Research Article

Interaction Effect of Planting Dates and Genotypes on Yield Related Traits of Chickpea

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Abstract | Chickpea is one of the most important pulse crop grown both in arid and semiarid regions of Pakistan. Productivity of chickpea is affected by several biotic and abiotic factors. Therefore, in this field experiment, 23 chickpea genotypes were examined under three different planting dates for yield components. Chickpea genotypes were examined using three replications in randomized complete block design (RCBD) to examine effect of genotypes, environments and genotype by planting date (G×P) interaction under early, normal and late planting at the University of Agriculture Peshawar during 2020-21. Statistically, pooled ANOVA revealed significant ($P \leq 0.01$) differences among genotypes, planting dates and G×P interaction for most of the studied traits. However, secondary branches plant^{-1}, seeds pod^{-1} and 100-grain weight were non-significantly influenced by G×P interaction. Mean data across three environments revealed that genotype NDC-122 produced maximum primary branches, genotype NDC-15-4 produced most pod plant^{-1} and seed pod^{-1}, while genotype NDC-15-4 produced highest seed yield. The G×P interaction revealed maximum primary branches plant^{-1} for genotype NDC-122, pods plant^{-1} for NDC-15-4, seeds pod^{-1} for NDC-15-4 and seed yield for genotype NDC-15-4. Seed yield showed high heritability of 0.94 under both early and normal planting and 0.91 under late planting. Biological yield also revealed high heritability of 0.80, 0.97 and 0.69 under early, normal and late planting, respectively. Seed yield showed positive genotypic and phenotypic association with plant height, secondary branches, pods plant^{-1}, seeds pod^{-1} and biological yield across all planting dates. Maximum seed yield was recorded for NIFA-2005 under early planting, for NDC-15-4 under normal planting, while for EG1 under late planting. Chickpea genotypes NDC-15-4, IG3 and MG5 demonstrated superior yield across three planting dates and can be incorporated into future breeding programs as elite genetic materials.

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Links Researchers

Introduction

Chickpea also called garbanzo bean is an important leguminous crop that belogs to family known as Fabaceae (Keifer and Effenberger, 2018). Chickpea is diploid self-pollinated crop having 16 chromosomes with genome size of 750 Mbp (Avinash and Janeja, 2024; Danakumara *et al*., 2024; Akanksha *et al*., 2016). This crop is mostly cultivated in arid and semiarid regions of many countries. Chickpea have medicinal value and can decrease the risk of numerous diseases when consumed. It is used for purification of blood due to its antiseptic and therapeutic values. It lowers cholesterol level, manage blood sugar and reduce the risk of cardiovascular disorders and diabetes (Noreen *et al*., 2024; Kakaei *et al*., 2024). Chickpea grain constitute 57-60% carbohydrates, 22% proteins, 4.8% ash, 1.4% fats and 4.87-15% moisture (Bayahi and Chaar, 2024; Jha *et al*., 2024; Hassan *et al*., 2008).

Production of chickpea is hindered by several abiotic and biotic factors such as planting time, water stress, diseases and insect pests that leads to yield loss (Ali *et al*., 2008). Chickpea crop is known to withstand heat stress but during reproductive phase, heat stress can leads to heavy yield loss (Rathod *et al*., 2024; FAO, 2018; SabaghPour *et al*., 2010). Climatic factors including light, rain fall, day length and temperature together with other factors like seed bed, variety, diseases and weeds are important when selecting planting date (Maleki *et al*., 2024; Khajehpour, 2000). Among biotic factors, common insects of chickpea are aphids, pod borer and gram caterpillar, while diseases affecting productivity of chickpea are bacterial blight, wilt and root rot (Priyadarshini *et al*., 2024; War *et al*., 2024; Khalil and Jan, 2002).

To cope with this, the process of selection is fruitful when a population has high genetic variation. Understanding genetic basis of variation is useful for genetic improvement as genetic variances are essential for crop improvement (Hailu, 2020). Improvement in seed yield of chickpea under unpredictable environmental conditions especially terminal temperature stress has many limitations. In this case, direct selection may waste resources without fruitful results (Saeed *et al*., 2025). Correlation studies provide information on the type and extent of association of yield with other component traits. Therefore, correlation can be exploited in chickpea breeding and selection programs (Bharat, 2024; Ahmad *et al*., 2003). Yield may be improved by selecting desirable genotype which has the ability to produce high yield in a given environment. G×E interaction may influence further quantitative characters that are agronomic and economically important such as grain yield (Maleki *et al*., 2024).

Planting date is a critical determinant of productivity and quality and exert significant influence on the performance of chickpea genotypes. Late planting has a negative effect on plant growth and result in reduced yield. While planting at optimum time provide more time for growth and development leading to increased seed yield (Husnain *et al*., 2015). Chickpea yield loss varies from 30 to 60 percent depending upon genotype, planting date and weather during the growing season. It has been observed that some genotypes of chickpea are resilient to water stress, thus planting can be delayed. Deviation from optimal planting dates, either early or late adversely impacts chickpea growth and productivity that reduces economic returns (Devasirvatham and Tan, 2018). With the development of new genotypes, it becomes essential to test them at different planting dates to exploit their full production potential (Lake and Sadras, 2024; Prasad *et al*., 2012). Therefore, current research study was planned to determine optimum planting date for chickpea in relation to growth and yield performance.

Materials and Methods

Experimental site, materials and design

Twenty-three chickpea genotypes were examined in a randomized complete block design with three replications under three different planting dates at the University of Agriculture Peshawar during 2020-21 (Table 1). Early plantation was performed on 3rd October, normal planting on 22nd October, while late planting was performed on 5th December of 2020. Area of experimental plot was 2.7m^2. Each genotype was sown into three rows each 3m long with inter row spacing of 30 cm, while plant to plant distance was 10 cm.

Land preparation and other treatments

Land was deep ploughed with chisel plough on 21th September and left open for one week. Cultivator followed by planking was used on 28 September, 2020 to break the clods, invert the soil properly and to conserve the moisture. Field was prepared one day before planting by rotavator and sown the seeds by manual seed drill for each planting date separately. Compound fertilizer DAP was applied as 2.3 kg plot^{-1} at the time of planting to each planting separately using standard rate of 50 kg acre^{-1}. First irrigation was performed 60 days after planting followed by hand weeding at wattar, while second irrigation was done during pod development stage for each planting. Also each planting was treated with insecticide Emamectin benzoate @200 ml acre^{-1} to control gram pod borer during the pod development period.

Meteorological data of experimental site

Meteorological data available at Agronomy Research Farm of University of Agriculture Peshawar was considered for the experimental site and the following weather variables were noted (See data at the end of the page).

Traits measured

Data was recorded on: Days to emergence (DE), Days to maturity (DM), Plant height (PH), primary (PBP) and secondary branches (SBP), pods plant^{-1} (PPP), seeds pod^{-1} (SPP), 100-grain weight (HGW), seed yield (SY) and biological yield (BY).

Days to emergence: Days to emergence were observed from the date of planting to the date when 50% of the plants emerged from the soil surface in each plot.

Days to maturity: The maturity data was noted from the time of planting until 90% of the plants in each plot reached physiological maturity.

Plant height (cm): The height of five randomly selected plants was measured from the soil surface to the tip at physiological maturity in each plot.

Primary branches plant^{-1}: Primary branches were counted on randomly selected five plants at the time of harvesting and averaged to compute mean value.

Secondary branches plant^{-1}: Secondary branches were counted on randomly selected five plants at the time of harvesting and then mean was computed.

Table 1: *List of 23 desi chickpea genotypes tested at the University of Agriculture Peshawar during 2020-21.*

Genotypes	Origin	Parents
AG1	PBG-UAP	ICC 19181 × NDC 4-20-4
BG4	-	-
BG5	-	-
EG1	-	-
GG1	-	-
IG1	-	-
IG2	-	-
IG3	-	-
KG1	-	-
MG4	-	-
MG5	-	-
NDC-122	NIFA	C-44 × ILC-195
NDC-15-1	-	PB-91/M
NDC-15-4	-	-
NDC-4-20-1	-	C-44/M
NDC-4-20-2	-	-
NDC-4-20-3	-	-
NDC-4-20-40	-	-
NDC-4-20-5	-	-
NDC-4-20-6	-	-
NIFA-2005	-	PB-91/M
KARAK-1	ARS Karak	Local selection
KARAK-3	-	-

NIFA= Nuclear Institute for Food and Agriculture, Tarnab Peshawar; PBG and UAP= Department of Plant Breeding and Genetics, University of Agriculture Peshawar, Khyber Pakhtunkhwa; ARS= Agricultural Research Station Karak.

Meteorological data at Research Farm of University of Agriculture Peshawar during 2020-21.

Weather variables	October	November	December	January	February	March	April	May
Min. Temperature °C	7	4	5	6	9	10	15	21
Max. Temperature °C	19	22	20	19	20	25	30	36
Avg. Temperature °C	13.0	13.0	12.5	12.6	14.4	17.5	22.4	28.7
Rainfall mm	18	23	40	36	60	88	76	31
Humidity (%)	49	50	52	53	54	53	42	28
Rainy days	1	2	2	3	3	4	3	3
Avg. Sun hours	8.3	8.2	8.0	8.4	8.6	9.8	11.3	12.5

Pods plant^{-1}: Data on pods plant^{-1} was recorded after pods from five randomly selected plants were taken and counted separately.

Seeds pod^{-1}: Data for seeds pods^{-1} was acquired by counting total numbers of seed from five pods picked from randomly selected five plants and then mean was calculated.

100-grain weight (g): A sample of 100-grains was taken from threshed seed lot and weighed using an electronic balance to calculate 100-grain weight.

Seed yield (kg ha^{-1}): The yield plot^{-1} was converted to kg ha^{-1} using the following formula.

$$\text{Seed yield (kg ha}^{-1}) = \frac{\text{Seed yield plot}^{-1}\text{ (g)}}{\text{Plot area (2.7 m2)}} \times 10000$$

Biological yield (kg ha^{-1}): Biological yield from each plot was calculated after harvesting and sun drying to estimate biological yield plot^{-1} using the following formula.

$$\text{Biological yield (kg ha}^{-1}) = \frac{\text{Biomass yield plot}^{-1}\text{ (g)}}{\text{Plot area (2.7 m2)}} \times 10000$$

Statistical analysis

To elucidate genotype × planting date (G×P) interaction, data collected across three planting dates was subjected to analysis as per Gomez and Gomez (1984) to estimate variance components for all the studied traits. Genotype planting date (G×P) interaction significantly affected critical yield components of chickpea, therefore data was subsequently analyzed separately for each planting date to estimate genetic parameters under each planting. Variance components such as genetic (σ^2g), phenotypic (σ^2p), environmental (σ^2e) variances and heritability (h^2) were computed using ANOVA.

Heritability estimates for traits was computed under each environment using the following formulas:

$$\sigma^2 g = (\text{Mean squares of genotype} - \text{Mean squares of error}) / \text{replications}$$
$$\sigma^2 e = \text{Mean squares of error}$$
$$\sigma^2 p = \sigma^2 g + \sigma^2 e$$
$$h^2_{bs} = \sigma^2 g / \sigma^2 p$$

Genotypic and phenotypic correlations among various traits were estimated as per Singh and Chaudhary (1985).

$$\text{Phenotypic correlation } (r_p) = CoV_p(x_1, x_2) / \sqrt{[V_p(x_1) \times V_p(x_2)]},$$
$$\text{Genotypic correlation } (r_g) = CoV_g(x_1, x_2) / \sqrt{[V_g(x_1) \times V_g(x_2)]}$$

Where; $CoV_p(x_1,x_2)$ = phenotypic covariance between two variables, $V_p(x_1)$ and $V_p(x_2)$ = phenotypic variances of two variables, $CoV_g(x_1, x_2)$ = genotypic covariance between two variables, $V_g(x_1)$ and $V_g(x_2)$ = genotypic variances of two variables.

Results and Discussion

Analysis of variance, range values and heritability

Days to emergence: The combined analysis for days to emergence across three environments (early, normal and late planting) showed significant (P≤0.01) variations among genotypes and environments. However, genotype × planting date interaction was non-significant for emergence days (Table 2). Across environments, mean for days to emergence ranged from 10.8 (NDC-4-20-2) to 14.7 days (NDC-4-20-1). Genotype × planting dates interaction for days to emergence ranged from 8.3 (NDC-4-20-2) to 16.0 days (MG4). The mean values for days to emergence ranged from 11.0 (NDC-15-1) to 15.3 (IG3) under early planting, from 8.3 (NDC-4-20-2) to 13.3 (MG4) under normal planting, while it ranged from 11.3 (NDC-4-20-2) to 16.0 (MG4) under late planting (Figure 1). Both early and late planted genotypes took more days to emerge as compared to normal planting. This is possibly due to temperature extremes that affect seed germination of chickpea (Shukla *et al*., 2010).

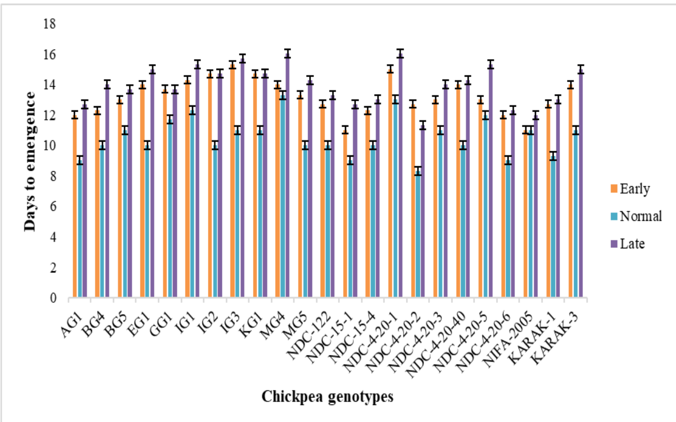

Figure 1: *Days to emergence of 23 chickpea genotypes examined under three different planting dates.*

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Table 2: *Mean square values for yield related traits of 23 chickpea genotypes across three environments (early, normal and late planting) at Peshawar during 2020-21.*

Traits	Replications (6)	Environments (2)	Genotypes (22)	G×Env (44)	Error (132)
Days to emergence	0.17	224.87**	11.57**	1.44ns	1.90
Days to maturity	0.39	8657.69**	29.17**	11.62**	2.85
Plant height	0.32	674.54**	19.86**	7.93**	2.64
Primary branches plant^{-1}	0.06	2.92**	0.57*	0.50*	0.34
Secondary branches plant^{-1}	0.40	233.32**	6.22**	1.53ns	1.52
Pods plant^{-1}	9.13	6840.76**	29.17**	14.69**	7.43
Seeds pod^{-1}	0.04	0.41**	0.43**	0.15ns	0.18
100-grain weight	2.46	32.37**	19.52**	4.30ns	3.31
Seed yield	196.79	14143462.01**	135070.51**	79300.00**	1984.84
Biological yield	5019.94	129881281.56**	1300243.78**	690536.08**	31828.84

**, **: significant at the probability of 0.05 and 0.01, respectively.*

Table 3: *Estimates of heritability (h^2) and variance components for studied traits in 23 chickpea genotypes evaluated across three planting environments (early, normal, and late) during the 2020-21 cropping season.*

Traits	Environment	Vg	Ve	Vp	h^2
Days to emergence	Early	0.73	2.06	2.79	0.26
	Normal	1.31	1.18	2.49	0.52
	Late	1.29	2.22	3.51	0.36
Days to maturity	Early	3.70	2.52	6.22	0.59
	Normal	8.22	3.98	12.20	0.67
	Late	2.72	1.93	4.65	0.58
Plant height	Early	4.48	2.04	6.53	0.68
	Normal	3.57	3.33	6.91	0.51
	Late	1.30	2.25	3.55	0.36
Primary branches plant^{-1}	Early	0.088	0.36	0.45	0.19
	Normal	0.11	0.4	0.51	0.21
	Late	0.043	0.2	0.25	0.17
Secondary branches plant^{-1}	Early	0.82	1.06	1.89	0.43
	Normal	0.75	1.65	2.4	0.31
	Late	0.17	1.3	1.48	0.12
Pods plant^{-1}	Early	1.18	8.3	9.49	0.12
	Normal	7.19	7.12	14.31	0.50
	Late	3.96	6.09	10.06	0.39
Seeds pod^{-1}	Early	0.02	0.17	0.19	0.11
	Normal	0.04	0.19	0.23	0.17
	Late	0.02	0.14	0.16	0.13
100 grain weight	Early	0.83	3.48	4.31	0.19
	Normal	3.33	2.94	6.27	0.53
	Late	1.98	3.28	5.26	0.38
Seed yield	Early	14073.58	769.98	14843.56	0.94
	Normal	74697.78	4365.96	79063.74	0.94
	Late	7169.2	713	7882.07	0.91
Biological yield	Early	212701.48	51131.17	263832.66	0.80
	Normal	582928.27	12471.96	595400.24	0.97
	Late	67082.39	29576.35	96658.74	0.69

Low broad sense heritability value of 0.26 was recorded for days to emergence under early planting, while moderate heritability of 0.52 and 0.36 were recorded for days to emergence under normal and late planting, respectively (Table 3). Previously, Soltani *et al.* (2006) also reported significant (P ≤ 0.01) variations among environments and non-significant genotype × environment interaction, while studying chickpea genotypes. Previously, Itana *et al.* (2024) reported moderate heritability for days to emergence which is similar to our findings.

Days to maturity

Pooled analysis for days to maturity showed significant (P≤0.01) variation across environments, genotypes and their interaction (G×P) (Table 2). Average across environments, mean for days to maturity ranged from 166.2 (Karak-1) to 172.4 days (NDC-4-20-1). The mean value for maturity ranged from 176.3 (Karak-3) to 183.7 (NDC-4-20-2) under early planting, from 165.0 (Karak-3) to 176.0 (NDC-4-20-2) under normal planting and from 154.0 (AG1) to 160.7 (IG3) under late planting (Figure 2). Early maturity is desirable due to our cropping pattern and intensity (Pathak *et al.*, 2012). Earliness can also be ensured by early and normal planting of chickpea (Rasool *et al.*, 2024).

Moderate broad sense heritability values of 0.59 and 0.58 were observed for maturity under early and late planting, respectively. Likewise, high broad sense heritability value of 0.67 was observed for days to maturity under normal planting condition (Table 3). Likewise, Yadav *et al.* (2010) reported significant variations across environments and genotypes, while their findings showed non-significant differences for genotype × environment interaction (G×E) which contradicted our findings. Likewise, Hailu (2020) also noticed high heritability in chickpea genotypes for days to maturity. Moreover, Malik *et al.* (2010) also noted moderate heritability for days to maturity in chickpea cultivars.

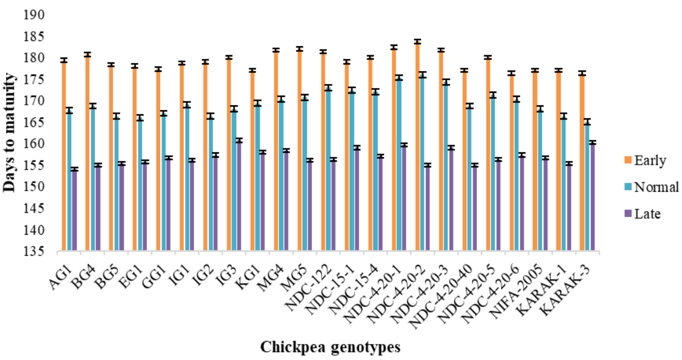

Figure 2: *Days to maturity of 23 chickpea genotypes examined under three different planting dates.*

Plant height (PH)

PH is a key morphological trait in chickpea that significantly influence lodging resistance, yield potential and adaptation to diverse environmental conditions. The analysis of variance for PH unveiled substantial variations across three environments and genotypes. Also, highly significant variations were observed for genotype × planting date interaction (Table 2). This highlight the variations at genetic level for PH.

Across environments, mean for PH of 23 chickpea genotypes ranged from 52.3 (BG4) to 57.9 cm (NDC-15-4). Plant height of 23 chickpea genotypes under early planting ranged from 53.0 (NDC-4-20-5) to 62.0 cm (NIFA-2005) and under normal planting, from 53.0 (NDC-4-20-6) to 61.0 cm (NDC-15-4). Moreover, under late planting, plant height ranged from 49.3 (BG4) to 55.0 cm (NIFA-2005). Chickpea genotypes had taller plants under normal planting (57.2 cm) than that of early (57.1 cm) and late plantings (51.7 cm) (Figure 3). Previous study by Gungor (2024) revealed that winter planted chickpea attained more height (50.8 cm) than spring planted crop (45.6 cm) due to optimum growing condition during winter months. Likewise, late planting reduced plant height across most locations during 2018 and 2019 (Richards *et al.*, 2022).

High heritability value of 0.68 was observed for PH under early planting condition. Likewise, moderate heritability values of 0.51 and 0.36 were observed for PH under normal and late planting, respectively (Table 3). Research findings of Tejasree *et al.* (2021) and Desai *et al.* (2016) coincide with our results, demonstrating significant variations among environments, genotypes as well as G×E effects on plant height. Previously, Mohibullah *et al.* (2020) revealed moderate heritability for PH, while Gautam *et al.* (2021) reported high heritability for PH which showed the importance of additive genetic factors in controlling PH.

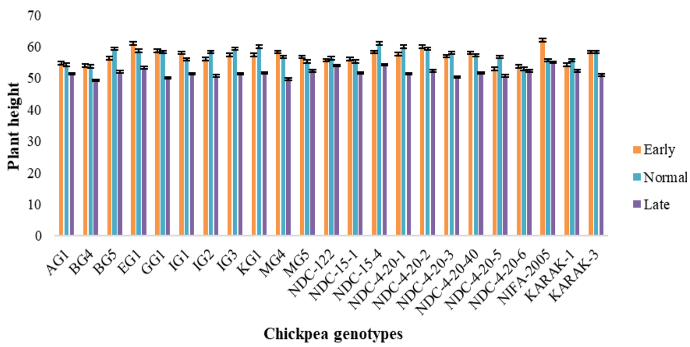

Figure 3: *Plant height of 23 chickpea genotypes examined under three different planting dates.*

Primary branches plant^{-1} (PBP)

PBP is important yield component in chickpea, affecting pod formation and seed yield. Mean square values for PBP revealed significant variations across environments and genotypes. Likewise, genotype × planting date interaction was also significant (Table 2). This proved the differential in performance of chickpea genotypes over different planting dates. Across environments, the mean for chickpea genotypes ranged from 2.1 (BG5) to 2.9 (NDC-122, NDC-4-20-2 and NDC-4-20-40). The mean values for primary branches ranged from 1.7 (NIFA-2005 and Karak-3) to 3.0 (AG1, NDC-4-20-2, EG1, NDC-4-20-1, IG3, NDC-15-4 and NDC-4-20-40) under early planting, from 2.3 (AG1, BG5, EG1 and IG3) to 3.3 (NDC-122, NDC-4-20-2 and NDC-4-20-5) under normal planting, while from 2.0 (AG1, BG4, BG5, GG1, IG2, NDC-4-20-1 and Karak-1) to 3.0 (NIFA-2005) under late planting (Figure 4). Three genotypes including AG1, EG1 and IG3 had more PBP under early planting, while other genotypes produced more primary branches under normal planting due to significant G×P interaction.

Low broad sense heritability of 0.19, 0.21 and 0.17 were recorded for PBP under early, normal and late planting, respectively (Table 3). Previously, Dehal *et* *al.* (2016) assessed the performance of 25 chickpea genotypes across normal and late planting conditions, revealing significant genotypic, environmental and genotype × environment interaction (G×E) for PBP. This emphasized the complex interplay between genetic and environmental factors influencing PBP. Low heritability for PBP in chickpea was also reported by Bhanu *et al.* (2017). However, previous research findings by Thakur *et al.* (2018) regarding heritability of PBP in chickpea crop contradicted with our findings.

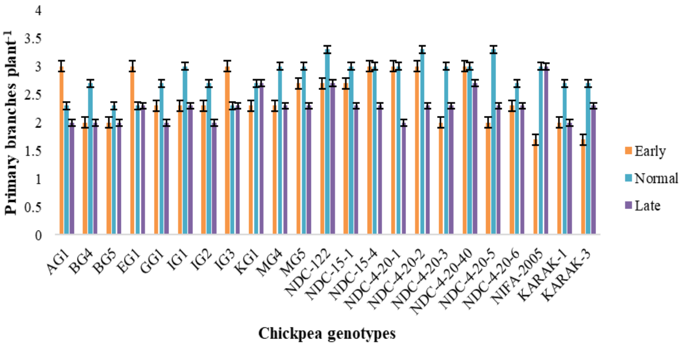

Figure 4: *Primary branches plant^{-1} of 23 chickpea genotypes examined under three different planting dates.*

Secondary branches plant^{-1} (SBP)

SBP in chickpea enhance yield potential, pod density and thus seed production. Mean square analysis revealed significant (P≤0.01) genetic and environmental effects on SBP in chickpea. This authenticated substantial variability among genotypes and planting dates for SBP. However, genotype × planting date interaction (G×P) was non-significant, suggesting stable expression for SBP across environments (Table 2). Average over three environments, mean for SBP of 23 chickpea genotypes ranged from 5.8 (MG4, Karak-1 and Karak-3) to 8.4 (EG1, IG3 and NDC-15-4). Mean secondary branches ranged from 4.7 (MG4) to 9.0 (IG3) under early planting, from 6.9 (Karak-1) to 11.0 (EG1and NDC-15-4) under normal planting, while from 4.3 (NDC-4-20-3 and Karak-3) to 7.1 (NDC-15-4) under late planting (Figure 5). Previously, Himanshu *et al.* (2024) reported that October planted chickpea crop produced more branches than November planted chickpea crop.

Moderate heritability values of 0.43 and 0.31 were recorded for SBP under both early and normal planting, respectively. However, low broad sense heritability (0.12) was recoded under late planting environment (Table 3). Previously, Hussen *et al.* (2013) also found substantial variations across environments and genotypes for SBP. But their findings of significant genotype × environment interaction for SBP were in contrast with our research results. Previous study by Mohan and Thiyagarajan (2019) also reported moderate heritability for SBP. However, Malik *et al.* (2010) assessed 20 chickpea cultivars and declared high heritability for SBP, which opposed our results.

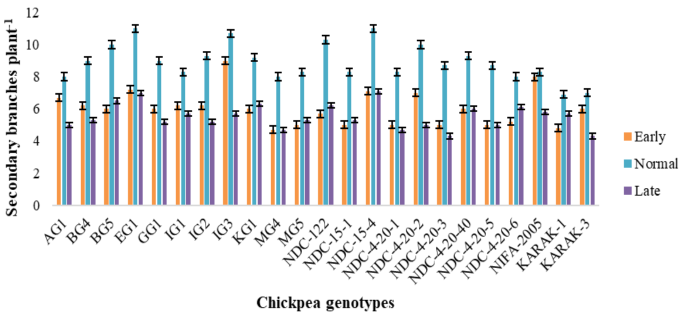

Figure 5: *Secondary branches plant^{-1} of 23 chickpea genotypes examined under three different planting dates.*

Pods plant^{-1} (PPP)

PPP is a key determinant of chickpea yield potential, reflecting the plant's reproductive efficiency and capacity for seed production. Pooled analysis for PPP depicted substantial (P≤0.01) variations across environments. Mean squares of data revealed highly significant (P ≤ 0.01) genetic and genotype × planting date interaction (G×P), highlighting the complex relationship between genetic and environmental factors influencing phenotypic expression (Table 2). Significant genotype × planting date interaction confirmed that performance of chickpea genotypes must vary over different planting dates. Average across three environments, PPP varied from 32.3 (MG4) to 40.2 (NDC-15-4) indicating significant interaction for this trait as evidenced by ANOVA. The mean values for pods plant^{-1} ranged from 28.7 (MG4) to 37.0 (NIFA-2005) under early planting, from 42.0 (IGI) to 54.7 (NDC-15-4) under normal planting, while from 24.0 (IG2) to 34.0 (NDC-15-4) under late planting (Figure 6). Optimum plant water status, temperature, photoperiod, sunshine hours, chlorophyll content and rate of photosynthesis under early planting result in more number of pods plant^{-1} (Kumar *et al.*, 2023).

Low broad sense heritability of 0.12 was estimated for PPP under early planting, while moderate broad sense heritability values of 0.50 and 0.39 were recorded for PPP under both normal and late planting, respectively (Table 3). Consistent with our study, Sharma *et al.* (2021) also observed significant genotypic, environmental and G×E interation for PPP in chickpea. Our results are also aligned with Bhanu *et al*. (2017) and Sharma *et al*. (2021), who demonstrated low and moderate heritability (0.25 and 0.38, respectively) for PPP in chickpea. This indicated that genotype had substantially influenced the studied trait.

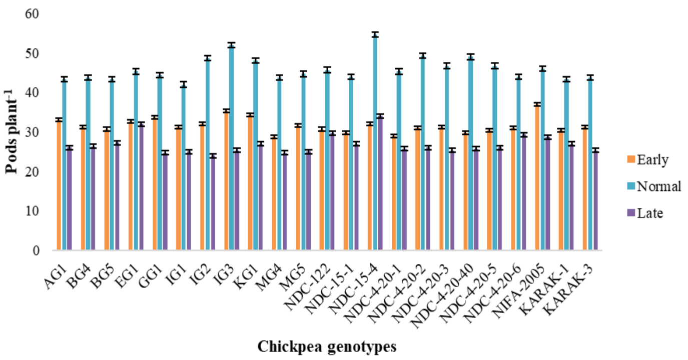

Figure 6: *Pods plant^{-1} of 23 chickpea genotypes examined under three different planting dates.*

Seeds pod^{-1} (SPP)

SPP directly affect chickpea seed yield as this directly impacts seed number per plant and overall seed weight. Mean square analysis for SPP unveiled substantial (P≤0.01) variations across environments and genotypes, while genotype × planting date interaction was non-significant for SPP (Table 2). This proved similar behaviour of chickpea genotypes for SPP under three different planting dates. Across environments, the mean of genotypes for SPP varied from 1.3 (Karak-1) to 2.3 (NDC-15-4). The mean seeds pod^{-1} values ranged from 1.3 (NDC-4-20-5 and Karak-1) to 2.3 (NIFA-2005) under early planting, from 1.2 (Karak-3) to 2.6 (NDC-15-4) under normal planting, while from 1.3 (IG2 and MG4) to 2.2 (EG1) under late planting (Figure 7). Likewise, Thapa *et al*. (2022) reported that seeds pod^{-1} (27.53) under early planting were greater than SPP (10.57) under late planting due to more time taken for photosynthesis and pod development.

SPP showed low broad sense heritability estimates under early (0.11), normal (0.17) and late (0.13) planting (Table 3). For SPP in chickpea, Kobraee *et al*. (2010) also declared significant differences among genotypes and environments. However, they reported highly significant differences for genotype × environment interaction which contradict our results. Previously, Tsehaye *et al*. (2020) studied 100 chickpea cultivars and found similar heritability estimates for SPP.

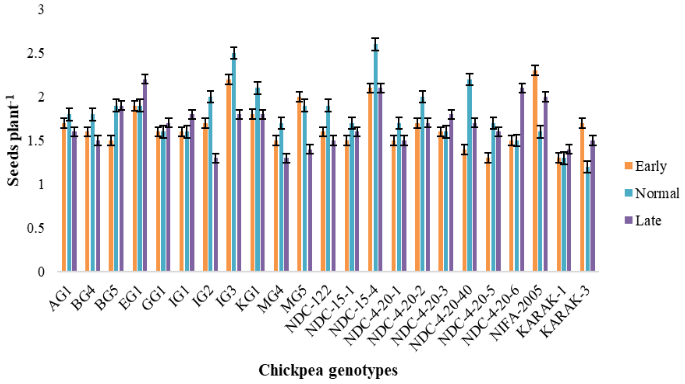

Figure 7: *Seeds plant^{-1} of 23 chickpea genotypes examined under three different planting dates.*

100-grain weight (HGW)

HGW is an important indicator of chickpea seed quality and yield potential, impacting grain density, size and market value. The combined analysis revealed highly significant variations for HGW across three environments and genotypes. However, genotype × planting date interaction was insignificant for HGW (Table 2). Mean of 23 chickpea genotypes for HGW over three environments ranged from 24.4 (Karak-3) to 31.2 g (MG4). The mean values for 100-grain weight under early planting ranged from 24.3 (Karak-1) to 30.1 g (MG4), from 22.7 (Karak-3) to 33.2 g (MG4) under normal planting, while from 24.2 (Karak-3) to 30.4 g (MG4) under late planting (Figure 8). Previous study by Sagar *et al*. (2023) reported that 100-grain weight of chickpea late planted on 15th January 2022 was statistically lower than HGW under early and normal plantation. Delayed planting result in shortening of grain filling duration, terminal heat stress and longer photoperiod which had reduced seed weight of chickpea (Kumar *et al*., 2023).

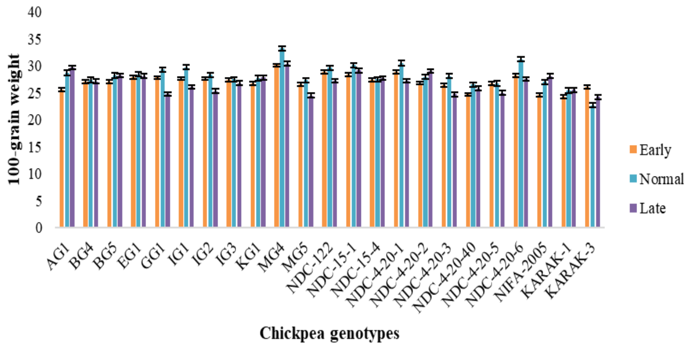

Figure 8: *100-grain weight of 23 chickpea genotypes examined under three different planting dates.*

Estimates of broad-sense heritability for HGW varied from 0.19 under early planting to moderate values of 0.53 and 0.37 under normal and late planting, respectively (Table 3). These findings suggested influence of environmental factors particularly planting time on HGW along with genetic control. The results of Kabir *et al.* (2009) are concurred with our findings for genotypes and genotype × environment interaction. However, they reported non-significant differences for environments which contradict our findings. Our findings are similar to Ali *et al.* (2011), who reported similar outcomes of heritability for HGW while studying 20 chickpea genotypes.

Seed yield (SY)

SY is the primary indicator of chickpea crop performance, reflecting the complex interactions between genetic potential, environmental factors and agronomic practices. Any change in planting time or environmental factors imposes several constraints in getting stable and high SY (Yadav *et al*., 2010). Pooled ANOVA for SY revealed highly significant variations across environments and genotypes (Table 2). The analysis also revealed significant genotype × planting date interaction (G×P) for SY, which means that chickpea SY significantly varied when planted over time. Genotype Karak-1 unveiled minimum SY (970.7 kg ha^{-1}) followed by Karak-3 (1015.9 kg ha^{-1}) and AG1 (1018.8 kg ha^{-1}), while maximum SY of 1440 kg ha^{-1} was obtained from NDC-15-4 followed by IG3 (1380 kg ha^{-1}) and MG5 (1310 kg ha^{-1}) across planting dates. The mean data for seed yield varied from 846.3 (MG4) to 1268.4 kg ha^{-1} (NIFA-2005) under early planting, from 1198.4 (Karak-3) to 2178.1 kg ha^{-1} (NDC-15-4) under normal planting, while from 747.0 (IG2) to 1080.0 kg ha^{-1} (EG1) under late planting (Figure 9). Genotypes performed better for seed yield under normal planting by producing mean yield of 1689.2 kg ha^{-1} followed by early planting having seed yield of 1001.8 kg ha^{-1}, while late planting condition was less productive with seed yield of 835.0 kg ha^{-1}. Previously, Rasool *et al.* (2024) also observed highest seed yield of 2776 kg ha^{-1} during 2021-22 and 2966 kg ha^{-1} during 2022-23 under normal planting and is concurrent with our results.

High heritability values were noticed for SY under early and normal planting (0.94 each) and late planting (0.91), respectively (Table 3). Similar results were reported by Getachew and Abraham (2021) for genotypes, environments and genotype × environment interaction, while testing chickpea genotype across different planting dates. Likewise, Dar *et al.* (2020) also unveiled similar results for heritability of SY in 35 chickpea genotypes which also supported our findings.

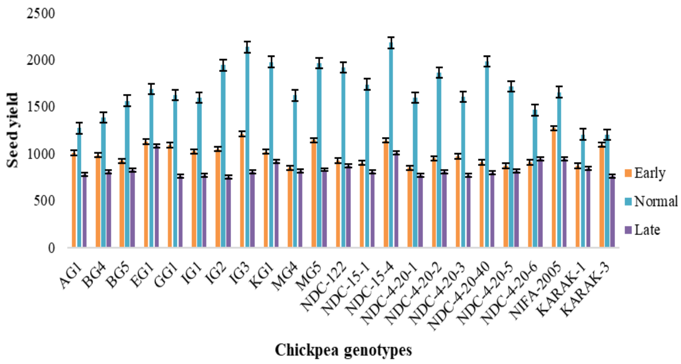

Figure 9: *Seed yield of 23 chickpea genotypes examined under three different planting dates.*

Biological yield (BY)

BY in chickpea is a comprehensive measure of plant productivity in the form of both economic yield and plant biomass. BY was significantly influenced by genotype, environment as well as genotype by planting date interaction (G×P) (Table 2). This indicated substantial genetic variability for BY across genotypes and environments. Mean data for BY across planting dates ranged from 2445.5 to 4024.7 kg ha^{-1}, with genotypes NDC-15-4, EG1 and NDC-4-20-2 exhibiting highest values (4024.7, 3821.7, and 3704.2 kg ha^{-1}, respectively). On the other hand, Karak-1, MG4, and Karak-3 displayed lowest BY (2445.5, 2647.5, and 2689 kg ha^{-1}, respectively). The mean biological yield varied from 1753.1 (karak-1) to 3779.4 kg ha^{-1} (NDC-4-20-2) under early planting. Likewise, biological yield under normal planting varied between 3524.7 (karak-1) and 6123.5 kg ha^{-1} (NDC-15-4). Moreover, under late planting biological yield ranged from 1487.7 (NDC-4-20-3) to 2687.2 kg ha^{-1} (EG1) (Figure 10). Likewise, Saeedian *et al.* (2024) presented that March planted chickpea crop was superior for all the studied traits including biological yield than April planted crop. Biomass conversion to grain can be maximized by optimization of planting time there by minimizing the stress during sensitive stage in chickpea (Lake and Sadras, 2014).

High broad sense heritability was noticed for BY under early (0.80), normal (0.97) and late (0.69) planting (Table 3). Hailu (2020) also reported substantial variations among genotypes, environments and genotype × environment interaction for BY while studying 49 chickpea genotypes under two different production systems. Tejasree *et al.* (2021) also displayed the same outcomes for the heritability of BY of 22 chickpea genotypes.

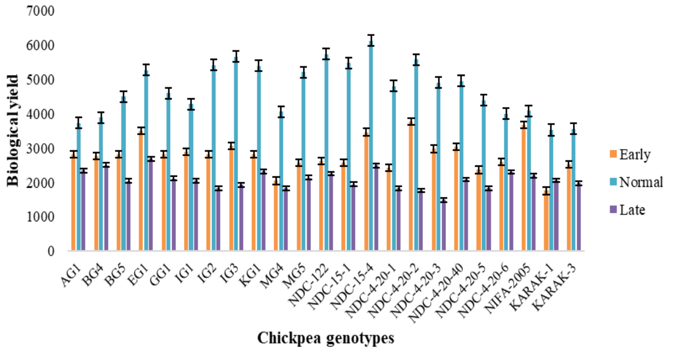

Figure 10: *Biological yield of 23 chickpea genotypes examined under three different planting dates.*

Genotypic and phenotypic correlations

Days to emergence: Days to emergence expressed significantly positive genotypic interrelation with primary branches plant^{-1} (r_g = 0.67**) under early planting (Table 4). Likewise, days to emergence under normal planting unveiled significant negative genotypic correlation with primary branches (r_g = -0.44*) (Table 5). Similarly, days to emergence under late planting condition depicted significant positive genotypic correlation with maturity (r_g = 0.57**) but significant negative association with plant height (r_g = -0.82**), secondary branches (r_g = -0.80**), pods plant^{-1} (r_g = -0.66**), seeds plant^{-1} (r_g = -0.87**) and 100-grain weight (r_g = -0.52**), while the under-study trait showed and negative phenotypic correlation with plant height (r_p = -0.51**) under late planting (Table 6). Previously, Shengu *et al.* (2018) also noticed similar correlation results for days to emergence with other mentioned traits in chickpea.

Days to maturity: Under early planting, days to maturity revealed significantly positive correlation with primary branches (r_g = 0.77**), seeds pods^{-1} (r_g = 0.55**) and 100-grain weight (r_g = 0.84**, r_p = 0.42*) (Table 4). Likewise, maturity revealed strong positive interrelationship with primary branches (r_g = 0.80**, r_p = 0.43*), 100-seed weight (r_g = 0.46*) and biological yield (r_g = 0.47*, r_p = 0.42*) under normal planting (Table 5). This proved that delay in maturity can provide more time for proper grain filling and establishing the plant canopy properly. Moreover, maturity expressed substantial and positive relationship with primary branches (r_g = 0.58**), while it showed negative interrelationship with secondary branches (r_g = -0.99**, r_p = -0.43*) and biological yield (r_g = -0.50**) in late planting (Table 6). The findings of Jain *et al.* (2020) and Ali *et al.* (2011) are in accordance to our results.

Plant height (PH): PH expressed significantly positive genotypic and phenotypic correlations with SBP (r_g = 0.64**, r_p = 0.55**), PPP (r_g = 0.58**, r_p = 0.44**), SPP (r_g = 0.99**, r_p = 0.57**), SY (r_g = 0.58**, r_p = 0.56**) and BY (r_g = 0.70**, r_p = 0.67**) under early planting (Table 4). Similarly, under normal planting conditions, PH was also positively correlated with SBP (r_g = 0.84**, r_p = 0.51**), PPP (r_g = 0.74**, r_p = 0.59**), SPP (r_g = 0.97**, r_p = 0.49*), SY (r_g = 0.56**, r_p = 0.44*) and BY (r_g = 0.64**, r_p = 0.52**) both at phenotypic and genotypic levels (Table 5). More the PH, more will be BY and ultimately number of branches and seed yield.Moreover, PH displayed significantly positive genotypic and phenotypic correlations with PBP (r_g = 0.98**, r_p = 0.56**), SBP (r_g = 0.99**, r_p = 0.66**), PPP (r_g = 0.97**, r_p = 0.75**), SPP (r_g = 0.98**, r_p = 0.53**), SY (r_g = 0.90**, r_p = 0.71**) and BY (r_g = 0.45*, r_p = 0.44*) under late planting (Table 6). Our inter relationship results for PH are parallel to Tsehaye *et al.* (2020) and Hussain *et al.* (2018).

Table 4: *Correlation (genotypic above and phenotypic below diagonal) among studied traits of 23 chickpea genotypes under early planting condition.*

Traits	DE	DM	PH	PBP	SBP	PP	SP	HGW	SY	BY
DE	-	-0.02	0.23	0.67**	0.02	0.34	-0.19	0.19	0.08	-0.18
DM	0.06	-	-0.03	0.77**	-0.15	-0.66**	0.55**	0.84**	-0.23	0.06
PH	0.12	-0.01	-	0.22	0.64**	0.58**	0.99**	-0.1	0.58**	0.70**
PBP	0.29	0.39	0.23	-	0.44*	-0.12	0.001	0.98**	-0.01	0.47*
SBP	0.11	-0.12	0.55**	0.23	-	0.99**	0.99**	-0.47*	0.91**	0.97**
PP	0.01	-0.33	0.44*	-0.16	0.76**	-	0.98**	-0.94**	0.96**	0.93**
SP	0.01	0.04	0.57**	0.18	0.76**	0.78**	-	-0.86**	0.98**	0.97**
HGW	0.20	0.42*	-0.07	0.36	-0.19	-0.33	-0.08	-	-0.38*	-0.21
SY	0.05	-0.21	0.56**	-0.01	0.76**	0.86**	0.90**	-0.17	-	0.63**
BY	-0.13	0.06	0.67**	0.31	0.76**	0.56**	0.65**	-0.16	0.60**	-

***,* = significant at 1 and 5% level of probability, respectively. Note: DE= days to emergence, DM= days to maturity, PH= plant height, PBP= primary branches plant^{-1}, SBP= secondary branches plant^{-1}, PPP= pods plant^{-1}, SPP= seeds plant^{-1}, HGW= hundred grain weight, SY= seed yield (kg ha^{-1}), BY= biological yield (kg ha^{-1}).*

Table 5: *Correlation (genotypic above and phenotypic below diagonal) among studied traits of 23 chickpea genotypes under normal planting condition.*

Traits	DE	DM	PH	PBP	SBP	PP	SPP	HGW	SY	BY
DE	-	-0.06	0.38	-0.44*	-0.22	-0.24	-0.39	0.28	-0.01	-0.20
DM	-0.04	-	0.17	0.80**	0.22	0.31	0.24	0.46*	0.36	0.47*
PH	0.23	0.08	-	-0.28	0.84**	0.74**	0.97**	-0.23	0.56**	0.64**
PBP	-0.34	0.43*	-0.15	-	0.35	0.16	0.08	-0.49*	0.16	0.31
SBP	-0.20	0.12	0.51**	0.04	-	0.99**	0.98**	0.08	0.98**	0.99**
PP	-0.21	0.24	0.59**	0.12	0.64**	-	0.99**	-0.32	0.92**	0.83**
SP	-0.19	0.19	0.49*	-0.02	0.82**	0.83**	-	0.15	0.99**	0.98**
HGW	0.27	0.40	-0.16	-0.26	0.11	-0.19	0.06	-	0.13	0.17
SY	-0.12	0.30	0.44*	0.08	0.71**	0.78**	0.90**	0.11	-	0.91**
BY	-0.28	0.42*	0.52**	0.18	0.77**	0.71**	0.82**	0.16	0.89**	-

***,* = significant at 1 and 5% level of probability, respectively.*

Table 6: *Correlation (genotypic above and phenotypic below diagonal) among studied traits of 23 chickpea genotypes under late planting condition.*

Traits	DE	DM	PH	PBP	SBP	PP	SP	HGW	SY	BY
DE	-	0.57**	-0.82**	0.001	-0.80**	-0.66**	-0.87**	-0.52**	-0.29	-0.26
DM	0.40	-	-0.26	0.58**	-0.99**	-0.24	-0.35	0.15	-0.18	-0.50**
PH	-0.51**	-0.23	-	0.98**	0.99**	0.97**	0.98**	0.4	0.90**	0.45*
PBP	-0.21	0.01	0.56**	-	0.05	0.68**	0.97**	-0.68**	0.42*	-0.64**
SBP	-0.25	-0.43*	0.66**	0.25	-	0.98**	0.96**	0.96**	0.99**	0.99**
PP	-0.39	-0.21	0.75**	0.28	0.78**	-	0.99**	0.49*	0.98**	0.84**
SPP	-0.28	-0.11	0.53**	0.34	0.68**	0.68**	-	0.99**	0.98**	0.97**
HGW	-0.15	0.02	0.2	0.16	0.32	0.36	0.31	-	0.41*	0.31
SY	-0.28	-0.24	0.71**	0.39	0.78**	0.90**	0.70**	0.25	-	0.76**
BY	-0.15	-0.40	0.44*	0.16	0.77**	0.70**	0.48*	0.17	0.75**	-

***,* = significant at 1 and 5% level of probability, respectively.*

Primary branches plant^{-1} (PBP): Early planting conditions revealed significant positive genotypic inter relationship of PBP with critical yield component traits including SBP (r_g = 0.44*), HGW (r_g = 0.98**) and BY (r_g = 0.47*) (Table 4), highlighting the genetic inter dependence of PBP with yield potential. Likewise, PBP expressed significantly negative genotypic inter relationship with HGW (r_g = -0.49*) under normal planting (Table 5). This suggest that more branches may affect normal photosynthetic pigments dissemination towards grains. PBP revealed significantly positive genotypic associations with PPP (0.68**), SPP (0.97**) and SY (0.42*), while negative genotypic association with HGW (-0.68**) and BY (-0.64**) under late planting (Table 6). These results are also supported by the past reports of Salih *et al.* (2018) and Ali and Ahsan (2012), who similarly reported parallel relationships between PP and SY in chickpea.

Secondary branches plant^{-1} (SBP): SBP displayed significant positive association with PPP (r_g = 0.99**, r_p = 0.76**), SPP (r_g = 0.99**, r_p = 0.76**), SY (r_g = 0.91**, r_p = 0.76**) and BY (r_g = 0.97**, r_p = 0.76**) under early planting (Table 4). Likewise, SBP exhibited significant positive phenotypic and genotypic inter relationship with PPP, SPP, SY and BY under normal and late planting conditions (Tables 5, 6), highlighting the importance of SBP as an indirect selection criterion for improving yield potential of chickpea. Previously, Rathod *et al.* (2020) also observed significant positive correlations between SBP and PPP thereby reinforcing the existence of these genetic associations.

Pods plant^{-1} (PPP): Significantly positive correlations of PPP was observed with SPP, SY and BY under early, normal and late planting conditions. PPP was positively correlated with SY (r_g = 0.96**, r_p = 0.86**) under early planting (Table 4), (r_g = 0.92**, r_p = 0.78**) under normal planting (Table 5) and (r_g = 0.98**, r_p = 0.90**) under late planting conditions (Table 6). Pods are the fruiting bodies in chickpea and most pulses. Therefore, increase in the number of pods per plant contribute to final economic yield. These findings are verified by previous studies (Rathod *et al*., 2020; Kobraee *et al*., 2010), demonstrating consistent genetic and phenotypic associations of PPP with these critical yield components in chickpea.

Seeds pod^{-1} (SPP): SPP exhibited positive genetic and phenotypic association with SY and BY across three planting dates. SPP was positively correlated with SY (r_g = 0.98**, r_p = 0.90**) under early planting (Table 4), (r_g = 0.99**, r_p = 0.90**) under normal planting (Table 5) and (r_g = 0.98**, r_p = 0.70**) under late planting conditions (Table 6). This authenticates the existence of this association. More seeds per fruit or pods enhance seed yield and can be used a direct selection criteria in chickpea breeding programs for increasing yield. These findings are in line with the previous reports of Kaur and Bhardwaj (2017) who studied correlation among yield components of 14 genotypes of chickpea.

Hundred grain weight (HGW): Under early planting condition, HGW showed significantly positive genotypic associations with PBP (r_g = 0.98**) but significantly negative relationship with SBP (r_g = -0.99**), PPP (r_g = -0.94**), SPP (r_g = -0.86**) and SY (r_g = -0.38*) (Table 4). Likewise, HGW revealed substantial negative genotypic association with PBP (-0.49*) under normal planting (Table 5). Moreover, HGW showed significantly positive genotypic correlation with SBP (r_g = 0.96**), PPP (r_g = 0.49*), SPP (r_g = 0.99**) and SY (r_g = 0.41*), but its association with DE (r_g = -0.52**) and PBP (r_g = -0.68**) was significant negative under late planting (Table 6). Similar correlation findings of HGW with PBP, SBP, SPP and SY were presented by Sharma *et al*. (2021) while testing 14 chickpea genotypes under five different production systems.

Seed yield (SY): Correlation study revealed that SY had strong positive inter relationship with PH, SBP, PPP, SPP and BY across three planting dates. SY showed positive correlation with SBP (r_g = 0.91**, r_p = 0.76**), PPP (r_g = 0.96**, r_p = 0.86**) and SPP (r_g = 0.98**, r_p = 0.90**) under early planting (Table 4). SY was significant positively correlated with SBP (r_g = 0.98**, r_p = 0.71**), PPP (r_g = 0.92**, r_p = 0.78**) and SPP (r_g = 0.99**, r_p = 0.90**) under normal planting (Table 5), while with SBP (r_g = 0.99*, r_p = 0.78**), PPP (r_g = 0.98**, r_p = 0.90**) and SPP (r_g = 0.98**, r_p = 0.70**) under late planting conditions (Table 6). Seed yield is the most complex variable contributed by other yield components and protected by traits associated with disease resistance. Past studies by Kumar *et al*. (2021) and Mir *et al*. (2018) reported similar outcomes for relationship of SY with the above mentioned traits, underscoring the complex genetic relationships underlying yield potential in chickpea.

Biological yield (BY): BY exhibited substantial positive genotypic and phenotypic correlations with PH, SBP, PPP, SPP and SY across three planting dates. BY was significant positively associated with PH (r_g = 0.70**, r_p = 0.67**), SBP (r_g = 0.97**, r_p = 0.76**) and SY (r_g = 0.63**, r_p = 0.60**) under early planting (Table 4). BY also showed positive association with PH (r_g = 0.64**, r_p = 0.52**), SBP (r_g = 0.99**, r_p = 0.77**) and SY (r_g = 0.91**, r_p = 0.89**) under normal planting (Table 5), while with PH (r_g = 0.45*, r_p = 0.44*), SBP (r_g = 0.99**, r_p = 0.77**) and SY (r_g = 0.76**, r_p = 0.75**) under late planting conditions (Table 6). These findings demonstrate consistent genetic and phenotypic associations between BY and critical yield-related traits. Our results are align with Verma *et al*. (2020), who evaluated 40 chickpea genotypes and reported similar correlations between BY and yield-contributing traits, validating the genetic relationships underlying yield potential of chickpea.

Conclusions and Recommendations

Across three environments, chickpea genotypes, NDC-15-4, IG3 and MG5 were top performer regarding yield and recommended to be tested for varietal development in different chickpea breeding programs. Considering independent environment, high seed yield was produced by genotype NIFA-2005 under early planting. Genotype NDC-15-4 produced maximum seed yield under normal planting. Genotype EG1 produced maximum seed yield under late planting. High heritability estimates were noticed in this study for both seed and biological yield under early, normal and late planting environments. Seed yield showed positive inter relationship with PH, SBP, PP, SPP and BY under each planting. So indirect selection through contributing traits could be focused for yield improvement in chickpea. Chickpea yield components were greatly affected by planting dates as per the results and performed better under normal planting as compared to early and late planting conditions.

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Novelty Statement

This study uncovers the unprecedented potential of NDC-15-4, IG3 and MG5 chickpea genotypes, which exhibit exceptional yield-related traits, offering a revolutionary solution to address the escalating national demand for food.

Author's Contribution

Hamayoon Khan: Conceptualization, conducted field trial, methodology, data collection, data analysis and writing.
Rooh Ullah: Conceptualization, conducted field trial, methodology and data collection
Rozina Gul: Supervision, validation and editing.
Aftab Jehan: Visualization, draft preparation and review this study.
Aizaz Akbar: Visualization, draft preparation and review this study
Muhammad Haris: Helped in format setting and final proofreading

Conflict of interest
The authors have declared no conflict of interest.

References

Ahmad, M.F., K. Mohammad and A. Maqbool. 2003. Genetic variability and trait correlation in wheat. Sarhad J. Agric., 19(3): 347-351.

Akanksha, T., B. Anita and P. Namita. 2016. Genetic variability, Correlation and Path analysis in yield and yield components in chickpea (*Cicer arietinum* L.) genotypes under late sown condition. Int. J. Agric. Sci., 8(3): 2884-2886.

Ali, M.A., N.N. Nawab, G. Rasool and M. Saleem. 2008. Estimates of variability and correlations for quantitative traits in chickpea (*Cicer arietinum* L.). J. Agric. Soc. Sci., 4(4): 177-179.

Ali, Q. and M. Ahsan. 2012. Estimation of genetic variability and correlation analysis for quantitative traits in chickpea (*Cicer arietinum* L.). Int. J. Agro. Vet. Med. Sci., 6(4): 241-249. https://doi.org/10.5455/ijavms.12877

Ali, Q., M.H.N. Tahir, H.A. Sadaqat, S. Arshad, J. Farooq, M. Ahsan, M. Waseem and A. Iqbal. 2011. Genetic variability and correlation analysis for quantitative traits in chickpea genotypes (*Cicer arietinum* L.). Afr. J. Bacteriol. Res., 3(1): 6-9.

Avinash, N. and H.S. Janeja. 2024. Genetic insights into fusarium wilt resistance in chickpea: Mechanisms and sustainable breeding strategies. J. Exp. Agric. Int., 46(6): 924-938. https://doi.org/10.9734/jeai/2024/v46i62545

Bayahi, K. and H. Chaar. 2024. Genetic study and temporal dynamics of the reaction to *Ascochyta rabiei* epidemic in improved lines and cultivars of chickpea (*Cicer arietinum* L.). Legum. sci., 6(3): 243. https://doi.org/10.1002/leg3.243

Bhanu, A.N., Singh, M.N., Tharu, R. and S.K. Saroj. 2017. Genetic variability, correlation and path coefficient analysis for quantitative traits in chickpea genotypes. Indian J. Agric. Res., 51(5): 560-570. https://doi.org/10.18805/IJARe.A-4687

Bharat, B., 2024. Revealing the genetic variability and correlation studies for productivity traits in advanced breeding lines of chickpea (*Cicer arietinum* L.). Plant Arch., 24(1): 125. https://doi.org/10.51470/PLANTARCHIVES.2024.v24.no.1.125

Danakumara, T., N. Kumar, B.S. Patil, T. Kumar, C. Bharadwaj, P.K. Jain, M.S. Nimmy, N. Joshi, S.K. Parida, S. Bindra and C. Kole. 2024. Unraveling the genetics of heat tolerance in chickpea landraces (*Cicer arietinum* L.) using genome-wide association studies. Front. Plant Sci., 15: 1376381. https://doi.org/10.3389/fpls.2024.1376381

Dar, M.A., R.U. Noor-ul-Saleem, R. Mir, Z.A. Dar, P.A. Sofi, S.A. Dar, B.A. Lone, F.A. Sheikh and U.R. Bhat. 2020. Cause and effect relationship in chickpea (*Cicer arietinum* L.) genotypes under temperate conditions. J. Adv.

Res., 21(10): 38-45. https://doi.org/10.9734/air/2020/v21i1030250

Dehal, I.B., R. Kalia and B. Kumar. 2016. Genetic estimates and path coefficient analysis in chickpea (*Cicer arietinum* L.) under normal and late sown environments. Legum. Res. Int. J., 39(4): 510-516. https://doi.org/10.18805/lr.v0iOF.9288

Desai, K., C.J. Tank, R.A. Gami and A.M. Patel. 2016. G×E Interaction and stability analysis in chickpea (*Cicer arietinum* L.). Int. J. Agric. Environ. Biotech., 9(4): 479-484. https://doi.org/10.5958/2230-732X.2016.00063.2

Devasirvatham, V. and D.K. Tan. 2018. Impact of high temperature and drought stresses on chickpea production. Agron., 8(8): 145. https://doi.org/10.3390/agronomy8080145

FAO, 2018. FAOSTAT, Crops. Retrieved September 28, 2018, from http://www.fao.org/faostat/en/#data/QC/.

Gautam, A., R.K. Panwar, S.K. Verma, A. Arora, A.K. Gaur and C. Chauhan. 2021. Assessment of genetic variability parameters for yield and its components in chickpea (*Cicer arietinum* L.). Biol Forum Int. J., 13(2): 651-655.

Getachew, A. and T. Abraham. 2021. Performance of chickpea varieties based on growth and yield parameters influenced by different planting dates at Toke Kutaye district, Ethiopia. Afr. J. Agric., 6(3): 14-21. https://doi.org/10.9734/ajrcs/2021/v6i330117

Gomez, K.A. and A.A. Gomez. 1984. Statistical procedures for agriculture research. John Willey and Sons Inc., New York, USA.

Gungor, H., 2024. Optimizing chickpea yield: GGE biplot analysis of planting seasons. Int. J. Agric. Nat. Res., 51(2): 127-139. https://doi.org/10.7764/ijanr.v51i2.2596

Hailu, F., 2020. Genetic variability, heritability and genetic advance of kabuli chickpea (*Cicer arietinum* L.) for agronomic traits at Central Ethiopia. Int. J. Plant Breed. Genet., 7(1): 710-714.

Hassan, E., M. Ahsan and M. Saleem. 2008. Genetic variability and inter-relationship for grain yield and its various components in chickpea (*Cicer arietinum* L.). J. Agric. Res., 46(2): 109-116.

Himanshu, R.S. Bochalya, K. Choudhary, M. Thakur and J. Bala. 2024. Effect of planting dates on growth characters of chickpea cultivars in mid hills of Himachal Pradesh. Int. J. Res. Agron., 7(8): 618-622. https://doi.org/10.33545/2618060X.2024.v7.i8Sh.1337

Husnain, M.S., S.T. Mahabub, H.E. Mazed and M.A. Pulok. 2015. Effect of planting time on growth, yield and seed quality of chickpea (BARI Chola-6). Int. J. Multidis. Res. Dev., 2(7): 136-141.

Hussain, Q., N. Ahmad, M. Adnan, R. Mehbob and A. Sohail. 2018. Estimates correlation coefficient among yield and yield attributing traits in twenty chickpea genotypes. Int. J. Agric. Environ. Res., 4(2): 84-87.

Hussen, S., F. Yirga and F. Tibebu. 2013. Effect of phosphorus fertilizer on yield and yield components in chickpea (*Cicer arietinum* L.) at Kelemeda, South, Wollo, Ethiopia. Int. J. Soil Crop Sci., 1(1): 1-4.

Itana, T., W. Mohammed and S. Abady. 2024. Genetic variability, heritability and expected genetic advance of yield and yield related traits in desi type chickpea (*Cicer arietinum* L.) at Bule Hora, Southern Ethiopia. Adv. Biosci. Bioeng., 12(2): 37-44.

Jain, S.K., L.D. Sharma, K.C. Gupta, V. Kumar and M.R. Yadav. 2020. Variability and character association for yield and quantitative traits under late sown conditions in chickpea (*Cicer arietinum* L.). Legum. Res. Int. J., 3(1): 5-17. https://doi.org/10.18805/LR-4432

Jha, U.C., H. Nayyar, M. Thudi, R. Beena, P.V. Vara Prasad and K.H. Siddique. 2024. Unlocking the nutritional potential of chickpea: Strategies for biofortification and enhanced multinutrient quality. Front. Plant Sci., 15: 1391496. https://doi.org/10.3389/fpls.2024.1391496

Kabir, A.F., M.N. Bari, M.A. Karim, Q.A. Khaliq and J.U. Ahmed. 2009. Effect of planting time and cultivars on the growth and yield of chickpea under rainfed condition. Bangladesh J. Agric. Res., 34(2): 335-342. https://doi.org/10.3329/bjar.v34i2.5807

Kakaei, M., F.U. Rehman and F. Fazeli. 2024. The effect of chickpeas metabolites on human diseases and the application of their valuable nutritional compounds suitable for human consumption. Cell. Mol. Biomed. Rep., 4(1): 30-42. https://doi.org/10.55705/cmbr.2023.395591.1153

Kaur, J. and N. Bhardwaj. 2019. Correlation studies for yield and its components in chickpea under low input conditions. Himachal J.

Agric. Res., 45(1 and 2): 15-19. https://doi.org/10.51396/ANRCM.1.2.2020.119-124

Keifer, G. and F. Effenberger. 2018. Pulses revolution-from food to nutritional security. Min. of Agri and FW (DAC and FW), GOI. Angewandte Chemie Int. Ed. 6(11): 951-952. https://doi.org/10.1002/anie.196709511

Khajehpour, M.R., 2000. Basis of Agronomy Jihad Daneshgahi Fahar Press, Iran. pp. 386-389.

Khalil, A.I. and A. Jan. 2002. Cropping technology. National Book Foundation, Pakistan. pp. 205-209.

Kobraee, S., K. Shamsi and B. Rasekhi. 2010. Investigation of correlation analysis and relationships between grain yield and other quantitative traits in chickpea (*Cicer arietinum* L.). Afr. J. Biotech., 9(16): 2342-2348.

Kumar A., N. Kumar, S. Devi, A.K. Dhaka, S. Khokhar. 2023. Physiology and yield of chickpea (*Cicer arietinum* L.) Genotypes in response to different planting dates in semi-arid regions of North India. Legum. Res. An Int. J., (1): 6. https://doi.org/10.18805/LR-5108

Kumar, G.A., V.T. Rao and Y. Prashanth. 2021. Study of genetic variability, correlation and path analysis for yield and yield attributing traits in early maturing chickpea (*Cicer arietinum* L.) lines. Pharm. Innov. J., 10(12): 1678-1682. https://doi.org/10.21275/SR21921194420

Lake, L. and V.O Sadras. 2014. The critical period for yield determination in chickpea (*Cicer arietinum* L.). Field Crops Res., 168: 1–7. https://doi.org/10.1016/j.fcr.2014.08.003

Maleki, H.H., H.H. Khoshro, H. Kanouni, S.S. Shobeiri and B.M. Ashour. 2024. Identifying dryland-resilient chickpea genotypes for autumn planting, with a focus on multi-trait stability parameters and biochemical enzyme activity. BMC Plant Biol., 24(1): 750. https://doi.org/10.1186/s12870-024-05463-0

Malik, S.R., A. Bakhsh, M.A. Asif, U. Iqbal and S.M. Iqbal. 2010. Assessment of genetic variability and interrelationship among some agronomic traits in chickpea. Int. J. Agric. Biol., 12(1): 81-85.

Mir, A.H., H. Fayaz, M.A. Bhat, A.A.W.P.A. Sofi and R. Mir. 2018. Correlation and principal component analysis for study of yield improvement in chickpea genotypes in Kashmir valley in north India. Int. J. Curr. Agric. Sci., 8(8A): 307-310.

Mohan, S. and K. Thiyagarajan. 2019. Genetic variability, correlation and path coefficient analysis in chickpea (*Cicer arietinum* L.) for yield and its component traits. Int. J. Curr. Microbiol. Appl. Sci., 8(5.1): 801-1808. https://doi.org/10.20546/ijcmas.2019.805.209

Mohibullah, M., S. Batool, M. Amin, M. Ilyas, A. Rehman and S. Ali. 2020. Genetic divergence and heritability studies for yield and yield attributes in various accessions of desi chickpea (*Cicer arietinum* L.). Sarhad J. Agric., 36(3): 734-741. https://doi.org/10.17582/journal.sja/2020/36.3.734.741

Noreen, A., A. Hameed and T.M. Shah. 2024. Field screening and identification of biochemical indices of pod borer (*Helicoverpa armigera*) resistance in chickpea mutants. Front. Plant Sci., 15: 1335158. https://doi.org/10.3389/fpls.2024.1335158

Pathak, G. C., B. Gupta and N. Pandey. 2012. Improving reproductive efficiency of chickpea by foliar application of zinc. Braz. J. Plant Physiol., 24: 173-180. https://doi.org/10.1590/S1677-04202012000300004

Prasad, D., A.S. Bangarwa, S. Kumar and A. Ram. 2012. Effect of planting dates and plant population on chickpea (*Cicer arietinum*) genotypes. Indian J. Agron., 57(2): 206-208. https://doi.org/10.59797/ija.v57i2.4623

Priyadarshini, P., G. Kalwan and P.K. Jain. 2024. Physiological and biochemical changes in contrasting chickpea genotypes under Fusarium wilt stress. Int. J. Adv. Biochem. Res., 8(2): 410-415. https://doi.org/10.33545/26174693.2024.v8.i2Sf.607

Rasool, I., K. Hussain, M.A. Ameen, A. Batool, M. Anam, A. Aziz, A. Hussain, M.T. Mahmood, Z. Maqsood, R.T. Ahmad and R.A. Samad. 2024. Evaluation of chickpea varieties for climate resilience and yield stability at different planting dates. Biol. Clin. Sci. Res. J., 986. https://doi.org/10.54112/bcsrj.v2024i1.986

Rathod, A.S., J.D. Jadhav, V.M. Londhe, V.T. Jadhav, S.V. Bagade, V.A. Sthool, A.M. Khobragade and Y.E. Kadam. 2024. Performance of chickpea (*Cicer arietinum* L.) cultivars under different planting window over scarcity zone of Maharashtra. Int. J. Res. Agron., 7(2): 37-41. https://doi.org/10.33545/2618060X.2024.v7.i2a.278

Rathod, V.L., V.N. Toprope and L.P. Godade. 2020.

Assessment of genetic variability character association and path analysis in F2 segregating population for quantitative traits in chickpea. Int. J. Curr. Microbiol. Appl. Sci., 9(8): 2485-2489. https://doi.org/10.20546/ijcmas.2020.908.283

Richards, M.F., L. Maphosa and A.L. Preston. 2022. Impact of planting time on chickpea (*Cicer arietinum* L.) biomass accumulation and yield. Agron. 12: 160. https://doi.org/10.3390/agronomy12010160

SabaghPour, S.H. Sfykhany, M. Pezeshkpur, P. Jahangiri, A. Sarparast, R. Karami, A. Pursyahbydy, M. Shahriari, D. Mahmoudi, F. Keshavarzi and K. Azad 2010. A new chickpea cultivar for dryland moderate and semi warm climate of Iran. Seed Plant Improv. J., 26: 293-295.

Saeed, I., G.S.S. Khattak, A. Jehan, S. Ahmad and A. Wahid. 2025. Association of canopy temperature depression and membrane relative injury with seed and biological yield in chickpea (*Cicer arietinum* L.) genotypes under field conditions. Int. J. Appl. Exp. Biol., 4(1): 139-147. https://doi.org/10.56612/ijaaeb.v1i1.106

Saeedian, M., M. Goldani, M. Parsa and S.R. Vessal. 2024. Grouping of candidate drought tolerant genotypes of chickpea (*Cicer arietinum* L.) based on yield and yield components in different planting dates in water deficit conditions. Iran. J. Pulses Res., 15(1): 141-158.

Sagar, A., N. Mahesh, O. Sampath and K.C Shakher. 2023. Agronomic evaluation of heat tolerant chickpea (*Cicer arietinum* L.) cultivars under late sown conditions. Int. J. Environ. Clim. Change, 9: 3322-3330. https://doi.org/10.9734/ijecc/2023/v13i92585

Salih, R.H., S.A. Abdullah and B.I. Mohammed. 2018. Effect of planting dates and two chickpea cultivars on some growth parameters and yield. Zanco J. Pure Appl. Sci., 30(4): 49-57. https://doi.org/10.21271/ZJPAS.30.4.5

Sharma, R.N., P.L. Johnson, H.C. Nanda, A. Sao, A.K. Sarawgi, S.K. Umesh, N. Prabha and A.K. Singh. 2021. Genetic variability, character association and co-heritability for yield traits over the locations in chickpea (*Cicer arietinum* L.). Legum. Res. Int. J., 44(7): 859-863.

Shengu, M.K., D. Hirpa and Z. Wolde. 2018. Genetic variability of some chickpea (*Cicer arietinum* L.) genotypes and correlation among yield and related traits in humid tropics of southern Ethiopia. J. Plant Breed. Crop Sci., 10(10): 298-303. https://doi.org/10.5897/JPBCS2018.0721

Shukla, O., P. Singh and P. Deshbhratar. 2010. Impact of phosphorous on biochemical changes in *Hordeum vulgare* L. in mixed cropping with Chickpea. J. Environ. Biol., 31: 575.

Singh, R.K and B.D. Chaudhary. 1985. Biometrical methods in quantitative genetic analysis. Kalyani Publishers, New Delhi, Ludhiana, India. pp. 39-78.

Soltani, A., M.J. Robertson, B. Torabi, M. Yousefi-Daz and M. Sarparast. 2006. Modelling seedling emergence in chickpea as influenced by temperature and planting depth. Agric. For. Meteorol., 138(4): 156-167. https://doi.org/10.1016/j.agrformet.2006.04.004

Tejasree, K., G. Lavanya, C. Raju and P. Brahmanjaneyulu. 2021. Estimation of correlation and path coefficient analysis for quantitative characters in chickpea at Uttar Pradesh (*Cicer arietinum* L.). Int. J. Plant Soil Sci., 33(22): 96-107. https://doi.org/10.9734/ijpss/2021/v33i2230687

Thakur, N.R., V.N. Toprope and S.P. Koppuravuri. 2018. Estimation of genetic variability, correlation and path analysis for yield and yield contributing traits in chickpea (*Cicer arietinum* L.). Int. J. Curr. Microbiol. Appl. Sci., 7(1): 2298-2304. https://doi.org/10.20546/ijcmas.2018.702.278

Thapa R.S., T. Singh, A. Kumar, H. Kumar and D. Pratap. 2022. Genetic divergence, variability and character association analysis in chickpea (*Cicer arietinum* L.) genotypes under normal and late sown conditions. Electron. J. Plant Breed. 13(2): 616-623. https://doi.org/10.37992/2022.1302.077

Tsehaye, A., A. Fikre and M. Bantayhu. 2020. Genetic variability and association analysis of desi-type chickpea (*Cicer arietinum* L.) advanced lines under potential environment in North Gondar, Ethiopia. Cogent Food Agric., 6(1): 659-668. https://doi.org/10.1080/23311932.2020.1806668

Verma, S., N. Madala, S. Halavath, B.G. Suresh and G.R. Lavanya. 2020. Evaluation of chickpea (*Cicer arietinum* L.) germplasm for yield and yield attributing traits in eastern plain zone of Uttar Pradesh. Int. J. Curr. Microbiol. Appl. Sci., 9(10): 1944-1956. https://doi.org/10.20546/

ijcmas.2020.910.238

War, W.A., J. Rasool, A.A. Bhat, S.A. Sheikh, K. Hussain and N. Fatimah. 2024. An overview of the biological aspects, nature of damage and strategies for managing the gram pod borer (*Helicoverpa armigera* Hubner) in Chickpea: A review. J. Sci. Res. Rep., 30(5): 643-659. https://doi.org/10.9734/jsrr/2024/v30i51983

Yadav, S.S., A.K. Verma, A.H. Rizvi, D. Singh, J. Kumar and M. Andrews. 2010. Impact of genotype × environment interactions on the relative performance of diverse groups of chickpea (*Cicer arietinum* L.) cultivars. Arch. Agron. Soil Sci., 56(1): 49-64. https://doi.org/10.1080/03650340902922688