Construction of Selection Indices for Yield and its Components in Chickpea Genotypes under the Influence of Phosphate and Bio-fertilizer Combinations

Ahmad Khudair Hussen Akoul[1] Dawood salman Madb[2]

[1.2]Tikrit University / College of Agriculture – Department of Field Crops

[1]E-mail: ah230038pag@st.tu.edu.iq

[2]E-mail: dawoodobaidy@tu.edu.iq

Abstract

This study was conducted at the experimental farm of the College of Agriculture, Tikrit University, during the winter growing season of 2024-2025. The objective was to construct selection indices for yield and its components in chickpea genotypes as influenced by various combinations of phosphate and bio-fertilizers. The results revealed that the triple interaction among the studied factors (**Bacterial Inoculation × Phosphate Fertilization × Genotype**) exerted a strong and superior synergistic effect on all growth and yield traits. Genotype **G6** significantly excelled in most productive and qualitative traits, recording the highest 100-seed weight (36.40 g) and seed yield (1335 kg ha^{-1}).

In addition, the simultaneous application of bacterial inoculation and phosphate fertilization at a rate of 160 kg P_2O_5 ha^{-1} significantly enhanced all crop traits; the number of seeds per pod increased to 1.31, the 100-seed weight rose to 35.25 g, while the seed yield and biological yield attained values of 1052 kg ha^{-1} and 2369 kg ha^{-1}, respectively. Since maximum economic performance of chickpea crops can be achieved through optimal selection of superior genotype (G6) along with suitable bacterial inoculation and optimum phosphate fertilization; thus, an integrated management strategy is essential.

Selection indices' variance analysis revealed genotype-environment interaction to be non-significant for the parameter. Indices I_23 and I_234 recorded maximum relative efficiency (>105%) and expected genetic gain. This indicates the importance of X_2 – number of pods per plant and X_3 – 100-seed weight as selection criteria for the improvement over final yield. On the other hand, index I24 (pods plant–1 and protein percentage) showed the least efficiency and was unfit for selection..

Keywords: Selection Indices, Phosphate Fertilization, Rhizobia Inoculation, Genotypes, Chickpea (*Cicer arietinum* L.).

ISSN 2072-3857

Introduction

Chickpea ranks third globally among the Chickpea is the third most cultivated pulse crop after soybean and common bean and is considered one of the oldest legumes grown in India. Chickpea nutritious composition shows high carbohydrates, protein (18-29%), fat (4-7%), starch, fibre, and other micronutrients. Chickpeas have long been grown in the Mediterranean climate of Europe (Lebanon), North Africa, and South Asia. The ancient medical compendium, especially “Ayurveda”, speaks volumes of its benefits. Chickpea protein also boasts high bioavailability and the hydrolysis products possess bioactive properties as antioxidants, as well as natural Angiotensin-I Converting Enzyme (ACE-1) inhibitors [24]

The developer selection is the basic pillar of field crop improvement programs wherein plant breeders are continuously striving for the improved yield traits along with their components. In view of the limitations of time, effort and cost, Selection Index technique is utilized to discriminate between various varieties and strains and to select the best one suited for a particular environment. Strains with the maximum index values are preferred as they are more efficient than direct selection for yield alone and [23] and [14] laid the scientific foundation for constructing these indices and estimating the Expected Genetic Gain thus proving them superior as a multi-trait selection strategy. To design such an index, it would be necessary to figure out the economic worth of each trait in addition to estimating genetic variance, phenotypic variance and correlation of the studied traits.

Natural rock phosphates are less reactive than soluble fertilizers, but their biological efficiency increases gradually because of soil physical and chemical processes and the action of soil microorganisms. Modern agriculture mainly uses synthesized fertilizers (TSP, MAP, DAP) that are made by treating the rocks by strong acid. Even though they do work, most part of this fertilizer does not get absorbed and is wasted damaging environment and economy. Of the 5 million tons of annual phosphate fertilizer production, roughly 9.5 million tons of phosphorus end up in the food chain from different crops and animal products.

Phosphorus is a key component in the physiological and biochemical processes of the plant and is a decisive factor in establishing the capacity of agricultural production. Due to their low efficiency as compared with organic fertilizers, “improving phosphorus bioavailability” is an objective of great interest for sustainability of farming operations.

Rhizobia bacteria are shown in this context as strategic partners for legume crops. In addition to the essential function of atmospheric nitrogen fixation by Alpha-proteobacteria strains, other groups have been discovered to function as Plant Growth-Promoting Rhizobacteria (PGPR), including Beta-proteobacteria and lactic acid bacteria, which solubilize phosphates and secrete plant hormones.

Evaluation of Genetic Diversity of Chickpea Crop (Cicer arietinum L.) is an Urgent Requirement for Maximum Utilization of these Biological Interactions. Because environmental effect on morphological (phenotypic) traits may mislead researchers, molecular markers (or selection indices) provide greater accuracy in selecting genotypes for hybridisation. Hence, the study aims to examine the response of 6 chickpea genotypes to the interaction of phosphate fertilization and bacterial inoculation. The field generally introduces those genotypes to the good performance under different environmental conditions, but their response to the essence of changes in environmental conditions and instability of the various characteristics. [5]. Faba bean crop residues can be utilized as livestock feed as well as to enhance soil fertility and improve its granular structure [8] Due to the significant role of chickpea in nitrogen fixation it is frequently grown in crop rotation with other crops [1]

Materials and Methods

Experimental Site and Agricultural Operations

The study was conducted during the winter growing season of 2024–2025 at the experimental farm of the Field Crops Department, College of Agriculture, University of Tikrit. The site is located at an altitude of 110 m above sea level, with geographical coordinates (34.27° N, 43.35° E). Prior to planting, random soil samples were collected from a depth of 0–30 cm to analyze their physical and chemical properties at the laboratory of the Anbar Agricultural Directorate (Table 1). The soil underwent two perpendicular plowings in accordance with scientific recommendations, followed by harrowing, leveling, and partitioning the field into experimental units, each measuring 4.5 m^2

Trial Execution

Nitrogen fertilization was applied to all experimental units using urea (46% N) at a rate of 40 kg ha^{-1} as a starter dose before planting. Phosphorus fertilization was also applied pre-planting according to the specified treatment levels. *Rhizobium* inoculum, carried on peat moss, was applied at two levels (with and without inoculation) at a rate of 10 g per hole.

Planting was performed on October 28th in rows spaced 0.3 m apart, with a distance of 0.15 m between hills. One seed was sown per hill in two rows per experimental unit (each row was 1.5 m long and contained 10 plants). Irrigation was provided as needed, and weeds were removed manually without the application of any additional chemical fertilizers.

Table (1): Some Chemical and Physical Properties of the Experimental Field Soil

Value	Unit	Property
7.58	—	**Soil Reaction$) pH($**
3.42	dS. m1-	**Electrical Conductivity$) E.C($**
19.7	mg .kg1soil	**Available Nitrogen**
6.24	mg .kg1-soil	**Available Phosphorus**
118.56	mg .kg1-soil	**Available Potassium**
5.2	g .kg1-	**Organic Matter**
231	g .kg1-soil	**Calcium Carbonate$) CaCO_3$(**
52.6	g .kg 1-soil	**Gypsum$) CaSO_4 \cdot 2H_2O($**
432	g .kg1-	**Sand**
209	g .kg1-	**Silt**
359	g .kg1-	**Clay**
Sandy Clay Loam*	—	**Soil Texture**

Experimental Treatments

The experiment was conducted using three factors as follows:

The First Factor (Genotypes): The study included six genotypes, as detailed in Table (2):

Table (2). Names, Pedigrees, and Sources of Chickpea Genotypes Used in the Study

No.	Study Code	Genotype Name	Pedigree	Source
1	**G3**	FLIP12-209C	F3QWP1HvMx4qp	ICARDA
2	**G5**	FLIP12-262C	F3QWPmcz7K3bX	ICARDA
3	**G6**	FLIP12-179C	F3QWPpJBxbI8o	ICARDA
4	**G7**	FLIP12-105C	F3QWPGzzMGDbM	ICARDA
5	**G8**	FLIP12-52C	F3QWPIfxpTIqy	ICARDA
6	**G11**	FLIP12-269C	F3QWPs7uh53s1	ICARDA

2. Second Factor (Bio-fertilization): This factor consisted of two levels: (without inoculation and with inoculation), coded as **B0** and **B1**respectively. The bacterium *Rhizobium ciceri* was obtained from the Agricultural Research Directorate of the Ministry of Science and Technology in Baghdad (coded as **A**). It was applied at two levels: the first without addition, and the second by adding 10 grams of peat moss carrying the bacterial inoculum per hill.

3. Third Factor (Phosphate Fertilization): This factor included three levels (0, 80, and 160) kg P ha^{-1} coded as **P0**, **P1** and **P2** respectively.

Studied Traits

To evaluate the traits mentioned below, ten plants were randomly selected from each experimental unit after harvest, excluding the border plants, once the crop reached full maturity.

Yield Traits:

1. **Number of Pods per Plant (pods plant^{-1}**The total number of pods was counted from ten randomly selected plants, and the arithmetic mean was calculated for each experimental unit.

2. **Number of Seeds per Pod (seeds \$pod^{-1}:** The total number of seeds was counted in ten randomly selected pods from each of the ten studied plants, then the average was calculated for each experimental unit.
3. **100-Seed Weight (g):** A random sample of 100 seeds was taken from the total seed yield of the ten studied plants.
4. **Individual Plant Yield (g plant^{-1}:** Ten plants were randomly selected from the experimental unit, and the average seed yield per plant was calculated in grams.
5. **Biological Yield (kg ha^{-1}:** The biological yield was determined by measuring the average dry weight of ten randomly selected dried plants from each unit. The total weight was divided by ten to obtain the mean in grams, converted to kilograms, and then multiplied by the plant population per hectare.
6. **Harvest Index (%):** Calculated for the ten plants studied randomly along a 2-meter line for each experimental unit using the following formula **[11]**
7. **Protein Percentage (%):** The crude protein percentage in the seeds was estimated using the **Micro-Kjeldahl** apparatus by calculating the nitrogen percentage and multiplying it by the constant 6.25 according to the method of **[13]**

Protein Percentage (%)
=Nitrogen Percentage×6.25

Experimental Design and Statistical Analysis

"The experiment was conducted using a **Randomized Complete Block Design (RCBD)** with a **factorial arrangement** of three factors."

- **Main Plots:** Included phosphate and bio-fertilization treatments.
- **Sub-Plots:** Included the studied genotypes.

Each treatment was replicated three times to ensure accuracy. Data were statistically analyzed, and means were compared using **Duncan's Multiple Range Test** at a probability level of **0.05**.

Selection Index

Selection indices were constructed for multiple traits to evaluate the **Expected Genetic Gain**. The best selection indices were those that achieved an expected genetic gain of more than 100% compared to selection for yield alone. The method of **[19]** was used to establish the selection indices (I_n) using all possible dual and triple combinations to select the minimum number of traits with the best selection return according to the equation:

$$I_n = b_1x_1 + b_2x_2 + \dots + b_nx_n$$

Results and Discussion

In table 3 are the results of the analysis of variance. There were highly significant differences among the six environments and among the studied genotypes for most traits. Individual plant yield, 100-seed weight and protein percentage showed the greatest significance with the first two trait being highly important with the latter being second. This indicates a performance evaluation reflects a wide genetic and environment diversity. 15 words The large interaction ($G \times E$) suggests that the ICARDA genotypes have differing genetic potential to adapt to the calcareous and alkaline constraints of the soil of the experimental site. Differential responses were observed among the genotypes due to the low quantity of phosphorus (6.24 mg kg^{-1}) and organic matter. This finding supports the observation of and [18] that high levels of calcium carbonate ($CaCO_3$) and pH are the main factors limiting nutrient availability. Additionally, the stability of the Harvest Index suggests the stability of the crop's physiological structure for dry matter partitioning under infrequent environmental stresses. So, the conclusion of [9] that growth is stable under dry conditions is supported. As a result, the effectiveness of direct selection indices, especially those concerning yield components, demonstrates that selection of 100-seed weight and number of pods is an ideal way to improve yield potential under this condition. This is also consistent with selection criteria of [16] and [12] that maximizes Expected Genetic Gain.

According to the results of selection index (Table 4), the relative efficiency of selection increases when selection for multiple traits is combined into an index as opposed to individual selection for yield I_1. The selection index I23 (pods number × 100 seed weight) exhibited relative efficiency of 105.71% and expected genetic gain of 9.07. Therefore, it was the best selection index for this plant population. The above results were confirmed by [21] and [2], according to which joint selection of yield components enhances the efficiency of expected genetic gain under chemical stress. In comparison, I_{24} indices revealed a marked decline in efficaciousness for efficient genotypes due to exclusion of 100-seed weight, thus indicating a strategic guiding role of 100-seed weight. The above is supported by [22] & [7] who noted seed weight is one of the highly heritable traits that is stable and contribute to compensate for the reduction in pod number under calcareous and alkaline soil environments.

Moreover, analysis of variance for the superior index (Table 5) for the two traits $(I_{2,3})$ among the six studied genotypes did not show any significant differences. Using the superior index on the genotypes revealed non-significant results suggesting all the genotypes have an equal potential for the selection of both these traits (number of pods per plant and 100-seed weight). The mean of the superior index varied from 591.3 for genotype G3 to 933.3 for genotype G6. These two traits could be adapted to various genotypes to improve yield. The research [5] and [22] confirm these findings.

Likewise, Duncan's Multiple Range Test results for genotype means (Table 6) indicated convergence behaviour of the six genotypes in performance. The genotypes were not significantly different from each other and were classified in a single statistical group, A. Genotype G6 had the highest mean value (933.3) and was statistically not different from any other genotype, although it was in high numbers. It suggests that the genotype has a similar response to environment in regards to the studied trait..

Table (3): Analysis of Variance (ANOVA) for Genotype-Environment Interaction (G \timesE)

A: Six Environments, B: Six Genotypes for the Studied Traits

Source of Variation	**d.f.**	**Individual Plant Yield**	**Number of Pods**	**Number of Seeds per Pod**	**100-Seed Weight**	**Harvest Index**	**Protein Percentage**
Replications (R)	2	45.58	776.99	0.02	2.90	14.93	0.01
Environments (A)	5	62.46 (n.s)	333.27 (n.s)	0.15 (n.s)	26.67 (n.s)	30.07 (n.s)	12.30**
Genotypes (B)	5	43.33 (n.s)	52.39 (n.s)	0.003 (n.s)	206.03**	23.81 (n.s)	27.75**
Interaction (A $\times$ B)	25	8.00 (n.s)	88.08 (n.s)	0.012 (n.s)	4.40 (n.s)	17.03 (n.s)	0.15 (n.s)
Error	70	46.57	3260.04	0.57	61.52	1174.03	2.53

Table (4): Priorities of Selection Indices (Ranked by Relative Efficiency)

Rank	Index Code	Index Components (Included Traits)	Expected Genetic Gain (ΔG)	Relative Efficiency (%)
1	**I_{23}**	No. of Pods + 100-Seed Weight	9.07	105.71%
2(Best)	**I_{234}**	No. of Pods + 100-Seed Weight + Protein %	9.05	105.47%
3	**I_{14}**	Plant Yield + Protein %	8.60	100.23%
4	**I_{1}**	Individual Plant Yield (Standard Index)	8.58	100.00%
5	**I_{12}**	Plant Yield + No. of Pods	8.22	95.80%
6	**I_{124}**	Plant Yield + No. of Pods + Protein %	8.15	94.98%
7	**I_{34}**	100-Seed Weight + Protein %	8.07	94.05%
8	**I_{13}**	Plant Yield + 100-Seed Weight	2.55	29.72%
9	**I_{123}**	Plant Yield + No. of Pods + 100-Seed Weight	2.53	29.48%
10	**I_{134}**	Plant Yield + 100-Seed Weight + Protein %	2.52	29.37%
11 (Weakest)	**I_{24}**	No. of Pods + Protein %	0.39	4.54%

Table (5): Analysis of Variance (ANOVA) for the Superior Selection Index (I_{23})

Source of Variation	Degrees of Freedom (DF)	Mean Squares (MS)	Calculated F-Value	Significance Level (Pr > F)
Replications (R)	2	5,095,910.39		
Genotypes (G)	5	54,229.57	1.28	0.3436 (n.s)
Experimental Error	10	42,249.17	—	—
Total	17	—	—	—

Table (6): Means of Genotypes for the Superior Selection Index

Rank	Genotype (G)	Mean	Duncan's Grouping*
1	**G6**	933.3	A
2	**G2**	818.1	A
3	**G5**	788.7	A
4	**G1**	684.4	A
5	**G4**	600.6	A
6	**G3**	591.3	A

Conclusions

1. **Superiority of Genotype G6:** Genotype **G6** excelled in the most critical yield traits, significantly outperforming others in six parameters: number of pods, 100-seed weight, individual plant yield, biological yield, harvest index, and total seed yield.
2. **Impact of Bio-fertilization:** The second level of rhizobial inoculation (**B1**) showed a remarkable effect on all studied traits except for the height of the lowest pod and pod length. It exhibited a moderate influence on plant height, number of days to physiological maturity, and the number of pods.
3. **Effect of Phosphate Fertilization:** The third level of phosphate fertilization (**P2**) achieved the highest means across most traits. However, no significant differences were observed among the three phosphorus levels for pod length. Regarding the height of the lowest pod, the second level (**P1**) showed the best performance, while the effect on the harvest index was marginal across all levels (**P0, P1, and P2**).
4. **Expected Genetic Gain:** The **Expected Genetic Gain**, expressed as a percentage of the general mean, was high for the number of pods per plant, 100-seed weight, and harvest index.
5. **Selection Index Analysis:** Based on the **SAS** analysis results for various traits, and according to the output of the selection index combining individual plant yield (Y_1) and 100-seed weight (Y_4), **Genotype G6** was identified as the overall superior genotype.

Recommendations

1. **Adoption of Genotype G6:** We recommend the utilization of **Genotype G6** due to its distinguished performance in terms of the number of primary and secondary branches, number of pods, 100-seed weight, individual plant yield, biological yield, and total seed yield.

2. **Bio-fertilization Application:** Emphasizing the use of bio-fertilization (rhizobial inoculation) to enhance overall crop performance across most parameters.
3. **Optimal Phosphorus Level:** Implementing the third level of phosphorus (**P2**) to improve most traits, with the exception of pod length and height of the lowest pod, which did not show significant improvement at this specific level.
4. **Genetic Conservation:** Increasing the focus on chickpea crops specifically by establishing a **Genetic Bank** for germplasm collection, improvement, and subsequent release to farmers.
5. **Selection Criteria:** We suggest adopting the **number of pods per plant** and **100-seed weight** as the most reliable indicators and selection criteria for improving total seed yield in breeding programs.

Foreign References

1. **Abdallah, D. M., Neima, H. A., & Mustafa, R. A**. (2022). Growth, Yield, and Quality Characteristics of Eight Winter Chickpea Varieties Under Rainfed Conditions. Tikrit Journal for Agricultural Sciences, 22(3), 148-157.
2. **Al-Jibouri, A. S. (2023).** Evaluation of selection indices for yield and its components in legume crops under semi-arid conditions. *Iraqi Journal of Agricultural Sciences, 54*(1), 112–125.
3. **Al-Mukhtar, M. A. (2000).** *Soil fertility and fertilizers*. National Library, University of Basrah, Iraq. (In Arabic).
4. **Al-Nuaimi, S. N. (1999).** *Fertilization of field crops*. Dar Al-Kutub for Printing and Publishing, University of Mosul, Iraq. (In Arabic).
5. **Al-Obaidi, M. S. (2020).** A study of genetic and environmental variation and correlation coefficients for several chickpea varieties under local environmental conditions. *Anbar Journal of Agricultural Sciences, 18*(1), 145–158. (In Arabic).
6. Al-Qaisi, A. M. H., & Al-Bayati, H. A. H. (2023). Genetic and phenotypic stability of chickpea genotypes under the influence of different planting dates. *IOP Conference Series: Earth and Environmental Science, 1158*(6), 062031.
7. **Al-Saadi, M. K. (2024).** *Quantitative genetics and its applications in crop breeding*. Scientific Books House for Publishing and Distribution, Baghdad, Iraq. (In Arabic).
8. **Altaweel, M. S., & Al-Shakarchy, W. Y. R.** (2021). Study of some genetic parameters in faba bean. Tikrit Journal for Agricultural Sciences, 21(3).
9. **Brady, N. C., & Weil, R. R. (2017).** *The Nature and Properties of Soils* (15th ed.). Pearson Education.
10. **Dawood, K. M. (2002).** *Statistics and design of agricultural experiments*. University of Mosul, College of Agriculture and Forestry, Dar Al-Kutub for Printing and Publishing, Mosul, Iraq. (In Arabic).
11. **Donald, C. M. (1962).** In search of yield. *Journal of the Australian Institute of Agricultural Science, 28,* 171–181.
12. **Falconer, D. S., & Mackay, T. F. (1996).** *Introduction to Quantitative Genetics* (4th ed.). Longman.
13. **Hart, F. L., & Fisher, H. J. (1971).** *Modern Food Analysis*. Springer-Verlag, New York.
14. **Hazel, L. N. (1943).** The genetic basis for constructing selection indices. *Genetics*, *28*(6), 476–490.
15. **ICARDA. (2015).** *Food Legume Improvement Program (FLIP): Annual Report*. International Center for Agricultural Research in the Dry Areas (ICARDA).
16. **Issa, T. A. (2011).** *Plant breeding and improvement*. Ministry of Higher Education and Scientific Research, University of Baghdad, College of Agriculture, Iraq. (In Arabic).
17. **Jassim, A. H., & Al-Tamimi, S. F. (2021).** *Principles of plant breeding (modern applications)*. University of Kufa, College of Agriculture, Iraq. (In Arabic).
18. **Kadir, G. A., Ahmed, S. M., & Hassan, R. K. (2020).** Effect of calcium carbonate on phosphorus availability in calcareous soils. *Journal of Arid Land Agriculture, 12*(2), 45–58.
19. **Miller, P. A., Williams, J. C., Robinson, H. F., & Comstock, R. E. (1958).** Estimates of genotypic and environmental variances and covariances in upland cotton and their implications in selection. *Agronomy Journal*, *50*(3), 126–131.
20. **Mwadzingeni, L., Afari-Sefa, V., & Shimelis, H. (2021).** Genetic

variability and selection indices for yield and yield-related traits in food legumes. *Frontiers in Plant Science*, *12*, 674–689.

21. **Othman, H. K., Al-Ahmady, M. J., & Suleiman, K. A. (2022).** Efficiency of selection indices in improving yield potential of some genotypes. *Journal of Applied Breeding and Genetics*, *9*(3), 201–215.
22. **Saleh, H. R., Mohammed, A. J., & Jassim, R. A. (2018).** Evaluation of yield stability and the effect of genotype-environment interaction for chickpea (*Cicer arietinum* L.) genotypes using different statistical models. *Iraqi Journal of Agricultural Sciences*, *49*(5), 820–832. (In Arabic).
23. **Smith, H. F. (1936).** A discriminant function for plant selection. *Annals of Eugenics*, *7*(2), 240–250.
24. **Turek, S., Wójciak, K. M., & Karwowska, M. (2019).** The influence of the protein hydrolysis process on the antioxidant and ACE-I inhibitory activity of chickpea protein. Technological Sciences.