P \leq 0.05$, and highly significant at $P \leq 0.01$, respectively. Envi = environment; Reps w/En = replications within environment; G × E = genotype × environment interaction; CV = coefficient of variation. The numbers in parentheses indicate the respective degrees of freedom.

**Table 3.** Genetic variance (Vg), environmental variance (Ve), phenotypic variance(Vp), heritability ($h^2$) and genetic advance (GA) of 44 chickpea genotypes for Untreated environment at Peshawar during 2022-23.

| Traits | $V_g$ | $V_e$ | $V_p$ | $h^2$ | GA |
|---|---|---|---|---|---|
| Days to emergence | 0.15 | 0.33 | 0.48 | 0.31 | 0.37 |
| Days to flowering | 1.95 | 0.51 | 2.46 | 0.79 | 2.19 |
| Days to maturity | 2.85 | 2.23 | 5.08 | 0.56 | 2.22 |
| Plant height | 30.61 | 6.53 | 37.14 | 0.82 | 8.79 |
| Productive branches | 0.47 | 0.46 | 0.93 | 0.50 | 0.84 |
| Larval count | 4.61 | 3.67 | 8.28 | 0.55 | 2.82 |
| Pod per plant | 46.12 | 5.04 | 51.16 | 0.90 | 11.32 |
| Seed per pod | 0.07 | 0.18 | 0.25 | 0.29 | 0.25 |
| Pod damage | 68.28 | 28.83 | 97.12 | 0.70 | 12.19 |
| 100-seed wt | 0.63 | 0.39 | 1.02 | 0.61 | 1.09 |
| Biological yield | 180869.3 | 175570.2 | 356439.5 | 0.50 | 525.38 |
| Grain Yield | 57157.2 | 36031.4 | 93188.6 | 0.61 | 322.36 |
| Harvest index | 23.96 | 11.21 | 35.17 | 0.68 | 7.09 |

Note: Vg = genetic variance; Ve = environmental variance; Vp = phenotypic variance; $h^2$ = broad-sense heritability; GA = genetic advance. Heritability ($h^2$) is expressed as a proportion of phenotypic variance.

The coefficients of variation ranged from 1.06% for days to maturity to 38.39% for larval count, indicating relatively high experimental variability for larval infestation but acceptable precision for most agro-morphological and yield traits. Overall, the significant genotype effects and genotype × environment interactions demonstrate substantial genetic variation among the evaluated chickpea genotypes and suggest differential responses to environmental conditions (Tables 3 and 4).

### 3.1 Days to emergence

The pooled analysis of variance revealed highly significant differences *($P \leq 0.01$)* among chickpea genotypes for days to 50% emergence, whereas the effects of environment and genotype × environment interaction (GEI) were non-significant (Table 2). The coefficient of variation was 7.26%, indicating acceptable experimental precision. Across environments, days to 50% emergence ranged from 7.33 to 9.33 days (Table 5). Genotype K-FLIP exhibited the longest emergence period, with a mean of 9.33 days, whereas D-08625 and K-60069 showed the earliest emergence, each requiring an average of 7.33 days. The overall means were 8.19 and 8.24 days in the untreated and treated environments, respectively, indicating only a small difference between the two environments. Because the environment and GEI effects were non-significant, the relative performance of genotypes for emergence was generally consistent across environments. The genotypic variance was lower than the environmental variance in both environments (0.15 vs. 0.33 in the untreated environment and 0.26 vs. 0.38 in the treated environment), resulting in moderate heritability estimates of 0.31 and 0.40, respectively, with low genetic advance of 0.37 and 0.56, respectively.

### 3.2 Days to flowering

Analysis of variance showed highly significant ($P \leq 0.01$) differences among chickpea genotypes and genotype × environment interaction, while the environmental effect was non-significant for days to 50% flowering (Table 2). Across environments, days to 50% flowering ranged from 105.67 to 113.00 days (Table 5). Genotype D-15005 was the earliest flowering genotype, with a mean of 105.67 days, whereas K-60066, K-60069, and K-60075 were among the latest, requiring 113.00 days to reach 50% flowering. The mean flowering time was 109.93 days in the untreated environment and 109.89 days in the treated environment, showing a negligible difference between environments. Genotypic variance exceeded environmental variance in both environments (1.95 vs. 0.50 in the untreated environment and 2.95 vs. 0.67 in the treated environment), resulting in high heritability estimates of 0.79 and 0.81, respectively. Genetic advance was relatively low (2.19) despite the high heritability, suggesting that genetic variation contributed substantially to the observed differences in flowering time (Tables 3 and 4).The significant GEI further indicates that some genotypes responded differently to the two environments.

### 3.3 Days to 90% maturity

Analysis of Variance showed highly significant (*$P \leq 0.01$*) difference among chickpea genotypes for days to 90% maturity, whereas the environment effect was not significant (Table 2). Genotypes D-15015, D-14014 matured earliest and K-600508 and NKC-10-99 matured latest across the environments (Table 6). The mean maturity was a little less in the untreated (167.93 days) than in the treated (168.12 days). The genotypic and environmental variances were 2.85 and 2.23 (untreated) and 2.07 and 4.20 (treated) respectively with moderate heritability (0.56 and 0.33) and low genetic advance (2.22 and 1.45) (Tables 3 and 4).

### 3.4 Plant height (cm)

The plant height (cm) varied from 47.37 to 73.30 and genotype K-01153 recorded the tallest plant height while D-KARAK-2 recorded the lowest plant height (Table 2). Average height of plants was slightly greater in untreated condition (54.58 cm) than in treated condition (54.26 cm).

**Table 4.** Genetic variance (Vg), environmental variance (Ve), phenotypic variance(Vp), heritability ($h^2$), and genetic advance (GA) of 44 chickpea genotypes for the treated environment at Peshawar during 2022-23.

| Traits | $V_g$ | $V_e$ | $V_p$ | $h^2$ | GA |
|---|---|---|---|---|---|
| Days to emergence | 0.26 | 0.38 | 0.64 | 0.40 | 0.56 |
| Days to flowering | 2.95 | 0.67 | 3.62 | 0.81 | 2.71 |
| Days to maturity | 2.07 | 4.20 | 6.27 | 0.33 | 1.45 |
| Plant height | 31.22 | 10.76 | 41.98 | 0.74 | 8.43 |
| Productive branches | 0.60 | 0.55 | 1.15 | 0.52 | 0.98 |
| Larval count | 2.66 | 3.13 | 5.79 | 0.45 | 1.90 |
| Pod per plant | 49.00 | 5.44 | 54.44 | 0.90 | 11.68 |
| Seed per pod | 0.08 | 0.09 | 0.17 | 0.47 | 0.34 |
| Pod damage | 14.41 | 9.04 | 23.45 | 0.61 | 5.19 |
| 100-seed wt. | 0.71 | 0.38 | 1.09 | 0.65 | 1.19 |
| Biological yield | 474604.2 | 417501.3 | 892105.5 | 0.53 | 881.04 |
| Grain Yield | 83743.26 | 40016.02 | 123759.28 | 0.67 | 414.83 |
| Harvest index | 31.91 | 12.58 | 44.49 | 0.71 | 8.33 |

Note: Vg = genetic variance; Ve = environmental variance; Vp = phenotypic variance; $h^2$ = broad-sense heritability; GA = genetic advance. Heritability ($h^2$) is expressed as a proportion of phenotypic variance.

**Table 5.** Mean performance of chickpea genotypes for days to emergence and days to flowering under untreated and treated environments.

| | Days to emergence | | | Days to Flowering | | |
|---|---|---|---|---|---|---|
| Genotypes | Untreated | Treated | Mean | Untreated | Treated | Mean |
| D-08625 | 7.33$^{a}$ | 7.33$^{a}$ | 7.33 | 111.33$^{ab}$ | 111.3$^{ab}$ | 111.33 |
| D-09027 | 8.33$^{b}$ | 7.33$^{a}$ | 7.83 | 112.00$^{ab}$ | 112.00$^{ab}$ | 112.00 |
| D-10008 | 8.00b$^{c}$ | 8.33$^{cd}$ | 8.17 | 110.67$^{ab}$ | 110.67$^{ab}$ | 110.67 |
| D-10039 | 7.67$^{ab}$ | 7.33$^{a}$ | 7.50 | 111.33$^{ab}$ | 111.33$^{ab}$ | 111.33 |
| D-11030 | 8.33$^{c}$ | 8.33$^{cd}$ | 8.33 | 110.33$^{ab}$ | 110.33$^{ab}$ | 110.33 |
| D-12011 | 9.00$^{c}$ | 7.67$^{ab}$ | 8.33 | 112.33$^{a}$ | 112.33$^{a}$ | 112.33 |
| D-13011 | 8.00b | 7.67$^{ab}$ | 7.83 | 109.67$^{ab}$ | 109.67$^{ab}$ | 109.67 |
| D-13012 | 8.67$^{de}$ | 9.00$^{ef}$ | 8.83 | 111.33$^{a}$ | 111.33$^{a}$ | 111.33 |
| D-13031 | 8.00$^{bc}$ | 8.33$^{cd}$ | 8.17 | 109.33$^{ab}$ | 109.33$^{ab}$ | 109.33 |
| D-13036 | 8.67$^{d}$ | 8.67$^{de}$ | 8.67 | 108.67$^{ab}$ | 108.67$^{ab}$ | 108.67 |
| D-14005 | 8.00$^{bc}$ | 8.33$^{cd}$ | 8.17 | 108.00$^{ab}$ | 108.00$^{ab}$ | 108.00 |
| D-15005 | 8.67$^{cd}$ | 8.33$^{cd}$ | 8.50 | 105.67$^{b}$ | 105.67$^{b}$ | 105.67 |
| D-15012 | 8.33$^{bc}$ | 8.00$^{bc}$ | 8.17 | 108.67$^{ab}$ | 108.67$^{ab}$ | 108.67 |
| D-15015 | 8.33$^{cd}$ | 8.67$^{de}$ | 8.50 | 107.67$^{ab}$ | 107.67$^{ab}$ | 107.67 |
| D-15018 | 8.67$^{d}$ | 8.67$^{de}$ | 8.67 | 110.67$^{ab}$ | 110.67$^{ab}$ | 110.67 |
| D-15020 | 7.33$^{bc}$ | 8.67$^{de}$ | 8.00 | 111.00$^{ab}$ | 111.00$^{ab}$ | 111.00 |
| D-15036 | 8.33$^{cd}$ | 8.67$^{cd}$ | 8.50 | 110.67$^{ab}$ | 110.67$^{ab}$ | 110.67 |
| D-93127 | 8.33$^{cd}$ | 8.33$^{cd}$ | 8.33 | 110.67$^{ab}$ | 110.67$^{ab}$ | 110.67 |
| D-97086 | 8.67$^{cd}$ | 8.33$^{ab}$ | 8.50 | 110.67$^{ab}$ | 110.67$^{ab}$ | 110.67 |
| D-14014 | 8.33$^{bc}$ | 7.67$^{ab}$ | 8.00 | 110.00$^{ab}$ | 110.00$^{ab}$ | 110.00 |
| K-01151 | 8.33$^{c}$ | 8.33$^{cd}$ | 8.33 | 112.00$^{ab}$ | 112.00$^{ab}$ | 112.00 |
| K-01153 | 9.00$^{ef}$ | 9.00$^{ef}$ | 9.00 | 111.67$^{ab}$ | 111.67$^{ab}$ | 111.67 |
| K-01155 | 8.67$^{ef}$ | 9.33$^{fg}$ | 9.00 | 109.33$^{ab}$ | 109.33$^{ab}$ | 109.33 |
| K-01158 | 8.67$^{cd}$ | 8.33$^{cd}$ | 8.50 | 109.67$^{ab}$ | 109.67$^{ab}$ | 109.67 |
| K-01208 | 8.00$^{d}$ | 9.33$^{fg}$ | 8.67 | 106.00$^{b}$ | 106.00$^{b}$ | 106.00 |
| K-01209 | 8.00$^{c}$ | 8.67$^{de}$ | 8.33 | 106.30$^{b}$ | 106.33$^{b}$ | 106.33 |
| K-01210 | 7.33$^{b}$ | 8.33$^{cd}$ | 7.83 | 109.00$^{ab}$ | 109.00$^{ab}$ | 109.00 |
| K-01213 | 8.00$^{ab}$ | 7.33$^{a}$ | 7.67 | 110.33$^{ab}$ | 110.33$^{ab}$ | 110.33 |
| K-08003 | 7.33$^{ab}$ | 7.67$^{ab}$ | 7.50 | 109.33$^{ab}$ | 109.33$^{ab}$ | 109.33 |
| K-08817 | 8.00$^{bc}$ | 8.33$^{cd}$ | 8.17 | 111.00$^{ab}$ | 111.00$^{ab}$ | 111.00 |
| K-08021 | 7.67$^{bc}$ | 8.33$^{cd}$ | 8.00 | 110.00$^{ab}$ | 110.00$^{ab}$ | 110.00 |
| K-60066 | 8.33$^{bc}$ | 7.67$^{ab}$ | 8.00 | 113.00$^{a}$ | 113.00$^{a}$ | 113.00 |
| K-60069 | 7.33$^{a}$ | 7.33$^{a}$ | 7.33 | 113.00$^{a}$ | 113.00$^{a}$ | 113.00 |
| K-60075 | 7.33$^{ab}$ | 7.67$^{ab}$ | 7.50 | 113.00$^{a}$ | 113.00$^{a}$ | 113.00 |
| K-70009 | 8.33$^{c}$ | 8.33$^{cd}$ | 8.33 | 110.67$^{ab}$ | 110.67$^{ab}$ | 110.67 |
| K-600508 | 7.67$^{ab}$ | 7.33a | 7.50 | 111.00$^{ab}$ | 111.00$^{ab}$ | 111.00 |
| K-CH-47 | 8.67$^{d}$ | 8.67$^{de}$ | 8.67 | 111.00$^{ab}$ | 111.00$^{ab}$ | 111.00 |
| K-FLIP | 9.00$^{f}$ | 9.67$^{g}$ | 9.33 | 108.00$^{ab}$ | 108.00$^{ab}$ | 108.00 |
| NKC(5-5-10) | 8.67$^{d}$ | 8.67$^{de}$ | 8.67 | 111.00$^{ab}$ | 111.00$^{ab}$ | 111.00 |
| NKC(10-99) | 7.67$^{ab}$ | 7.67$^{ab}$ | 7.67 | 107.67$^{ab}$ | 107.67$^{ab}$ | 107.67 |
| D-KARAK-1 | 7.67$^{ab}$ | 7.67$^{ab}$ | 7.67 | 111.33$^{ab}$ | 111.33$^{ab}$ | 111.33 |
| D-KARAK-2 | 8.33$^{bc}$ | 7.67$^{ab}$ | 8.00 | 111.67$^{ab}$ | 111.67$^{ab}$ | 111.67 |
| D-KARAK-3 | 8.33$^{c}$ | 8.33$^{cd}$ | 8.33 | 108.33$^{ab}$ | 108.33$^{ab}$ | 108.33 |
| NIFA | 8.33$^{c}$ | 8.33$^{cd}$ | 8.33 | 107.33$^{ab}$ | 108.33$^{ab}$ | 108.83 |
| **Mean** | **8.19** | **8.24** | | **109.93** | **109.89** | |

**Table 6.** Mean performance of chickpea genotypes for days to maturity and plant height under untreated and treated environments.

| | Days to Maturity | | | Plant Height (cm) | | |
|---|---|---|---|---|---|---|
| **Genotype** | **Untreated** | **Treated** | **Mean** | **Untreated** | **Treated** | **Mean** |
| D-08625 | 168.67[abc] | 169.00[bc] | 168.84 | 59.13[bc] | 53.47[cd] | 56.30 |
| D-09027 | 170.33[c] | 168.67[bcd] | 169.5 | 54.03[cd] | 52.73[cd] | 53.38 |
| D-10008 | 166.00[de] | 172.00[k] | 169.00 | 55.47[cd] | 59.97[bc] | 57.72 |
| D-10039 | 168.33[ab] | 169.33[bc] | 168.83 | 61.87[bc] | 60.00[bc] | 60.93 |
| D-11030 | 171.67[c] | 168.00[ae] | 169.83 | 56.20[c] | 47.00[d] | 51.60 |
| D-12011 | 168.67[abc] | 167.00[ad] | 167.83 | 49.80[d] | 58.67[bc] | 54.23 |
| D-13011 | 166.00[de] | 169.67[bcf] | 167.83 | 52.33[cd] | 48.67[d] | 50.50 |
| D-13012 | 166.00[de] | 166.00[di] | 166.00 | 49.83[d] | 49.67[d] | 49.75 |
| D-13031 | 165.33[e] | 168.33[ace] | 166.83 | 49.50[d] | 48.53[d] | 49.02 |
| D-13036 | 165.67[de] | 166.00[di] | 165.84 | 50.23[cd] | 46.50[d] | 48.37 |
| D-14005 | 166.67[de] | 169.67[dhi] | 168.17 | 59.40[bc] | 49.23[d] | 54.32 |
| D-15005 | 165.00[e] | 166.00[di] | 165.50 | 51.87[cd] | 58.73[bc] | 55.30 |
| D-15012 | 166.67[de] | 166.33[dhi] | 166.50 | 52.17[cd] | 51.80[cd] | 51.98 |
| D-15015 | 165.67[de] | 164.00[j] | 164.83 | 52.03[cd] | 49.83[d] | 50.93 |
| D-15018 | 167.33[de] | 165.00[ij] | 166.17 | 49.67[d] | 53.07[cd] | 51.37 |
| D-15020 | 166.67[de] | 168.33[ace] | 167.50 | 47.80[d] | 49.33[d] | 48.57 |
| D-15036 | 166.00[de] | 165.67[di] | 165.83 | 53.33[cd] | 47.47[d] | 50.40 |
| D-93127 | 167.33[de] | 168.33[ace] | 167.83 | 53.37[cd] | 53.97[cd] | 53.67 |
| D-97086 | 167.33[de] | 167.00[ad] | 167.17 | 51.93[cd] | 55.50[cd] | 53.72 |
| D-14014 | 165.67[de] | 164.00[j] | 164.83 | 60.17[bc] | 53.57[cd] | 56.87 |
| K-01151 | 168.33[ab] | 170.33[bf] | 169.33 | 61.87[bc] | 60.00[bc] | 60.93 |
| K-01153 | 169.67[bc] | 169.67[bcf] | 169.67 | 74.93[a] | 71.67[a] | 73.30 |
| K-01155 | 169.33[abc] | 170.00[bf] | 169.67 | 61.47[bc] | 62.43[bc] | 61.95 |
| K-01158 | 168.67[abc] | 168.00[ae] | 168.33 | 58.03[bc] | 58.67[bc] | 58.35 |
| K-01208 | 169.00[abc] | 169.67[bcf] | 169.33 | 60.47[bc] | 61.40[bc] | 60.93 |
| K-01209 | 169.00[abc] | 167.67[arh] | 168.33 | 61.43[bc] | 55.33[cd] | 58.38 |
| K-01210 | 169.33[abc] | 166.67[adh] | 168.00 | 51.13[cd] | 58.83[bc] | 54.98 |
| K-01213 | 168.67[abc] | 167.00[ad] | 167.83 | 56.33[c] | 64.57[b] | 60.45 |
| K-08003 | 169.00[abc] | 167.33[adgh] | 168.17 | 56.07[cd] | 60.87[bc] | 58.47 |
| K-08817 | 167.67[aef] | 171.00[fk] | 169.33 | 54.07[cd] | 45.33[d] | 49.70 |
| K-08021 | 168.33[abf] | 168.33[ace] | 168.33 | 54.47[d] | 59.10[bc] | 56.78 |
| K-60066 | 168.00[aef] | 169.67[bcf] | 168.33 | 47.67[d] | 54.50[d] | 51.08 |
| K-60069 | 167.67[aef] | 169.67[bcf] | 168.67 | 54.90[cd] | 52.83[cd] | 53.87 |
| K-60075 | 170.33[c] | 170.00[bf] | 170.17 | 52.67[cd] | 56.47[c] | 54.57 |
| K-70009 | 167.67[aef] | 169.00[bc] | 168.33 | 59.60[bc] | 46.37[d] | 52.98 |
| K-600508 | 171.33[k] | 169.33[bc] | 170.33 | 63.00[b] | 55.70[cd] | 59.35 |
| K-CH-47 | 164.67[hi] | 171.00[fk] | 167.83 | 60.53[bc] | 53.37[cd] | 56.95 |
| K-FLIP | 166.67[de] | 167.33[adgh] | 167.00 | 62.10[bc] | 60.47[bc] | 61.28 |
| NKC(5-5-10) | 169.00[abc] | 166.00di | 167.50 | 55.33[cd] | 61.53[bc] | 58.43 |
| NKC(10-99) | 170.67[jkl] | 170.00[bf] | 170.33 | 49.00[d] | 53.17[cd] | 51.08 |
| D-KARAK-1 | 169.00[abc] | 167.33[bf] | 168.17 | 54.07[cd] | 45.33[d] | 49.70 |
| D-KARAK-2 | 171.33[kl] | 167.00[adgh] | 169.17 | 48.17 | 46.57[d] | 47.37 |
| D-KARAK-3 | 170.33[cjkl] | 168.00[adh] | 169.17 | 46.67[d] | 56.47[c] | 51.57 |
| NIFA | 164.33[i] | 168.67[ae] | 166.50 | 52.17[a] | 51.80[cd] | 51.98 |
| **Mean** | **167.93** | **168.12** | | **54.58** | **54.26** | |

Plant height ranged from 46.67 to 74.93 cm under untreated conditions and from 45.33 to 71.67 cm under treated conditions with genotype K-01153 producing the highest and D-KARAK producing the lowest height under both conditions. The genotypic variance was higher than that in the environment in both the two environments (treated, 31.22, and untreated, 30.61) and the heritability was high (0.74 and 0.82, respectively) while the genetic advance was low (8.43 and 8.79, respectively) (Tables 3 and 4, respectively).

### 3.5 Productive branches plant$^{-1}$

The number of productive branches per plant differed significantlamong genotypes and between pest management environments, with a significant genotype × environment interaction (GEI) as revealed by pooled analysis of variance (Table 2), suggesting genotype × environment interaction. In both environments, the productive branches ranged from 7.50 to 10.50 with D-11030 having the highest and D-KARAK-2 having the lowest number of productive branches (Table 5). The mean values were slightly higher in treated condition (8.83) than in untreated condition (8.59). For the untreated condition the values were in the range 6.67 – 10.33, and, for the treated condition, were in the range 7.0 – 10.67, with D-11030 obtaining the best values for both conditions. There were moderate heritability (0.50 and 0.52) and low genetic advance (0.84 and 0.98) (Tables 3, and 4)

### 3.6 Larval count

The larval count showed highly significant difference among the genotype, environments and genotype x environment interaction (GEI) (Table 2). The 2.0 to 8.0 larval plants-1 density of plants was observed across the environments, and genotype K-08003 exhibited the highest infestation and genotype D-14005 exhibited the lowest infestation (Table 7). Confirmed effectiveness of insect control with the average number of larvae collected from the untreated condition (6.23) being higher than the treated condition (3.38). Larval count was 2.0-11.0 for untreated and 0.67-7.67 for treated with K-01208 and K-70009 having the highest and the lowest count, respectively. The genotypic and environmental differences were similar in the untreated (4.60 vs. 3.66) and treated (2.66 vs. 3.13) environments and the genotypic heritability was moderate (0.55 and 0.45) and the genetic advance was low (2.82 and 1.90) (Tables 3 and 4).

### 3.7 Pods plant$^{-1}$

The combined variance analysis showed highly significant ($P \leq 0.01$) genotype, environment and genotype × environment interaction (GEI) effects, reflecting the high effect of environment on the performance of genotype (Table 2). Pods per plant varied from 30.0 to 60.33 in different environments but genotype D-11030 had the highest pods per plant and K-600508 the lowest in all the environments (Table 8). The treated had a significantly higher mean pod number than the untreated (49.94 versus 34.64). Values of untreated conditions ranged from 20.33 to 56.0 and those of treated conditions were from 38.33 to 64.67, D-11030 being the best performer. The genotypic variance was significantly greater than environmental variance (46.12 vs 5.04) in both environments, leading to high heritability (0.90) but low genetic advance (11.32–11.68) (Tables 3 and 4) which means that the selection gain was small while the genetic control was strong.

### 3.8 Seeds pod$^{-1}$

Analysis of variance revealed highly significant differences among genotypes, environments and genotype by environment interaction (GEI) for the number of seeds pod$^{-1}$ (Table 2). Under all environments the number of seeds/pod was 1.0 to 2.0, with the genotype K-08817 yielding the highest and K-01208 the lowest (Table 8). The mean values for the treated was greater (1.67) than the untreated (1.48). The untreated level ranged from 1.0 to 2.0, the treated level ranged from 1.0 to 2.33, genotype D-11030 had the highest value. Genotypic variance was smaller than environmental variance (0.07 vs 0.18) and similar when treated (0.08 vs 0.09) which led to low to moderate heritability (0.29 and 0.47) and low genetic advance (0.25 and 0.34) (Tables 3 and 4).

### 3.9 Pod damaged (%)

The combined analysis of variance showed highly significant differences ($P \leq 0.01$) among chickpea genotypes, environments and genotype × environment interaction (GEI) for pod damage percentage (Table 2). Pod damage percentage ranged from 5.08% to 24.83% across environments, with genotype K-01213 showing the maximum and D-14005 the minimum pod damage percentage (Table 9). The use of untreated conditions (19.27%) resulted in more mean pod damage than the treated conditions (7.00%) indicating that the pest was controlled. The damage caused under untreated conditions ranged from 5.01% to 38.03%, whereas under the treated conditions the damage ranged from 1.31% to 15.41% (K-08817 showed highest damage while K-70009 showed lowest damage). The genotypic variance was higher than the environmental variance in both the untreated and treated conditions (Tables 3 and 4), resulting in moderate to high heritability (0.70 and 0.61), however, low genetic advance (12.19 and 5.19), respectively.

### 3.10 100- seed weight (g)

The results of pooled analysis of variance showed highly significant ($P \leq 0.01$) variations among the genotypes, environments and genotype × environment interaction (GEI) for the 100-seed weight (Table 2). In all the environments, 100-seed weight varied from 25.08 g to 29.50 g with the highest value in D-11030 and the lowest value in D-14005 (Table 9). The mean values were higher for treated conditions (26.89 g) than for untreated conditions (26.38 g). Values ranged from 25.18-28.79 g under untreated conditions and 24.54-30.21 g under treated conditions with D-11030 being the best under both conditions. The genotypic variance was higher than the environmental variance in both environments (untreated and treated) (Tables 3 and 4) and thus was moderate to high (0.61 and 0.65) but small genetic advance was obtained (1.09 and 1.19).

**Table 7.** Mean performance of chickpea genotypes for productive branches plant$^{-1}$ and larval count under untreated and treated environments.

| | **Productive Branches plant$^{-1}$** | | | **Larval count** | | |
|---|---|---|---|---|---|---|
| **Genotype** | **Untreated** | **Treated** | **Mean** | **Untreated** | **Treated** | **Mean** |
| D-08625 | 9.00$^{e}$ | 10.33$^{b}$ | 9.67 | 5.67$^{cde}$ | 2.00$^{efgh}$ | 3.83 |
| D-09027 | 9.33$^{d}$ | 9.00$^{f}$ | 9.17 | 9.00$^{ab}$ | 1.67$^{fgh}$ | 5.33 |
| D-10008 | 8.33$^{g}$ | 8.67$^{g}$ | 8.50 | 3.33$^{ef}$ | 5.00$^{abcde}$ | 4.17 |
| D-10039 | 8.33$^{g}$ | 8.67$^{g}$ | 8.50 | 3.00$^{ef}$ | 2.67$^{defgh}$ | 2.83 |
| D-11030 | 10.33$^{a}$ | 10.67$^{a}$ | 10.50 | 4.00$^{ef}$ | 2.00$^{efgh}$ | 3.00 |
| D-12011 | 9.00$^{e}$ | 8.33$^{i}$ | 8.67 | 5.00$^{cdef}$ | 3.33$^{cdefgh}$ | 4.17 |
| D-13011 | 8.00$^{h}$ | 9.00$^{f}$ | 8.50 | 3.33$^{ef}$ | 1.67$^{fgh}$ | 2.50 |
| D-13012 | 9.67$^{c}$ | 9.00$^{f}$ | 9.33 | 3.67$^{ef}$ | 1.67$^{fgh}$ | 2.67 |
| D-13031 | 8.33$^{g}$ | 9.67$^{d}$ | 9.00 | 3.67$^{ef}$ | 2.00$^{efgh}$ | 2.83 |
| D-13036 | 8.00$^{h}$ | 10.33$^{b}$ | 9.17 | 3.33$^{ef}$ | 1.00$^{gh}$ | 2.17 |
| D-14005 | 9.67$^{c}$ | 8.67$^{g}$d | 9.17 | 3.00$^{ef}$ | 1.00$^{gh}$ | 2.00 |
| D-15005 | 8.67$^{f}$ | 8.67$^{g}$ | 8.67 | 4.00$^{ef}$ | 3.67$^{bcdef}$ | 3.83 |
| D-15012 | 8.00$^{h}$ | 8.00$^{i}$ | 8.00 | 6.67$^{bcd}$ | 0.67$^{h}$ | 3.67 |
| D-15015 | 8.33$^{g}$ | 9.00$^{f}$ | 8.67 | 7.33$^{bcd}$ | 7.67$^{a}$ | 7.50 |
| D-15018 | 9.67$^{c}$ | 10.00$^{c}$ | 9.83 | 3.00$^{ef}$ | 4.67$^{abcdef}$ | 3.83 |
| D-15020 | 9.33$^{d}$ | 9.00$^{f}$ | 9.167 | 5.67$^{cde}$ | 5.00$^{abcde}$ | 5.33 |
| D-15036 | 9.33$^{d}$ | 7.33$^{l}$ | 8.33 | 2.00$^{f}$ | 4.33$^{bcdef}$ | 3.17 |
| D-93127 | 8.00$^{h}$ | 9.33$^{e}$ | 8.67 | 5.33$^{cde}$ | 4.00$^{bcdefg}$ | 4.67 |
| D-97086 | 9.00$^{e}$ | 8.67$^{g}$ | 8.83 | 10.00$^{a}$ | 5.33$^{abcd}$ | 7.67 |
| D-14014 | 8.00$^{h}$ | 9.67$^{d}$ | 8.83 | 5.00$^{cdef}$ | 4.67$^{abcdef}$ | 4.83 |
| K-01151 | 9.33$^{d}$ | 8.67$^{g}$ | 9.00 | 6.00$^{cde}$ | 6.00$^{abc}$ | 6.00 |
| K-01153 | 10.00$^{b}$ | 10.33$^{b}$ | 10.17 | 9.00$^{ab}$ | 1.00$^{gh}$ | 5.00 |
| K-01155 | 8.67$^{f}$ | 7.67$^{k}$ | 8.17 | 6.67$^{bcd}$ | 6.00$^{abc}$ | 6.33 |
| K-01158 | 8.33$^{g}$ | 7.33$^{l}$ | 7.83 | 9.00$^{ab}$ | 4.00$^{bcdefg}$ | 6.50 |
| K-01208 | 8.67$^{f}$ | 8.33$^{i}$ | 8.50 | 11.00$^{a}$ | 0.67$^{h}$ | 5.83 |
| K-01209 | 8.67$^{f}$ | 9.00$^{f}$ | 8.83 | 8.67$^{ab}$ | 6.33$^{abc}$ | 7.50 |
| K-01210 | 7.33$^{j}$ | 8.00$^{i}$ | 7.67 | 7.00$^{bcd}$ | 4.67$^{abcdef}$ | 5.83 |
| K-01213 | 8.00$^{h}$ | 9.00$^{f}$ | 8.50 | 10.33$^{a}$ | 5.33$^{abcd}$ | 7.83 |
| K-08003 | 8.00$^{h}$ | 7.67$^{k}$ | 7.83 | 9.33$^{ab}$ | 6.67$^{ab}$ | 8.00 |
| K-08817 | 6.67$^{l}$ | 8.67$^{g}$ | 7.67 | 9.33$^{ab}$ | 4.00$^{bcdefg}$ | 6.67 |
| K-08021 | 7.67$^{i}$ | 9.00$^{f}$ | 8.33 | 7.67$^{bc}$ | 3.67$^{bcdefgh}$ | 5.67 |
| K-60066 | 8.67$^{f}$ | 10.00$^{c}$ | 9.33 | 5.67$^{cde}$ | 5.00$^{abcde}$ | 5.33 |
| K-60069 | 9.00$^{e}$ | 8.67$^{g}$ | 8.83 | 5.67$^{cde}$ | 0.67$^{h}$ | 3.17 |
| K-60075 | 8.67$^{f}$ | 9.00$^{f}$ | 8.83 | 4.33$^{def}$ | 1.00$^{gh}$ | 2.67 |
| K-70009 | 8.33$^{g}$ | 7.00$^{m}$ | 7.67 | 9.33$^{ab}$ | 0.67$^{h}$ | 5.00 |
| K-600508 | 8.67$^{f}$ | 8.00$^{j}$ | 8.33 | 3.33$^{ef}$ | 1.67$^{fgh}$ | 2.50 |
| K-CH-47 | 7.67$^{i}$ | 8.60$^{h}$ | 8.17 | 8.00$^{abc}$ | 4.00$^{bcdefg}$ | 6.00 |
| K-FLIP | 8.33$^{g}$ | 7.00$^{m}$ | 7.67 | 8.33$^{ab}$ | 5.00$^{abcde}$ | 6.67 |
| NKC(5-5-20) | 8.33$^{g}$ | 10.00$^{c}$ | 9.17 | 9.33$^{bcd}$ | 4.67$^{abcdef}$ | 7.00 |
| NKC(10-99) | 9.33$^{d}$ | 10.00$^{c}$ | 9.67 | 7.00$^{bcd}$ | 4.67$^{abcdef}$ | 5.83 |
| D-KARAK-1 | 7.67$^{i}$ | 8.67$^{g}$ | 8.17 | 6.33$^{bcd}$ | 1.67$^{fgh}$ | 4.00 |
| D-KARAK-2 | 7.00$^{k}$ | 8.00$^{j}$ | 7.50 | 6.33$^{bcd}$ | 3.00$^{defgh}$ | 4.67 |
| D-KARAK-3 | 9.33$^{d}$ | 8.67$^{g}$ | 9.00 | 5.33$^{cde}$ | 3.33$^{cdefgh}$ | 4.33 |
| NIFA | 9.67$^{c}$ | 9.00$^{f}$ | 9.33 | 5.00$^{cdef}$ | 1.00$^{gh}$ | 3.00 |
| **Mean** | **8.59** | **8.83** | | **6.23** | **3.38** | |

**Table 8.** Mean performance of chickpea genotypes for pods plant$^{-1}$ and seeds pod$^{-1}$ under untreated and treated environments.

| Pods plant$^{-1}$ | | | | Seeds pod$^{-1}$ | | |
|---|---|---|---|---|---|---|
| **Genotype** | **Untreated** | **Treated** | **Mean** | **Untreated** | **Treated** | **Mean** |
| D-08625 | 43.00$^{b}$ | 56.33$^{bc}$ | 49.67 | 1.33$^{cd}$ | 2.00$^{a}$ | 1.67 |
| D-09027 | 36.33$^{c}$ | 54.67$^{c}$ | 45.50 | 1.00$^{d}$ | 2.00$^{a}$ | 1.50 |
| D-10008 | 43.33$^{b}$ | 60.67$^{ab}$ | 52.00 | 1.33$^{cd}$ | 2.00$^{a}$ | 1.67 |
| D-10039 | 38.67$^{c}$ | 55.00$^{bc}$ | 46.83 | 2.00$^{ab}$ | 1.00$^{d}$ | 1.50 |
| D-11030 | 56.00$^{a}$ | 64.67$^{a}$ | 60.33 | 1.33$^{cd}$ | 2.33$^{a}$ | 1.83 |
| D-12011 | 40.33$^{c}$ | 51.67$^{cd}$ | 46.00 | 1.67$^{bc}$ | 1.33$^{bcd}$ | 1.50 |
| D-13011 | 35.00$^{cd}$ | 60.33$^{ab}$ | 47.67 | 1.67$^{bc}$ | 1.33$^{bcd}$ | 1.50 |
| D-13012 | 37.33$^{c}$ | 61.00$^{ab}$ | 49.17 | 1.67$^{bc}$ | 2.00$^{a}$ | 1.83 |
| D-13031 | 33.67$^{d}$ | 56.00$^{bc}$ | 44.83 | 1.33$^{cd}$ | 1.33$^{bcd}$ | 1.33 |
| D-13036 | 38.67$^{bc}$ | 51.67$^{cd}$ | 45.17 | 2.00$^{ab}$ | 1.67$^{b}$ | 1.83 |
| D-14005 | 37.00$^{c}$ | 53.00$^{c}$ | 45.00 | 1.33$^{cd}$ | 1.33$^{bcd}$ | 1.33 |
| D-15005 | 34.67$^{d}$ | 46.67$^{de}$ | 40.67 | 1.67$^{bc}$ | 1.67$^{b}$ | 1.67 |
| D-15012 | 35.67$^{cd}$ | 49.67$^{d}$ | 42.67 | 2.00$^{ab}$ | 2.00$^{a}$ | 2.00 |
| D-15015 | 33.67$^{d}$ | 47.67$^{d}$ | 40.67 | 1.67$^{bc}$ | 1.67$^{b}$ | 1.67 |
| D-15018 | 33.33$^{d}$ | 47.33$^{d}$ | 40.33 | 1.67$^{bc}$ | 2.00$^{a}$ | 1.83 |
| D-15020 | 39.67$^{bc}$ | 50.33$^{d}$ | 45.00 | 1.67$^{bc}$ | 1.33$^{bcd}$ | 1.50 |
| D-15036 | 33.33$^{d}$ | 42.33$^{ef}$ | 37.83 | 1.33$^{cd}$ | 1.67$^{b}$ | 1.50 |
| D-93127 | 36.00$^{c}$ | 52.67$^{c}$ | 44.33 | 1.00$^{d}$ | 1.67$^{b}$ | 1.33 |
| D-97086 | 37.00$^{c}$ | 55.00$^{bc}$ | 46.00 | 2.00$^{ab}$ | 1.67$^{b}$ | 1.83 |
| D-14014 | 27.00$^{efg}$ | 38.67$^{f}$ | 32.83 | 1.00$^{d}$ | 1.67$^{b}$ | 1.33 |
| K-01151 | 35.00$^{cd}$ | 53.33$^{c}$ | 44.16 | 2.00$^{ab}$ | 1.67$^{b}$ | 1.83 |
| K-01153 | 52.67$^{a}$ | 63.67$^{a}$ | 58.17 | 1.33$^{cd}$ | 2.00$^{a}$ | 1.67 |
| K-01155 | 35.67$^{d}$ | 54.33$^{c}$ | 45.00 | 2.00$^{ab}$ | 1.33$^{bcd}$ | 1.67 |
| K-01158 | 34.67$^{d}$ | 49.67$^{d}$ | 42.17 | 1.00$^{d}$ | 2.00$^{a}$ | 1.50 |
| K-01208 | 31.33$^{de}$ | 41.67$^{ef}$ | 36.50 | 1.00$^{d}$ | 1.00$^{d}$ | 1.00 |
| K-01209 | 31.67$^{de}$ | 51.00$^{d}$ | 41.33 | 1.67$^{bc}$ | 2.00$^{a}$ | 1.83 |
| K-01210 | 29.33$^{ef}$ | 38.33$^{f}$ | 33.83 | 1.00$^{d}$ | 2.00$^{a}$ | 1.50 |
| K-01213 | 35.00$^{cd}$ | 45.67$^{e}$ | 40.33 | 1.33$^{cd}$ | 1.87$^{ab}$ | 1.60 |
| K-08003 | 34.33$^{d}$ | 51.00$^{d}$ | 42.67 | 1.00$^{d}$ | 1.33$^{bcd}$ | 1.17 |
| K-08817 | 39.67$^{bc}$ | 57.00$^{bc}$ | 48.33 | 1.33$^{cd}$ | 2.00$^{a}$ | 1.67 |
| K-08021 | 36.67$^{c}$ | 50.00$^{d}$ | 43.50 | 2.00$^{ab}$ | 2.33$^{a}$ | 2.17 |
| K-60066 | 39.67$^{bc}$ | 49.67$^{d}$ | 48.33 | 1.00$^{d}$ | 2.00$^{a}$ | 1.50 |
| K-60069 | 36.67$^{c}$ | 50.33$^{d}$ | 43.50 | 2.00$^{ab}$ | 1.67$^{b}$ | 1.83 |
| K-60075 | 27.00$^{efg}$ | 38.67$^{f}$ | 32.83 | 1.67$^{bc}$ | 2.00$^{a}$ | 1.83 |
| K-70009 | 36.00$^{c}$ | 49.67$^{d}$ | 42.83 | 1.33$^{cd}$ | 1.67$^{b}$ | 1.50 |
| K-600508 | 21.67$^{gh}$ | 38.33$^{f}$ | 30.00 | 1.00$^{d}$ | 1.33$^{bcd}$ | 1.17 |
| K-CH-47 | 25.33$^{fg}$ | 50.00$^{d}$ | 37.67 | 1.33$^{cd}$ | 1.33$^{bcd}$ | 1.33 |
| K-FLIP | 23.00$^{gh}$ | 47.33$^{d}$ | 35.17 | 2.00$^{ab}$ | 1.60$^{bc}$ | 1.80 |
| NKC(5-5-20) | 30.33$^{de}$ | 45.00$^{e}$ | 37.67 | 1.33$^{cd}$ | 1.33$^{bcd}$ | 1.33 |
| NKC(10-99) | 33.67$^{d}$ | 44.00$^{e}$ | 38.83 | 1.33$^{cd}$ | 1.77$^{ab}$ | 1.55 |
| D-KARAK-1 | 32.67$^{de}$ | 41.00$^{ef}$ | 36.83 | 1.67$^{bc}$ | 1.00$^{d}$ | 1.33 |
| D-KARAK-2 | 20.33$^{h}$ | 44.67$^{e}$ | 32.50 | 1.33$^{cd}$ | 1.33$^{bcd}$ | 1.33 |
| D-KARAK-3 | 38.67$^{bc}$ | 47.00$^{d}$ | 52.00 | 2.00$^{ab}$ | 2.00$^{a}$ | 2.00 |
| NIFA-2005 | 37.00$^{c}$ | 50.67$^{d}$ | 43.83 | 1.00$^{d}$ | 1.33$^{bcd}$ | 1.17 |
| **Mean** | **34.64** | **49.94** | | **1.48** | **1.67** | |

**Table 9.** Mean performance of chickpea genotypes for pod damage and 100-seed weight under untreated and treated environments.

| | Pod damage (%) | | | 100-seed weight (g) | | |
|---|---|---|---|---|---|---|
| **Genotype** | **Untreated** | **Treated** | **Mean** | **Untreated** | **Treated** | **Mean** |
| D-08625 | 13.16[b] | 3.39[c] | 8.28 | 27.12[b] | 27.51[b] | 27.31 |
| D-09027 | 24.96[a] | 3.01[c] | 13.98 | 26.58[b] | 26.97[b] | 26.78 |
| D-10008 | 7.68[c] | 8.32[a] | 8.00 | 26.36[b] | 26.75[b] | 26.56 |
| D-10039 | 7.69[c] | 5.62[b] | 6.65 | 26.18[b] | 26.57[b] | 26.37 |
| D-11030 | 9.65[c] | 3.70[c] | 6.68 | 28.79[b] | 30.21[a] | 29.50 |
| D-12011 | 12.60[b] | 6.44[b] | 9.52 | 25.88[c] | 26.27[b] | 26.08 |
| D-13011 | 9.87[b] | 2.56[c] | 6.22 | 25.66[c] | 26.05[b] | 25.86 |
| D-13012 | 9.76[b] | 2.51[c] | 6.13 | 25.29[c] | 25.68[c] | 25.49 |
| D-13031 | 10.78[b] | 3.53[c] | 7.16 | 26.34[b] | 26.73[b] | 26.53 |
| D-13036 | 8.64[c] | 1.92[c] | 5.28 | 26.26[b] | 26.65[b] | 26.46 |
| D-14005 | 8.33[c] | 1.82[c] | 5.08 | 25.26[c] | 24.54[c] | 25.08 |
| D-15005 | 11.61[b] | 7.79[b] | 9.70 | 27.42[b] | 27.81[b] | 27.61 |
| D-15012 | 18.26[a] | 1.26[c] | 9.76 | 26.66[b] | 27.05[b] | 26.85 |
| D-15015 | 20.50[a] | 15.41[a] | 17.95 | 26.29[b] | 26.68[b] | 26.48 |
| D-15018 | 8.99[c] | 9.86[a] | 9.42 | 26.49[b] | 26.88[b] | 26.68 |
| D-15020 | 17.17[a] | 10.54[a] | 13.85 | 25.76[c] | 26.15[b] | 25.96 |
| D-15036 | 5.01[c] | 8.50[a] | 6.75 | 26.46 | 26.85[b] | 26.65 |
| D-93127 | 15.92[b] | 9.60[a] | 12.76 | 27.57[b] | 27.96[b] | 27.76 |
| D-97086 | 27.79[a] | 10.10[a] | 18.95 | 26.71[b] | 27.14[b] | 26.92 |
| D-14014 | 13.64[b] | 8.49[a] | 11.07 | 24.39[c] | 29.95[a] | 25.67 |
| K-01151 | 15.67[b] | 10.87[a] | 13.27 | 25.96[c] | 26.35[b] | 26.16 |
| K-01153 | 25.91[b] | 1.82[c] | 13.87 | 25.59[c] | 25.98[c] | 25.79 |
| K-01155 | 16.97[a] | 11.00[a] | 13.99 | 26.01[c] | 27.14[b] | 26.57 |
| K-01158 | 25.45[a] | 7.29[b] | 16.37 | 25.48[c] | 25.87[c] | 25.68 |
| K-01208 | 32.02[c] | 1.33[c] | 16.68 | 25.64[c] | 26.02[b] | 25.83 |
| K-01209 | 27.82[a] | 15.07[a] | 21.45 | 25.26[c] | 25.28[c] | 25.24 |
| K-01210 | 22.14[a] | 9.19[a] | 15.67 | 26.67[b] | 27.06[b] | 26.86 |
| K-01213 | 35.53[a] | 14.12[a] | 24.83 | 25.43[c] | 27.51[b] | 26.46 |
| K-08003 | 26.62[a] | 14.52[a] | 20.57 | 26.13[b] | 26.52[b] | 26.32 |
| K-08817 | 38.03[a] | 11.03[a] | 24.53 | 25.91[c] | 26.89[b] | 26.40 |
| K-08021 | 22.21[a] | 7.12[b] | 14.67 | 25.54[c] | 27.26[b] | 26.40 |
| K-60066 | 14.40[b] | 8.86[a] | 11.63 | 27.44[b] | 27.84[b] | 26.11 |
| K-60069 | 15.95[b] | 1.36[c] | 8.66 | 28.71[a] | 29.1[b] | 28.90 |
| D-60075 | 16.30[a] | 2.44[c] | 9.37 | 26.99[b] | 26.29[b] | 26.64 |
| K-70009 | 26.05[a] | 1.31[d] | 13.68 | 27.3[b] | 27.30[b] | 27.3 |
| K-600508 | 15.32[b] | 4.57[b] | 9.94 | 26.44[b] | 26.83[b] | 26.64 |
| K-CH-47 | 31.64[a] | 8.02[a] | 19.83 | 26.71[b] | 27.10[b] | 26.90 |
| K-FLIP | 36.53[a] | 10.50[a] | 23.51 | 26.54[b] | 27.20[b] | 26.87 |
| NKC(5-5-20) | 30.82[a] | 10.38[a] | 20.60 | 27.7[b] | 26.42[b] | 27.09 |
| NKC(10-99) | 21.01[a] | 10.59[a] | 15.80 | 25.71[c] | 27.25[b] | 26.48 |
| D-KARAK-1 | 19.53[a] | 4.21[b] | 11.87 | 26.67[b] | 27.05[b] | 26.86 |
| D-KARAK-2 | 31.20[a] | 6.93[b] | 19.06 | 25.18[c] | 26.07[b] | 25.63 |
| D-KARAK-3 | 22.58[a] | 9.24[b] | 15.91 | 25.99[c] | 26.38[b] | 26.18 |
| NIFA-2005 | 16.08[a] | 1.82[a] | 8.95 | 26.88[b] | 27.27[b] | 27.07 |
| **Mean** | **19.27** | **7.00** | | **26.38** | **26.89** | |

### 3.11 Biological yield (kg ha-1)

Pooled analysis of variance revealed highly significant ($P \leq 0.01$) differences among genotypes, environments, and genotype × environment interaction (GEI) for biological yield (Table 2). Across environments, biological yield ranged from 3088.6 to 5585.0 kg ha$^{-1}$, with genotype K-01130 showing the maximum and NKC-10-99 the minimum yield (Table 10).

Mean biological yield was higher under treated (4672.08 kg ha$^{-1}$) than untreated conditions (4040.68 kg ha$^{-1}$). Under untreated conditions, yield ranged from 2840.3 to 5266.3 kg ha$^{-1}$, while under treated conditions it ranged from 3218.5 to 5903.7 kg ha$^{-1}$, with genotype D-11030 consistently performing best. Genotypic and environmental variances were 180869.3 and 175570.2 under untreated conditions and treated 474604.2 and 417501.3 environments, resulting in moderate heritability (0.50 and 0.51) and high genetic advance (525.38 and 881.04) (Tables 3 and 4).

### 3.12 Seed yield (kg ha-1)

The differences among the genotypes, environments, and genotype × environment interaction (GEI) in seed yield were highly significant (*P≤0.01*) as shown in pooled analysis of variance (Table 2). In all environments, seed yield was in the range of 1291.4 – 2421.0 kg ha$^{-1}$ and D-11030 recorded the highest while K-08817 recorded the lowest yield (Table 10). The seed yield under treated conditions was higher than that under untreated conditions with a mean of 1865.4 kg ha$^{-1}$ and 1575.41 kg ha$^{-1}$ respectively. Seed yield from 1104.9 to 2323.6 kg ha$^{-1}$ under untreated conditions compared to 1261.8 to 2518.5 kg ha$^{-1}$ under treated conditions with D-11030 being the best performer. In both the untreated and treated conditions genotypic variance was greater than environmental variance (Tables 3 and 4). Heritability estimates were 0.61 and 0.67 under untreated and treated condition respectively and genetic advance were 322.26 and 414.83 under untreated and treated condition respectively.

### 3.13 Harvest index (%)

Pooled analysis of variance revealed highly significant (*P≤0.01*) differences among genotypes, environments, and genotype × environment interaction (GEI) for harvest index (Table 1). Across environments, harvest index ranged from 33.28% to 47.06%, with genotype D-15012 showing the highest and D-09027 the lowest values (Table 11). Mean harvest index was higher under treated (40.77%) than untreated conditions (39.26%). Under untreated conditions, values ranged from 29.50% to 52.88%, while under treated conditions they ranged from 30.15% to 55.66%, with genotype D-15020 showing the maximum performance. Genotypic variance exceeded environmental variance under both untreated (23.96 vs 11.21) and treated (31.91 vs 12.58) environments, resulting in high heritability (0.68 and 0.71) but low genetic advance (7.09 and 8.33) (Tables 3 and 4), respectively.

## 4. Discussion

The contrasting pest-management environments revealed substantial genetic differentiation among the 44 chickpea genotypes and, importantly, demonstrated that the expression of several traits depended on the interaction between genotype and pod-borer management. This interaction is particularly relevant for chickpea improvement because yield, phenology and pest resistance are jointly determined by genetic background and the intensity of biotic stress. Rather than identifying genotypes solely on the basis of performance under protected conditions, evaluation under both insecticide-treated and untreated environments provides a more realistic assessment of genetic resilience and adaptation.

### 4.1. Phenological traits and plant architecture

Early and uniform emergence is an important component of crop establishment because it determines the initial plant population and can influence subsequent competition for resources. In the present study, days to 50% emergence was comparatively stable across pest-management environments, with neither environment nor genotype × environment interaction significantly affecting the trait. The moderate heritability and low genetic advance suggest that although genetic differences contributed to variation in emergence, the scope for rapid improvement through direct selection is limited. The stability of emergence is biologically plausible because pod-borer pressure is unlikely to exert a strong influence before substantial vegetative and reproductive tissues develop. The moderate heritability observed here agrees with the previously reported pattern for emergence [25], whereas the contrast with other estimates [26] may reflect differences in germplasm, environmental conditions and experimental design. Thus, emergence appears to be a relatively stable trait under contrasting pod-borer-management conditions but is unlikely to provide a major target for direct genetic improvement.

Flowering time is more closely linked to adaptation because the timing of reproductive development can determine whether plants encounter terminal drought, high temperature or late-season disease and insect pressure. In the present study, genotypes differed substantially in days to 50% flowering, and the significant genotype × environment interaction indicated that flowering responses were not completely uniform between management conditions. The predominance of genotypic over environmental variance and high heritability indicate a strong genetic component to flowering time, although the relatively low genetic advance suggests that the observed variation may not translate proportionally into selection response. This pattern is consistent with previous evidence of substantial genetic variation for flowering time in chickpea [27]. The combination of high heritability and low genetic advance is also consistent with earlier observations [28], suggesting that flowering time may be genetically controlled but influenced by genetic architecture that limits rapid improvement through direct selection. Therefore, flowering time should be considered primarily as an adaptive trait and evaluated together with yield and stress-response characteristics rather than selected in isolation.

Maturity duration similarly contributes to adaptation by determining the length of the crop cycle and the likelihood of escaping late-season environmental stresses. Genotypic differences in days to 90% maturity were significant, whereas the mean maturity duration differed only marginally between untreated and treated conditions. The moderate heritability estimates and relatively low genetic advance indicate that both genetic and environmental components contribute to maturity variation. The limited influence of pod-borer management on average maturity suggests that reproductive duration itself was relatively resilient to pest control, even though individual genotypes responded differently. Previous studies have also reported significant genetic variation and moderate-to-high heritability for maturity in chickpea [29 -31], while genotype × environment interactions reported in broader chickpea evaluations further emphasize the importance of assessing maturity under contrasting conditions [30]. Collectively, these results indicate that maturity is genetically variable but that direct selection for earlier maturity alone may provide limited gain; its value is greater when combined with adaptation, yield potential and pest resistance.

Plant height is an important component of chickpea architecture because it reflects vegetative growth and can influence biomass accumulation and reproductive development. In this study, plant height varied widely among genotypes, with K-01153 producing the tallest plants, while genotype differences were maintained across the two management environments. The predominance of genotypic variance over environmental variance and high heritability indicate substantial genetic control of plant height, whereas the relatively low genetic advance indicates that phenotypic variation may not translate directly into large selection gains. Similar genetic variability and high heritability for plant height have been reported in chickpea [32]. The combination of high heritability and comparatively modest genetic advance may indicate a contribution of non-additive genetic effects or restricted additive variation, although the present experiment cannot distinguish among these mechanisms. Plant height should therefore be considered alongside reproductive traits and yield rather than used as an independent selection criterion.

Productive branches provide the structural basis for pod formation and therefore represent an important intermediate component of yield. In the present study, branch number was significantly affected by genotype, pest-management environment and genotype × environment interaction, with D-11030 consistently producing among the highest numbers of productive branches. The increase under insecticide-treated conditions suggests that reduced pest pressure may have preserved reproductive growth, while the significant interaction indicates that genotypes differed in their capacity to maintain branching under contrasting pest pressure. Similar genetic variation for branching and yield-related traits has been reported in chickpea [33], and the present moderate heritability estimates suggest that both genetic and environmental factors contributed to branch formation. However, the low genetic advance indicates limited expected gain from direct selection. These results support the evaluation of productive branching under both protected and pest-exposed conditions because stable branching may contribute to identifying genotypes capable of maintaining yield components under biotic stress [34].

### 4.2. Pod-borer pressure and resistance

Larval abundance provides a direct measure of the intensity of pod-borer pressure and is therefore central to distinguishing intrinsic host resistance from the apparent performance of genotypes under chemical protection. Larval populations were substantially greater in the untreated environment than in the insecticide-treated environment, while significant genotype and genotype × environment effects demonstrated that genotypes differed in both infestation level and response to pest management. The lower larval abundance under insecticide treatment confirms that the contrasting environments generated meaningful differences in pest pressure, whereas the persistence of genotype effects indicates that host-associated differences contributed to infestation patterns. Similar genotype-dependent responses to environmental variation have been reported in chickpea [35]. Moderate heritability together with low genetic advance suggests that larval abundance is influenced by both genetic and environmental factors and that selection based solely on larval counts may be inefficient. Consequently, larval abundance is most informative when combined with direct measures of pod damage and yield performance.

Pod damage integrates pest abundance, feeding behavior and host response and is therefore a more direct indicator of agronomic resistance than larval number alone. In the present study, pod damage was markedly greater in the untreated environment than in the insecticide-treated environment, while substantial genotype × environment interaction demonstrated that resistance expression varied among genotypes according to pest-management conditions. The mean reduction in damage from 19.27% under untreated conditions to 7.00% under insecticide treatment confirms the strong contribution of pest pressure to reproductive injury. The particularly low damage recorded for D-14005 identifies this genotype as a promising source of resistance, whereas the high damage observed in susceptible genotypes highlights considerable exploitable genetic variation. Similar variation in pod damage and genotype responses has been documented in chickpea [13, 44]. Although the relatively high heritability indicates a substantial genetic component, the low genetic advance suggests that resistance should not be inferred from heritability alone. Instead, combining pod-damage measurements with yield and performance under untreated conditions provides a stronger basis for identifying durable resistance.

### 4.3. Yield components and reproductive performance

Pods per plant is a major determinant of chickpea yield because it integrates reproductive establishment and the plant's ability to retain reproductive structures under stress. In this study, pod number was strongly affected by genotype, pest-management environment and genotype × environment interaction, with D-11030 consistently producing the greatest number of pods. Mean pod number increased markedly from 34.64 under untreated conditions to 49.94 under insecticide-treated conditions, indicating that pod-borer pressure substantially constrained reproductive productivity. This response is consistent with the role of pod-feeding insects in damaging flowers and developing reproductive structures and suggests that protection from infestation allowed a greater proportion of reproductive sites to develop into pods. Similar environmental effects on yield components have been reported in chickpea [40].

**Table 10.** Mean performance of chickpea genotypes for biological yield and grain yield under untreated and treated environments.

| | Biological Yield (Kg ha$^{-1}$) | | | Grain Yield (Kg ha$^{-1}$) | | |
|---|---|---|---|---|---|---|
| **Genotype** | **Untreated** | **Treated** | **Mean** | **Untreated** | **Treated** | **Mean** |
| D-08625 | 4503$^{a}$ | 4859.2$^{b}$ | 4681.1 | 1791.3$^{b}$ | 1530.5$^{c}$ | 1660.9 |
| D-09027 | 4348.6$^{b}$ | 5145.6$^{a}$ | 4747.1 | 1584.1$^{b}$ | 1556.3$^{c}$ | 1570.2 |
| D-10008 | 4626.7$^{a}$ | 5666.6$^{a}$ | 5146.6 | 1828.6$^{b}$ | 2065.7$^{b}$ | 1947.2 |
| D-10039 | 4323.1$^{b}$ | 5334.5$^{a}$ | 4828.8 | 1427.2$^{c}$ | 2302.4$^{a}$ | 1864.8 |
| D-11030 | 5266.3$^{a}$ | 5903.7$^{a}$ | 5585.0 | 2323.6$^{a}$ | 2518.5$^{a}$ | 2421.0 |
| D-12011 | 4571.6$^{a}$ | 5637.0$^{a}$ | 5104.3 | 1876.5$^{b}$ | 1981.4$^{b}$ | 1929.0 |
| D-13011 | 4488.8$^{a}$ | 5779.5$^{a}$ | 5134.4 | 1654.3$^{b}$ | 2277.7$^{a}$ | 1966.0 |
| D-13012 | 4038.2$^{a}$ | 5800.3$^{a}$ | 4919.2 | 1593.8$^{b}$ | 2407.4$^{a}$ | 2000.6 |
| D-13031 | 4345.6$^{b}$ | 5850.6$^{a}$ | 5098.1 | 2045.7$^{a}$ | 2432.0$^{a}$ | 2238.9 |
| D-13036 | 5100$^{a}$ | 4845.6$^{b}$ | 4972.8 | 2061.7$^{a}$ | 1883.3$^{b}$ | 1972.5 |
| D-14005 | 4043.2$^{b}$ | 4927.1$^{b}$ | 4485.1 | 1617.2$^{b}$ | 1888.8$^{b}$ | 1753.0 |
| D-15005 | 3881.9$^{b}$ | 4580.2$^{b}$ | 4231.0 | 1308.6$^{c}$ | 1851.8$^{b}$ | 1580.2 |
| D-15012 | 3423.8$^{c}$ | 3807.4$^{c}$ | 3615.6 | 1358.0$^{c}$ | 2085.1$^{b}$ | 1721.6 |
| D-15015 | 3884.2$^{b}$ | 4412.3$^{b}$ | 4148.2 | 1388.8$^{c}$ | 2092.5$^{b}$ | 1740.7 |
| D-15018 | 3343.2$^{c}$ | 3503.7$^{c}$ | 3423.4 | 1493.8$^{b}$ | 1506.1$^{c}$ | 1500 |
| D-15020 | 3571.6$^{c}$ | 3524.6$^{c}$ | 3548.1 | 1345.6$^{c}$ | 1851.8$^{b}$ | 1598.7 |
| D-15036 | 4664.1$^{a}$ | 4760.4$^{b}$ | 4712.3 | 1703.7$^{b}$ | 2012.3$^{b}$ | 1858.0 |
| D-93127 | 4011.1$^{b}$ | 4090.1$^{c}$ | 4050.6 | 1565.4$^{b}$ | 1697.5$^{b}$ | 1631.4 |
| D-97086 | 4173.5$^{b}$ | 4537.0$^{b}$ | 4355.2 | 1679.0$^{b}$ | 1901.2$^{b}$ | 1790.1 |
| D-14014 | 4335.8$^{b}$ | 4402.4$^{b}$ | 4369.1 | 1271.6$^{c}$ | 1886.4$^{b}$ | 1579.0 |
| K-01151 | 3807.4$^{b}$ | 3713.5$^{c}$ | 3760.4 | 1550.6$^{b}$ | 1740.7$^{b}$ | 1645.6 |
| K-01153 | 4279.0$^{b}$ | 5265.4$^{a}$ | 4772.2 | 2147.8$^{a}$ | 2234.5$^{a}$ | 2191.2 |
| K-01155 | 3704.9$^{b}$ | 3882.7$^{c}$ | 3793.8 | 1283.9$^{c}$ | 1796.2$^{b}$ | 1540.1 |
| K-01158 | 3320.9$^{c}$ | 5222.2$^{a}$ | 4271.6 | 1104.9$^{c}$ | 1925.9$^{b}$ | 1515.4 |
| K-01208 | 4241.1$^{b}$ | 3218.5$^{d}$ | 3779.8 | 1555.5$^{b}$ | 1500$^{c}$ | 1527.7 |
| K-01209 | 4038.4$^{b}$ | 5445.6$^{a}$ | 4742.0 | 1543.2$^{b}$ | 2132.3$^{a}$ | 1837.8 |
| K-01210 | 4086.4$^{b}$ | 4617.2$^{b}$ | 4351.8 | 1548.3$^{b}$ | 2065.4$^{b}$ | 1806.9 |
| K-01213 | 4186.9$^{c}$ | 5351.8$^{a}$ | 4769.3 | 1603.9$^{b}$ | 1970.7$^{b}$ | 1787.3 |
| K-08003 | 3202.4$^{c}$ | 4993.8$^{b}$ | 4098.1 | 1219.7$^{c}$ | 2036.0$^{b}$ | 1627.8 |
| K-08817 | 3555.5$^{c}$ | 3611.1$^{c}$ | 3583.3 | 1320.9$^{c}$ | 1261.8$^{c}$ | 1291.4 |
| K-08021 | 3503.7$^{c}$ | 5556.7$^{a}$ | 4530.2 | 1209.8$^{c}$ | 2197.5$^{a}$ | 1703.7 |
| K-60066 | 4103.9$^{b}$ | 5237.0$^{a}$ | 4670.4 | 1668.5$^{b}$ | 1975.3$^{b}$ | 1821.9 |
| K-60069 | 3564.1$^{c}$ | 4345.6$^{b}$ | 3954.9 | 1506.1$^{b}$ | 1604.9$^{c}$ | 1555.5 |
| K-60075 | 3949.3$^{b}$ | 5222.2$^{a}$ | 4585.8 | 1456.7$^{c}$ | 2006.2$^{b}$ | 1731.5 |
| K-70009 | 3760.3$^{b}$ | 3748.1$^{c}$ | 3754.2 | 1505.6$^{b}$ | 1395.0$^{c}$ | 1450.3 |
| K-600508 | 4307.9$^{b}$ | 4387.6$^{b}$ | 4347.8 | 1679.0$^{b}$ | 1444.4$^{c}$ | 1561.7 |
| K-CH-47 | 4168.8$^{b}$ | 4304.9$^{b}$ | 4236.9 | 1274.9$^{c}$ | 1647.7$^{c}$ | 1461.3 |
| K-FLIP | 4438.3$^{b}$ | 4075.3$^{c}$ | 4256.8 | 1543.2$^{b}$ | 1423.7$^{c}$ | 1483.4 |
| NKC(5-5-20) | 3692.3$^{b}$ | 4466.6$^{b}$ | 4079.4 | 1965.4$^{a}$ | 1543.2$^{c}$ | 1754.3 |
| NKC(10-99) | 2840.3$^{c}$ | 3337.0$^{c}$ | 3088.6 | 1506.1$^{b}$ | 1293.8$^{c}$ | 1400 |
| D-KARAK-1 | 4171.3$^{b}$ | 3493.8$^{c}$ | 3832.5 | 1271.6$^{c}$ | 1703.7$^{b}$ | 1487.6 |
| D-KARAK-2 | 3401.9$^{c}$ | 3907.5$^{c}$ | 3654.7 | 1524.6$^{b}$ | 1506.1$^{c}$ | 1515.4 |
| D-KARAK-3 | 4269.1$^{b}$ | 5661.7$^{a}$ | 4965.4 | 1629.6$^{b}$ | 1845.6$^{b}$ | 1737.6 |
| NIFA | 4349.8$^{b}$ | 4804.9$^{b}$ | 4577.3 | 1777.7$^{b}$ | 1962.9$^{b}$ | 1870.3 |
| **Mean** | **4040.68** | **4672.08** | | **1575.41** | **1865.4** | |

**Table 11.** Mean performance of chickpea genotypes for harvest index under untreated and treated environments.

| | Harvest Index% | | |
|---|---|---|---|
| **Genotype** | **Untreated** | **Treated** | **Mean** |
| D-08625 | $39.82^{c}$ | $31.38^{e}$ | 35.60 |
| D-09027 | $36.39^{c}$ | $30.15^{e}$ | 33.28 |
| D-10008 | $39.57^{c}$ | $36.45^{d}$ | 38.01 |
| D-10039 | $32.95^{d}$ | $43.06^{c}$ | 38.01 |
| D-11030 | $44.08^{b}$ | $42.93^{c}$ | 43.50 |
| D-12011 | $40.88^{c}$ | $35.08^{d}$ | 37.98 |
| D-13011 | $36.87^{c}$ | $39.42^{c}$ | 37.98 |
| D-13012 | $39.54^{c}$ | $41.45^{c}$ | 40.50 |
| D-13031 | $46.80^{b}$ | $41.57^{c}$ | 44.19 |
| D-13036 | $40.37^{c}$ | $38.80^{c}$ | 39.58 |
| D-14005 | $40.87^{c}$ | $39.15^{c}$ | 40.01 |
| D-15005 | $33.60^{d}$ | $40.57^{c}$ | 37.09 |
| D-15012 | $39.59^{b}$ | $54.54^{a}$ | 47.06 |
| D-15015 | $35.83^{c}$ | $52.73^{a}$ | 44.28 |
| D-15018 | $44.87^{c}$ | $48.50^{b}$ | 46.69 |
| D-15020 | $37.90^{c}$ | $55.66^{a}$ | 46.78 |
| D-15036 | $36.70^{c}$ | $43.76^{c}$ | 40.23 |
| D-93127 | $41.25^{c}$ | $42.56^{c}$ | 41.90 |
| D-97086 | $39.84^{c}$ | $43.44^{c}$ | 41.64 |
| D-14014 | $29.50^{e}$ | $42.80^{c}$ | 36.15 |
| K-01151 | $40.67^{c}$ | $48.90^{b}$ | 44.78 |
| K-01153 | $50.31^{a}$ | $42.33^{c}$ | 46.32 |
| K-01155 | $34.57^{d}$ | $45.72^{b}$ | 40.15 |
| K-01158 | $33.24^{d}$ | $37.20^{d}$ | 35.22 |
| K-01208 | $37.36^{c}$ | $52.41^{a}$ | 44.88 |
| K-01209 | $38.25^{c}$ | $39.18^{c}$ | 38.71 |
| K-01210 | $37.03^{c}$ | $44.71^{b}$ | 40.87 |
| K-01213 | $37.77^{c}$ | $36.81^{d}$ | 37.29 |
| K-08003 | $38.57^{c}$ | $40.61^{c}$ | 39.59 |
| K-08817 | $37.05^{d}$ | $34.95^{d}$ | 36.00 |
| K-08021 | $34.53^{c}$ | $39.53^{c}$ | 37.03 |
| K-60066 | $40.56^{b}$ | $37.68^{d}$ | 39.12 |
| K-60069 | $42.19^{c}$ | $36.95^{d}$ | 39.57 |
| K-60075 | $36.96^{c}$ | $38.37^{d}$ | 37.67 |
| K-70009 | $40.13^{c}$ | $37.11^{e}$ | 38.62 |
| K-600508 | $38.97^{e}$ | 33.07d | 36.02 |
| K-CH-47 | $30.64^{e}$ | $38.20^{d}$ | 34.42 |
| K-FLIP | $34.76^{d}$ | $34.86^{d}$ | 34.81 |
| NKC(5-5-20) | $49.60^{a}$ | $34.21^{d}$ | 41.91 |
| NKC(10-99) | $52.88^{a}$ | $39.14^{c}$ | 46.25 |
| D-KARAK-1 | $30.63^{e}$ | $48.78^{b}$ | 39.70 |
| D-KARAK-2 | $43.67^{b}$ | $38.46^{d}$ | 41.06 |
| D-KARAK-3 | $37.98^{c}$ | $32.59^{e}$ | 35.28 |
| NIFA | $42.14^{b}$ | $40.84^{c}$ | 41.49 |
| **Mean** | **39.26** | **40.77** | |

Although pod number showed very high heritability, its relatively low genetic advance indicates that high heritability did not necessarily translate into proportionally large expected selection gains. Thus, pod number represents a genetically informative trait, but its breeding value is greatest when considered together with pest resistance and yield stability [37].

Seeds per pod is a more specific measure of reproductive success because it reflects the extent to which established pods successfully develop and retain seeds. The present study showed significant genotype, environment and genotype × environment effects, with seed number generally higher under insecticide-treated conditions than under untreated conditions. The relatively high environmental contribution and low-to-moderate heritability indicate that seed number was more sensitive to environmental conditions than traits such as flowering time or pod number. Reduced pod-borer pressure may have improved the retention and development of reproductive structures, thereby increasing the opportunity for seed formation. Previous studies have similarly reported substantial environmental influence on seeds per pod and variable heritability estimates in chickpea [38, 39]. The low genetic advance observed here further indicates that direct selection for seeds per pod alone is unlikely to produce substantial improvement. Instead, this trait should be incorporated into multi-trait selection strategies targeting reproductive stability under pest pressure.

Seed size is an important component of chickpea market value and yield because it contributes directly to grain weight and can reflect the plant's ability to complete seed filling under stress. The present study revealed significant genotype, environment and genotype × environment effects for 100-seed weight, with the mean value increasing from 26.38 g under untreated conditions to 26.89 g under insecticide treatment. The improvement under pest protection suggests that reduced reproductive damage may have allowed greater allocation of assimilates to surviving seeds and more complete seed development. The predominance of genotypic variance and moderate-to-high heritability indicates substantial genetic influence, but the low genetic advance suggests limited expected improvement from direct selection. A similar combination of heritability and limited genetic advance has been reported for yield-related traits in chickpea [29]. Therefore, seed size may provide useful information for genotype discrimination, but its selection should be integrated with pod-borer resistance and overall grain yield.

**4.4. Biomass production and seed yield**

Biological yield provides an integrated measure of vegetative and reproductive biomass accumulation and is therefore useful for understanding how pest pressure influences whole-plant productivity. In the present study, biological yield was significantly affected by genotype, pest-management environment and genotype × environment interaction, and mean biomass increased from 4040.68 kg $ha^{-1}$ under untreated conditions to 4672.08 kg $h^{-1}$ under insecticide treatment. D-11030 showed consistently high biomass production in both environments, reaching 5266.3 kg $ha^{-1}$ under untreated conditions and 5903.7 kg $ha^{-1}$ under treated conditions. The increase in biomass under pest protection is consistent with reduced tissue and reproductive damage, which would allow greater maintenance of photosynthetic activity and biomass accumulation. Moderate heritability combined with high genetic advance indicates that biological yield has greater potential for response to selection than several of the component traits considered above. Similar genetic variability and heritable variation for yield traits have been reported in chickpea [44–46], while the occurrence of significant genotype × environment interactions in previous studies reinforces the importance of evaluating biomass production under contrasting conditions [47]. Thus, biological yield appears to combine meaningful genetic variation with appreciable selection potential, although stable grain production remains the more direct breeding objective.

Seed yield is the ultimate agronomic measure of genotype performance because it integrates phenology, plant architecture, reproductive development, seed formation and the consequences of pest injury. The strong genotype, environment and genotype × environment effects observed here demonstrate that grain production was determined by both genetic potential and the ability of individual genotypes to tolerate or escape pod-borer pressure. Mean seed yield increased from 1575.41 kg ha−1 under untreated conditions to 1865.4 kg ha−1 under insecticide treatment, while D-11030 maintained the highest yield across both environments, reaching 2323.6 kg ha−1 without insecticide and 2518.5 kg ha−1 under insecticide protection. The relatively modest increase in D-11030 compared with several more susceptible genotypes suggests that its superior performance was not simply a consequence of chemical protection but reflected a comparatively stable yield potential under contrasting pest pressure. This interpretation is supported by its high pod production, productive branching and relatively low pod damage. The predominance of genotypic variance, together with heritability estimates of 0.61 and 0.67 and high genetic advance, indicates substantial opportunity for genetic improvement of seed yield. Similar heritable variation and selection potential for grain yield have been reported in chickpea [47]. Nevertheless, the significant genotype × environment interaction shows that high yield in a single environment is insufficient evidence of broad adaptation. The most valuable breeding materials are therefore those that combine high yield with reduced pest damage and relatively stable performance across contrasting management environments.

Harvest index provides a complementary measure of reproductive efficiency by describing the proportion of accumulated biomass ultimately partitioned into grain. In the present study, harvest index differed significantly among genotypes and between pest-management environments, and the significant genotype × environment interaction indicated that assimilate partitioning responded differently among genotypes to pest pressure. Mean harvest index increased from 39.26% under untreated conditions to 40.77% under insecticide treatment, consistent with improved reproductive development when pod-borer injury was reduced. The high heritability estimates indicate a strong genetic component to harvest index, but the relatively low genetic advance suggests that direct selection for this ratio alone may have limited effectiveness. Similar environmental effects on harvest index have been reported in chickpea [38]. Because harvest index can increase either through greater grain production or through changes in total biomass, its interpretation in breeding should remain linked to absolute seed yield and pest resistance rather than being used as an independent target [29].

### 4.5. Implications for chickpea improvement

Taken together, the results show that pod-borer management does not simply alter the mean performance of chickpea genotypes; it changes the expression of genetic differences among them. The significant genotype × environment interactions observed for most yield and pest-related traits indicate that selection based exclusively on insecticide-protected conditions could favour genotypes whose performance depends strongly on pest suppression. Conversely, evaluation under untreated conditions exposes variation in host resistance and yield maintenance that is directly relevant to sustainable production. This distinction is particularly important because effective breeding for sustainable pest management requires genotypes that can maintain reproductive development and grain production when chemical protection is reduced.

The most compelling evidence comes from the joint performance of the leading genotypes. D-11030 combined high and relatively stable seed yield with strong biomass production, numerous productive branches and pods, while D-14005 showed the lowest pod damage. K-01153 also demonstrated strong productivity, whereas K-01213 and K-70009 provided additional genetic variation relevant to the combined objectives of yield and reduced pod-borer damage. These genotypes therefore represent different but potentially complementary sources of breeding value: some contribute high yield potential, whereas others provide stronger resistance-related traits. Their value will ultimately depend on whether these traits remain stable across broader environmental conditions.

Overall, the study demonstrates that combining pest resistance with yield stability provides a more informative breeding criterion than either trait alone. High heritability and genetic advance for biological and seed yield indicate meaningful potential for selection, whereas the lower genetic advance observed for several component and resistance traits cautions against relying on single-trait selection. The identification of genotypes that maintain productivity while experiencing contrasting pod-borer pressure provides a practical starting point for developing chickpea cultivars that are less dependent on insecticide protection. However, because the present experiment represents two pest-management environments at one location and in one growing season, the stability of these genotypes should be tested across multiple locations, seasons and pest-pressure regimes before broad adaptation is inferred. Such validation will be essential for determining whether the identified combinations of yield potential and pod-borer resistance represent stable genetic adaptation rather than site- or season-specific responses.

## 5. Conclusions

The study revealed substantial genetic variation among the 44 chickpea (*Cicer arietinum* L.) genotypes for most agro-morphological and yield-related traits. Significant genotype × pest-management interactions indicated differential genotype responses to treated and untreated conditions. High heritability and genetic advance for biological and seed yield indicated good potential for genetic improvement through selection. D-11030 showed superior and consistent seed yield across both conditions, while D-14005 exhibited the lowest pod damage. D-11030, D-14005, K-01153, K-01213, and K-70009 were identified as promising genotypes combining high yield and reduced pod-borer damage. These genotypes warrant further multi-environment and multi-year evaluation to confirm their stability and suitability for chickpea improvement and sustainable production.

## Author contributions

Sarbaz Khan: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing—original draft; writing—review and editing. Rozina Gul: Conceptualization; data curation; formal analysis; funding acquisition; investigation; methodology; project administration; resources; software; supervision; validation; visualization; writing—original draft; writing -review and editing. Husnain Arif: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review and editing. Furqan Alam: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing - Review and editing. Sada Bahar: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Supervision, Writing - Review and editing. Hamayoon Khan: Resources, software, supervision, writing (Review and editing). Sheryar Khan: Formal analysis, supervision, validation, visualization, writing – review and editing. Asfandyar Khan: conceptualization, data curation, investigation, methodology, supervision, validation, writing – review and editing.

## Ethical approval

Not applicable.

## Conflicts of Interest

The authors report no conflicts of interest.

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## Data availability statement

The data presented in this study are available on request from the corresponding author.

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