

The Effect of Genotype and Combination of Phosphorus and Potassium Levels on the Quality Traits of Quinoa (*Chenopodium quinoa* Willd)

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I. Abstract:

A field experiment was conducted at the Agricultural Research Station—Agriculture college —University of Basrah, during the 2024–2025 winter season to study the response of three genotypes of quinoa (Titicaca, Q12, and Q31), designated as V1, V2, and V3, to five combinations of phosphate and potassium fertilizers ((0-0), (45-60), (45-120), (90-60), (90-120)), which were designated as (F1, F2, F3, F4, F5). The experiment was conducted according to the general experimental method using a completely randomized block design (R.C.B.D.) with three replications. The results of the statistical analysis showed that the Titicaca genetic line outperformed the control in most of the studied traits (leaf chlorophyll content, percentage of protein, percentage of phosphorus and potassium in seeds) with averages of (255.0 mg100 g⁻¹ WF, 13.76, 0.32, 0.94) % for the traits respectively, compared to the control treatment (K0, P0), which recorded the lowest averages.

Fertilizer levels had a significant effect on the traits studied, with the fifth fertilizer combination (90P–120K) the highest averages for all studied traits, excelling in leaf chlorophyll content, protein content, phosphorus content in seeds, and potassium content in seeds, with averages of 254.80 mg100 g⁻¹ WF, 14.23, 0.38, and 1.07% for the respective traits, compared to the control treatment (K0, P0), which recorded the lowest averages.

The interaction between factors had a significant effect on most traits, with combination V1 (Titicaca) and F5 (P90 and K120) exceeding the controls in leaf chlorophyll content, protein content, phosphorus content in seeds, and potassium content in seeds, with averages of 344.40 mg100 g⁻¹WF, 14.92%, 0.42%, and 1.21%, respectively.

Keywords : *quinoa, chlorophyll, protein, carbohydrates, phosphate, potassium.*

This research is excerpted from the lead researcher's doctoral dissertation.

II. Introduction :

In light of the changing climatic conditions facing the agricultural sector in arid and semi-arid regions—particularly in southern Iraq—such as limited and saline irrigation water and rising soil salinity —researchers have been prompted to seek out non-traditional crops characterized by high environmental adaptability and nutritional value. Quinoa thus emerges as a promising solution due to its exceptional ability to adapt to multiple environmental stresses (FAO, 2013).

Quinoa (*Chenopodium quinoa* Wild) is a field crop belonging to the *Chenopodiaceae* family. It is a subtropical annual crop characterized by strong, deep roots that help it withstand drought and endure long periods without irrigation (Matiacevich and Castelli, 2006). The crop is notable for containing nearly all essential vitamins and amino acids, except glutamine, which can cause health issues in people with wheat allergies (Li, 2018). Quinoa seeds also have multiple uses, as they can be used to make bread and pastries. Because they are free of oxalates and nitrates, their green parts are used as feed for poultry and livestock due to their high nutritional value, and these characteristics make the crop desirable and versatile (Galwey, 1992).

Conventional fertilizers play an important role in increasing crop yield and quality. Among these fertilizers is phosphate fertilizer, as phosphorus is an essential element required by all plants in large quantities due to its effectiveness in plant nutrition (metabolic processes), such as the synthesis of energy compounds (ATP and ADP), cell formation and division, root growth and development, and its role in the synthesis of cell membranes and nucleic acids (DNA and RNA), as well as photosynthesis and respiration (Mengel and Kirkby, 1987).

Potassium supplementation is also important due to its significant role in facilitating many metabolic processes, including photosynthesis, chlorophyll synthesis, carbohydrate metabolism, and the synthesis of proteins and amino acids, It also delays leaf senescence and plays an active role in stomatal opening and closing; it is most abundant in the cytoplasm and chloroplasts (Salim *et al.*, 2019).

In their study, Ali *et al.* (2023) investigated the effect of applying potassium fertilizer at rates of 90, 140, and 190 kg ha⁻¹; the 190 kg ha⁻¹ rate -1 recorded the highest averages for all study characteristics, with nitrogen, phosphorus, potassium, and protein content reaching 2.11%, 0.378%, 2.14%, and 14.83%, respectively.

Abdolahpour and Pour (2021) noted in their study evaluating NPK fertilizer levels on quinoa that the results indicated the effect of NPK fertilization rates on all measured traits was significant, concluding that the 120:100:80 rate was the highest average value for chlorophyll a, chlorophyll b, total chlorophyll, and protein content in the seeds.

III. Materials and Methods:

A field experiment was conducted at the Agricultural Research Station affiliated with the College of Agriculture at the University of Basrah, located 29 km north of Basra Governorate at 47.80°W longitude and 30.57°N latitude, during the 2024–2025 winter season. The objective was to study the response of three genotypes of the quinoa crop (Titicaca, Q12, and Q31), designated as V1, V2, and V3, to five combinations of phosphate and potassium fertilizers ((0-0), (45-60), (45-120), (90-60), (90-120)), which were designated as (F1, F2, F3, F4, F5).

The seeds were planted in a loamy soil mixture on the recommended planting date of November 1, 2025. Random representative samples of the field soil were taken before planting at a depth of 0–30 cm. These samples were mixed to ensure homogeneity, air-dried, ground, sieved through a 2-mm mesh sieve, and a sample was taken for chemical and physical analysis, the results of which are shown in Table 1. The soil sample was analyzed at the Central Laboratory of the College of Agriculture, University of Basrah.

The soil was prepared for planting by plowing it twice in perpendicular directions using a reversible plow, then leveling and smoothing it with a grader. The land was then marked out, a drip irrigation system was installed, and the area was divided according to the experimental design into plots, each with an area of (2×2) m² and containing 4 rows, with a row length of 2 m, 35 cm between each row, and 25 cm between each plant. Phosphate fertilizer was applied in the form of calcium superphosphate (P₂O₅), potassium in the form of K₂O, and nitrogen fertilizer in three applications totaling 180 kg N. e-1 (Al-asadi and Al-dogagy, 2021). The experiment was conducted using a randomized complete block design (R.C.B.D.) with three replicates. The different treatments were randomly distributed within each block, resulting in a total of 3 × 5 × 3 = 45 experimental units. The experimental data were analyzed using GenStat 12 software, and mean comparisons were performed using the Least Significant Difference (LSD) test at a significance level of 0.05 (Al-Sahoki *et al.*, 1990).

Table (1) Some chemical and physical properties of the experimental field soil before planting

Analysis		Unity	Depth (0-30) cm
Soil Breaks	Sand	gm.kg ⁻¹	286.2
	Silt		322.1
	Clay		398.3
Soil texture			clay loam
electrical conductivity		ds m ⁻¹	7.55
Soil reactivity degree		pH	7.83
Organic matter		%	0.86
Ready Nitrogen		ppm	310
Ready Phosphorus		ppm	62.95
Ready Potassium		ppm	34.1

IV. Results and Discussion:

1. Total chlorophyll content of the leaves: (mg100 g⁻¹ WF).

The results in Table 2 showed significant effects of genotypes, fertilizer combinations, and their interactions on leaf chlorophyll content. Genotype V1 (Titicaca) performed best, recording the highest mean value of 254.8 mg100 g⁻¹ WF, while genotype V2 (Q12) had the lowest mean of 138.9 mg 100 g⁻¹. Fertilizer combination 5 (p 90-k120) achieved the highest average of 254.8 mg 100 g⁻¹, compared to the control treatment, which recorded the lowest average of 114.1 mg 100 g⁻¹. This superiority may be attributed to the role of the fertilizer combination of (P and K) in increasing the activity of metabolic processes within the plant, such as photosynthesis, amino acid synthesis, and the production of energy compounds (ATP and ADP), as well as chloroplast formation, in addition to promoting cell division and elongation, which leads to good vegetative growth and root mass (Marschner, 2012). These results are consistent with those reported by Alavifazel *et al.*, 2022; Wang *et al.*, 2022; and Amiryousefi *et al.*, 2020. From the results in the same table, it is observed that the interaction treatment for the first genotype (V1) outperformed when treated with fertilizer combination F5, recording the highest mean of 344.4 mg g⁻¹ WF.

Table (2) Effect of P and K fertilization levels, genotypes, and their interactions on leaf chlorophyll content (mg 100 g⁻¹ WF).

genotypes	fertilization levels P, K					V- average
	F1	F2	F3	F4	F5	
V1	159.3	203.6	257.3	310.3	344.4	255.0
V2	87.3	116.2	128.5	162.8	199.5	138.9
V3	95.7	110.5	125.9	194.0	220.4	149.3
F- average	114.1	143.4	170.5	222.4	254.8	
LSD 0.05	genotypes	Fertilizer combinations			Interaction	
	30.34	39.17			67.85	

2. Protein content (%).

The results in Table 3 showed that there were significant effects of genotypes, fertilizer combinations, and their interaction on the protein content in seeds. Genotype V1 (Titicaca) outperformed the others, recording the highest mean value of 13.76%, while genotype V2 (Q12) achieved the lowest mean of 12.12%. Fertilizer combination F5 achieved the highest mean of 14.23% compared to the control treatment, which recorded the lowest mean of 10.86%. This superiority may be attributed to the role of the P and K fertilizer formulation, as it increased the activation of enzymes, including nitrate reductase, which is responsible for the conversion of nitrate to ammonium—a fundamental process in converting absorbed nitrogen into amino acids and subsequently into proteins stored in the seeds (Ahmed *et al.*, 2019). These results are consistent with those reported by Hasan and Hussien (2025).

The results in the table show that the interaction treatment for Genotype 1 (Titicaca) outperformed the treatment with Fertilizer Mixture 5 (F5), recording a higher average of 14.92%, while the average for this trait decreased significantly when Genotype V1 was treated with the control treatment (without fertilization).

Table (3) Effect of P and K fertilization levels, genetic combinations, and their interactions on seed protein content (%).

genotypes	fertilization levels P, K					V- average
	F1	F2	F3	F4	F5	
V1	11.82	13.65	13.95	14.47	14.92	13.76
V2	9.69	12.00	12.26	13.04	13.63	12.12
V3	11.06	13.00	13.70	13.80	14.15	13.14
F- average	10.86	12.88	13.31	13.77	14.23	
LSD 0.05	genotypes	Fertilizer combinations			Interaction	
	0.263	0.340			0.589	

3. Carbohydrate content: (%).

The results in Table 4 showed significant effects of genotypes, fertilizer combinations, and their interaction on the carbohydrate content in seeds. Genotype V3 (Q31) outperformed the others, recording the highest mean value for this trait at 61.49%, while genotype V1 (Titicaca) had the lowest mean of 60.89%. Fertilizer combination F1 had the highest mean of 63.72% compared to combination F5, which recorded the lowest mean of 60.04%. The superiority of the control treatment in carbohydrate content may be attributed to the reduced metabolic conversion rate of primary sugars toward amino acid synthesis due to a lack of nutrient supply, which prompted the plant to store photosynthetic products as starch in the seeds. In contrast, in high-fertilizer treatments, these substances were consumed as energy for protein synthesis, leading to a decrease in carbohydrates and an inverse relationship between protein and carbohydrate content resulting from competition for metabolic energy within the plant (Bhatia et al., 1987). These results are consistent with those reported by Yazdanpoor *et al.*, (2023) and Kiyani *et al.* (2022).

From the results of the same table, it is observed that the second genetic combination (Q12) and the control treatment (F1) outperformed the others, recording the highest average of 64.888%.

Table (4) Effect of P and K fertilization levels, genotypes, and their interactions on the carbohydrate content of seeds (%).

genotypes	fertilization levels P, K					V- average
	F1	F2	F3	F4	F5	
V1	62.63	61.50	60.53	60.24	59.56	60.89
V2	64.88	62.58	62.21	61.11	60.25	62.21
V3	63.64	61.41	61.21	60.85	60.32	61.49
F- average	63.72	61.83	61.32	60.73	60.04	
LSD 0.05	genotypes	Fertilizer combinations			Interaction	
	0.199	0.257			0.446	

4. Phosphorus content in seeds (%).

The results in Table 5 showed that the genotypes, fertilizer combinations, and their interactions had significant effects on the phosphorus content in seeds. Genotype V1 (Titicaca) outperformed the others, recording the highest mean value of 0.32%, while genotype V2 (Q12) had the lowest mean of 0.29%. Fertilizer combination F5 achieved the highest mean of 0.38% compared to the control treatment, which recorded the lowest mean of 0.25%. This superiority may be attributed to the role of phosphorus and potassium fertilization in increasing the phosphorus content in quinoa seeds as a result of the higher amount of available phosphorus in the soil, improved absorption and transport within the plant, and potassium's contribution to enzyme activation and improved nutrient transport to the seeds. Furthermore, phosphorus is an essential element in energy metabolism and nucleic acid synthesis; therefore, its accumulation in seeds increases during the filling stage (Wang *et al.*, 2022). These results are consistent with those reported by Al-Naggar *et al.* (2022).

From the results of the same table, it is observed that the interaction treatment for the first genotype (Titicaca) outperformed its treatment with the fifth fertilizer combination (F5), recording the highest average of 0.42%, while the lowest average for the trait was recorded for the third genotype (V3) in the comparison treatment, with an average of 0.25%.

Table (5) Effect of P and K fertilization levels, genetic combinations, and their interaction on the phosphorus content in seeds (%).

genotypes	fertilization levels P, K					V- average
	F1	F2	F3	F4	F5	
V1	0.26	0.29	0.29	0.35	0.42	0.32
V2	0.26	0.27	0.31	0.32	0.32	0.29
V3	0.25	0.28	0.30	0.35	0.39	0.31
F- average	0.25	0.28	0.30	0.34	0.38	
LSD 0.05	genotypes	Fertilizer combinations			Interaction	
	0.015	0.019			0.034	

5. Potassium content in seeds (%).

The results in Table 6 showed that there were significant effects of genotypes, fertilizer combinations, and their interaction on the potassium content in seeds. Genotype V1 (Titicaca) outperformed the others, recording the highest mean value of 0.94%, while genotype V2 (Q12) had the lowest mean of 0.62%. Fertilizer combination F5 achieved the highest mean of 1.07% compared to the control treatment, which recorded the lowest mean of 0.62%. This may be attributed to the role of mineral fertilization in improving vegetative growth, increasing photosynthetic efficiency, and activating the enzymes responsible for the formation and transport of carbohydrates, which is reflected in increased accumulation of nutrients in the seeds, including potassium. Furthermore, the improvement in the plant's overall nutritional status resulting from fertilization may enhance root absorption efficiency, thereby increasing the final seed content of this element (Marschner, 2012). These results are consistent with those reported by Al-Naggar *et al.* (2022).

The table shows that the interaction treatment for the first genotype (V1) outperformed the treatment with fertilizer mixture F5, recording the highest average of 0.65%.

Table (6) Effect of P and K fertilization levels, genotypes, and their interaction on the potassium content in seeds (%).

genotypes	fertilization levels P, K					V- average
	F1	F2	F3	F4	F5	
V1	0.65	0.87	0.98	1.01	1.21	0.94
V2	0.60	0.76	0.89	0.95	0.99	0.84
V3	0.60	0.96	0.98	0.99	1.00	0.91
F- average	0.62	0.86	0.95	0.98	1.07	
LSD 0.05	genotypes	Fertilizer combinations			Interaction	
	0.039	0.050			0.087	

V. Conclusions:

The results of the study show that the first genetic line (Titicaca) outperformed the others in most of the traits studied and is considered the most suitable for the conditions of the region. Furthermore, the fifth fertilizer combination (K120-P90) showed statistically significant superiority in most traits, and the interaction between the first genetic combination (Titicaca) and the fifth fertilizer level (K120-P90) achieved the best performance in most of the studied traits.

VI. Reference:

- Al-Sahoki, Hamid Jalub Wahib, and Karima Muhammad. (1990). Applications in Experimental Design and Analysis. Ministry of Higher Education and Scientific Research, University of Baghdad. Dar al-Hikma for Printing and Publishing, University of Mosul.
- Abdolapour, H., and Pour, A. P. (2021). Effect of Nitrogen, Phosphorus and Potassium Fertilizers on Morpho-Physiological Characteristics and Seed Yield of Quinoa (*Chenopodium quinoa* Willd.). journal of crop ecophysiology, 15(57), 57–72. <https://www.magiran.com/paper/2263050> LK -
- Ahmed, S., Griffin, T. S., Kraner, D., Schaffner, M. K., Sharma, D., Hazel, M., Leitch, A. R., Orians, C. M., Han, W., Stepp, J. R., Robbat, A., Matyas, C., Long, C., Xue, D., Houser, R. F., and Cash, S. B. (2019). Environmental Factors Variably Impact Tea Secondary Metabolites in the Context of Climate Change. 10(August), 1–16. <https://doi.org/10.3389/fpls.2019.00939>
- Al-asadi, W. A. J., and Al-dogagy, K. A. (2021). The Effect of Nitrogen Fertilizer Levels and Planting Dates on Some Growth Traits and Yield of the Quinoa Plant (*Chenopodium quinoa* Wild.
- Al-Naggar, A. M., ATTA, M., El-moneim, m., and Al-metwally Al-metwally, m. (2022). Low-N tolerance, N-use Efficiency and Responsiveness of 37 *Chenopodium quinoa* Genotypes Under Organic and Mineral Fertilizer Conditions. Plant Cell Biotechnology and Molecular Biology, 34–51. <https://doi.org/10.56557/pcbmb/2022/v23i5-67416>

- Alavifazel, M., Jorfi, A., Gilani, A., and Ardakani, M. R. (2022). OPEN ACCESS Leaf Chlorophyll Changes and Morphological Features of Quinoa (*Chenopodium quinoa*) Cultivars by P-Zn Ratios in Greenhouse Condition. In Journal of Crop Nutrition Science . 8: (1). <https://jcn.s.ahvaz.iau.ir/>
- Ali, E. S. E. S. E. S., El-Samad, E. E. D. H. A., Abdelaal, H. A., and AbouSekken, M. S. (2023). Enhancement of Quinoa Grain Yield and Nutritional Quality by Potassium Fertilization Combined with Foliar Spraying of Seaweed Extract. Journal of Ecological Engineering, 24(3), 341–356. <https://doi.org/10.12911/22998993/158384>
- Amiryousefi, M., Tadayon, M. R., and Ebrahimi, R. (2020). Effect of chemical and biological fertilizers on some physiological traits, yield components and yield of quinoa plant.
- FAO 2013. Launch of the international year of Quinoa: UN celebrates Andean super food. The Food and Agricultural Organization of United Nation, Rome, I. <http://www.fao.org/quinoa-2013/press-room/news/detail/en/> (Accessed 1. 7. 15.). (n. d.). N. T. (n.d.). No Title.
- Galwey, N. W. (1992). The potential of quinoa as a multi-purpose crop for agricultural diversification: a review. Industrial Crops and Products, 1(2), 101–106. [https://doi.org/https://doi.org/10.1016/0926-6690\(92\)90006-H](https://doi.org/https://doi.org/10.1016/0926-6690(92)90006-H)
- Hasan, B. K., and Hussien, T. E. (2025). Effect of Three Levels Application of NPK Fertilizer and Irrigation Method on Yield and Yield Components of Quinoa (*Chenopodium quinoa* Willd.). Natural and Engineering Sciences, 10(1), 120–127. <https://doi.org/10.28978/nesciences.1642273>
- Kiyan, H. F., Tatari, M., Tokalo, M. R., Salehi, M., and Ghalibaf, K. H. H. (2022). The effect of deficit irrigation and fertilizer on quantitative and qualitative yield of quinoa (*Chenopodium quinoa*). Ital J Agrometeorol, 1, 83–99.
- Li, L. (2018). Nutritional properties of quinoa (*Chenopodium quinoa* Wild.) and its effects on cardiometabolic risk factors and gut microbiota By. March.
- Marschner, H. (2011). Marschner's mineral nutrition of higher plants. Academic press.
- Matiacevich, S. B., and Castelli, M. L. (2006). Water-dependent thermal transitions in quinoa embryos. 448, 117–122. <https://doi.org/10.1016/j.tca.2006.06.016>
- Mengel, K., and Kirkby, E. A. (1987). Principles of plant nutrition. Bern. International Potash Institute, 685.
- Production_and_Biological_Nitrogen_Fixation_of_Tro.pdf.opdownload. (n.d.).
- Salim, S. A., Al-Hadeethi, I. K., Adil, S., and Alobaydi, J. (n.d.). Role of Irrigation Scheduling and Potassium Fertilization on Soil Moisture Depletion and Distribution of Quinoa Root (Irrigation Scheduling Fertilization and Their Effect on Moisture Depletion and Yield).
- Wang, Q., Guo, Y., Huang, T., Zhang, X., Zhang, P., Xie, H., Liu, J., Li, L., Kong, Z., and Qin, P. (2022). Transcriptome and Metabolome Analyses Revealed the Response Mechanism of Quinoa Seedlings to Different Phosphorus Stresses. International Journal of Molecular Sciences, 23(9). <https://doi.org/10.3390/ijms23094704>
- Yazdanpoor, A., Soluki, M., Dahmardeh, M., and Khammari, I. (2023). Investigating the combined effect of organic and chemical fertilizers on quantitative and qualitative yield of Quinoa (*Chenopodium quinoa*) under drought stress. 15(4), 1059–1072. <https://doi.org/10.22077/escs.2021.4231.1991>

