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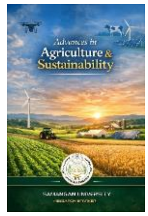

Evaluation of Different Levels of Phosphorus Fertilizer on Yield and Yield Components of Barley (*Hordeum vulgare* L.) under the Environmental Conditions of Baghlan Province

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Keywords

Phosphorus fertilization, Grain yield, Yield components, Barley, Afghanistan.

Research/Review Article

Abstract

Evaluation of the different levels of phosphorus fertilizer on yield and yield components of barley (*Hordeum Vulgare* l.). The experiment was conducted at the Puza-i-Ishan Research Farm in Baghlan Province during the 2025 growing season. The study was laid out in a Randomized Complete Block Design (RCBD) over a total area of 324 m². The treatments consisted of four phosphorus levels: a control (0 kg/ha) and three application rates (40, 80, and 120 kg/ha). Statistical analysis revealed that increasing phosphorus levels had a positive and significant effect on the growth and yield attributes of barley. Although higher doses led to numerical increases in several parameters, these improvements were not statistically significant in all cases. Phosphorus application significantly enhanced the number of spikelets per spike, the number of tillers, the number of spikes, plant height, spike length, grain weight, biological yield, and harvest index (HI). The highest values for most studied traits, including spikelets per spike, plant height, spikes per unit area, grain weight, and biological yield, were recorded at the 120 kg P/ha level. For certain traits, such as 1000-grain weight and tiller number, intermediate levels did not differ significantly from the highest dose. Overall, the results highlight the critical role of phosphorus in improving both vegetative and reproductive growth of barley. Therefore, the application of 120 kg P_2O_5 ha^{-1} is recommended to achieve maximum agronomic response under the environmental conditions of Baghlan Province.

1. Introduction

Barley (*Hordeum vulgare* L.) is recognized as one of the most significant cereal crops produced globally (Wang et al., 2017). In terms of global production, it ranks fourth after wheat, maize, and rice (FAO, 2019). Global barley production is estimated at approximately 141.7 million tons (USDA, 2017). The European Union, Russia, Canada, the United States, and Argentina are the five major barley-producing entities. The European Union leads with a production of approximately 20.5 million tons, followed by the Russian Federation with 8 million tons. Production in Canada, the USA, and Argentina is estimated at 7.3, 3.1, and 2.8 million tons, respectively (USDA, 2017). In Afghanistan, barley is a vital cereal crop, ranking as the most cultivated grain after wheat and rice. Due to its high tolerance to cold and drought, short growing season, and low water requirements, it is extensively cultivated in high-altitude and semi-arid regions, particularly in Bamyan, Daikundi, Ghor, Badakhshan, Takhar, Faryab, Herat, and Balkh provinces (Ramazani et al., 2016).

The primary factors contributing to low barley productivity in Afghanistan include poor soil fertility, the use of low-yielding varieties, waterlogging, drought, frost, soil acidity (low pH), pests and diseases, poor agronomic management, limited access to improved seeds, and weed competition (Zhang et al., 2020). Among these, low soil fertility and the cultivation of low-yielding varieties are the most significant constraints threatening barley production (Mohammadi et al., 2020).

Phosphorus (P) not only directly affects vegetative growth but also plays a crucial role in enhancing yield components, such as the number of spikes per unit area, spikelets per spike, grains per spike, and 1,000-grain weight. Research has shown that balanced phosphorus application increases the uptake of other nutrients, improves photosynthetic efficiency, and enhances the translocation of photosynthates to the grains, ultimately leading to higher biological and grain yields (Havlin et al., 2014).

Many researchers have investigated the effects of various phosphorus fertilizer levels on barley yield and its components. Findings indicate that increasing phosphorus levels up to a certain threshold significantly improves morphological and yield traits. For instance, Singh et al. (2018) reported that phosphorus application increased the number of tillers, spike length, and grain yield. Similarly, Tandon (2019) demonstrated that appropriate phosphorus fertilization plays a vital role in increasing 1,000-grain weight and harvest index. Moges et al. (2018) stated that increased phosphorus rates led to higher grain yields; specifically, they observed a yield of 70.74 kg/ha at a level of 40 kg P/ha compared to 52.53 kg/ha in the control. Kumar et al. (2025) noted that the application of 120 kg P/ha increased straw yield, biological yield, and harvest index, resulting in maximum economic profit for farmers. Furthermore, Rahul et al. (2023) reported that adding phosphorus up to 60 kg/ha improved post-harvest soil properties, including Electrical Conductivity (EC), Organic Carbon (OC), and the availability of N, P, and K.

Considering the limited research conducted under the specific environmental conditions of Baghlan Province and the need for farmers to receive scientific and practical recommendations for phosphorus management, this study was conducted. The objective was to evaluate the effect of various phosphorus fertilizer levels on the yield and yield components of barley (*Hordeum vulgare* L.) and to determine the optimal phosphorus level for maximizing growth and yield in this region.

2. Materials and Methods

This research was conducted at the research farm of the Agriculture Faculty, Baghlan University, located in Pooza-Eshan, during late winter (March) of 1403 AH (2025). The experimental site is situated at an elevation of 510 meters above sea level and geographically positioned at 68°45' E longitude and 36° N latitude. The average annual rainfall of the region ranges between 250 and 300 millimeters. The experiment was carried out using a Randomized Complete Block Design (RCBD) with three replications and a control treatment (no phosphorus application). In total, 12 plots were established, each with an area of 3 m² (2 m in length and 1.5 m in width). The spacing between blocks was maintained at 1.5 meters, and the spacing between plots was set at 0.5 meters. In this study, three phosphorus levels (40, 80, and 120 kg ha^{-1}) along with a control treatment (no phosphorus application) were evaluated. The seed used belonged to a local barley variety widely cultivated by farmers across Afghanistan. To assess the effect of phosphorus fertilizer levels on the growth and yield of barley, diammonium phosphate (DAP) a commonly available fertilizer was applied.

For data collection, five plants were randomly selected and marked in each plot. Growth-related data were recorded at different growth stages from sowing to harvest, as required. Yield-related data were collected at harvest. To determine grain and biological yield, plants within a one-square-meter area of each plot were harvested, cleaned, dried, and weighed. The traits evaluated in this study included growth and yield characteristics of barley: plant height, number of spikes per plant, spike length, spike weight, plant weight, number of spikelets per spike, number of spikes per square meter, number of tillers per square meter, number of grains per plant, thousand-grain weight, biological yield, and harvest index.

Data analysis was performed using OPSTAT, an online statistical analysis software. Analysis of variance (ANOVA) was conducted to determine significant differences among treatments. Subsequently, mean comparisons were carried out using Duncan's Multiple Range Test (DMRT) at the 5% probability level to identify statistically significant differences among treatments. Microsoft Excel was used for preparing tables and graphs.

3. Results

This chapter is devoted to the presentation and analysis of the results obtained from the field experiment. In this section, based on the experimental design employed, the data collected during the course of the study are statistically analyzed, and the results are presented in a systematic and scientific manner. Subsequently, the findings are compared with those of previous research, and possible reasons for the observed differences or similarities are discussed.

3.1 Plant height (cm)

Statistical analysis of the obtained data indicates that plant height increased significantly with higher rates of phosphorus application Table (1). The maximum plant height was recorded in the P_{120} treatment, with a mean of 80.6 cm. Conversely, the minimum plant height was observed in the control treatment P_0 with a mean of 60.222 cm, which was significantly different from all other treatments. Furthermore, at phosphorus levels of 40 and 80 kg, plant height reached 71.356 cm and 71.811 cm, respectively; both were statistically categorized within group (b) Figure (3).

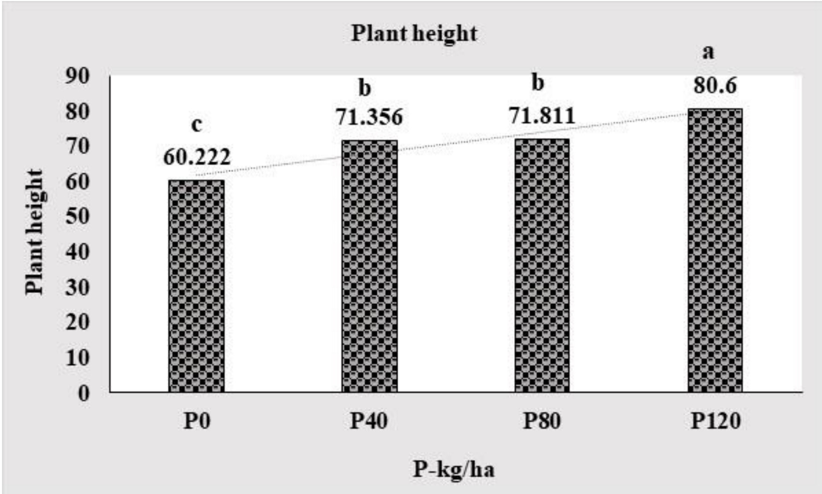

Figure 3. The effect of different phosphorus fertilizer rates on the number of Plant height (cm)

3.2 Number of tillers per (m^2)

Statistical analysis of the obtained data on the number of tillers per square meter indicates that higher phosphorus application rates had a positive effect on tiller production (Table 1). Comparison of the mean values reveals that the maximum number of tillers (188) was recorded under the application of 120 kg phosphorus per hectare. This was followed by 167.3 tillers with 80 kg phosphorus per hectare and 164.5 tillers with 40 kg phosphorus per hectare. In contrast, the minimum number of tillers (134.7) was observed in the control treatment (P0), where no phosphorus was applied (Figure 1).

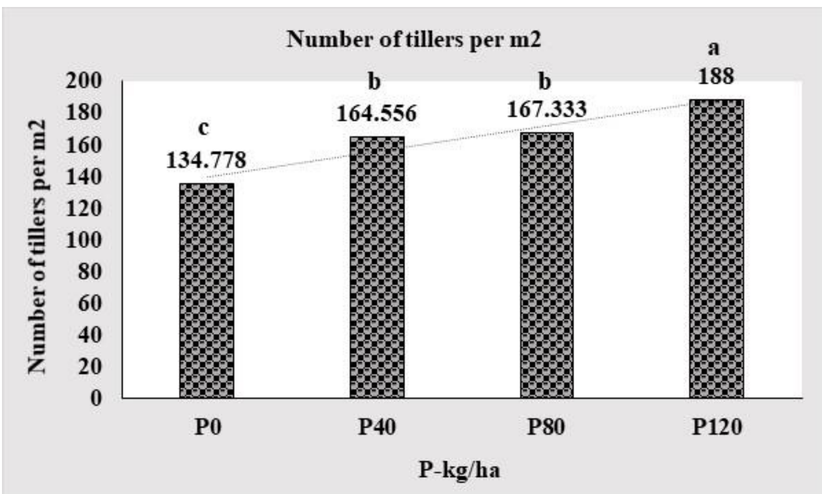

Figure 2. The effect of different phosphorus fertilizer rates on the number of Number of tillers per m^2

3.3 Number of spikelet in a spike

Statistical analysis of the data regarding the number of spikelet per spike indicates that increasing phosphorus application significantly enhanced this parameter (Table 1). The maximum value (20.1) was recorded in the 120 kg P/ha treatment, while the minimum value (18.578) was observed in the control treatment (P_0). According to the statistical results, the P_{120} treatment was placed in the highest Increasing group (a). Conversely, the P_0 and P_{40} treatments were categorized in the lower statistical group (b). The P_{80} treatment, positioned in the intermediate group (ab), showed no significant difference compared to either the control or the P_{120} treatments. These findings demonstrate that phosphorus application at a rate of 120 kg/ha plays an effective role in increasing the number of spikelet per spike in barley plants (Figure1).

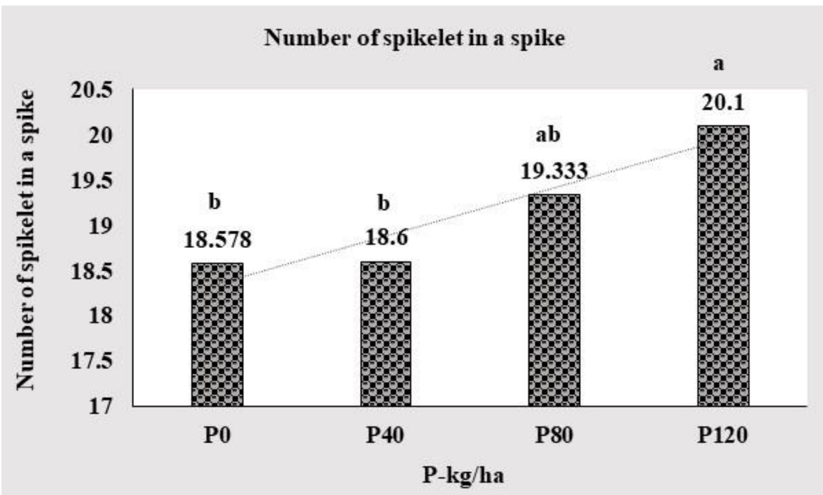

Figure 1. Number of spikelet per spike as affected by phosphorus fertilizer levels.

3.4 Number of spikes per plant

Statistical analysis of the obtained data demonstrates that increasing phosphorus application resulted in a higher number of spikes per plant (Table 1). The maximum number of spikes (7.844 per plant) was recorded in the P_{120} treatment, which was statistically categorized at the highest level, denoted by the letter *a*. In contrast, the minimum number of spikes (5.444 per plant) was observed in the control treatment (P_0), which showed a significant increase when compared with P_{120}. Furthermore, the number of spikes in the P_{40} and P_{80} treatments was 6.289 and 6.511, respectively. These treatments were statistically grouped as *b* and *ab*, indicating an increase relative to the control (P_0). However, their differences from the P_{120} treatment were less pronounced statistically (Figure 4).

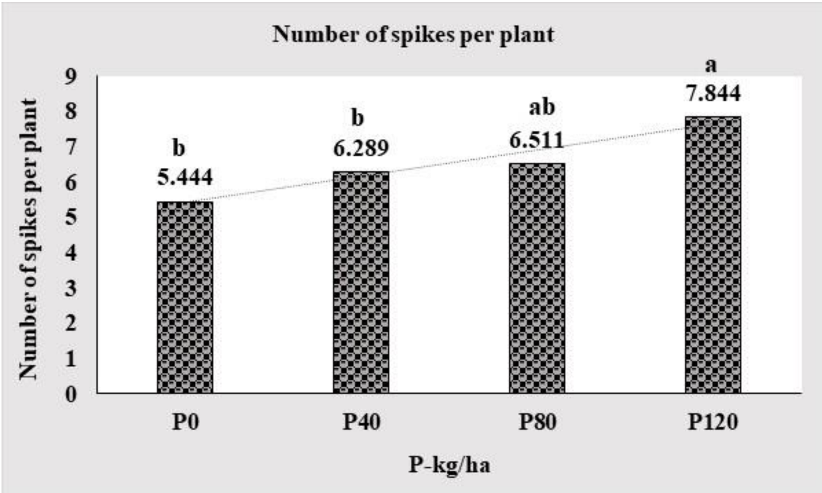

Figure 4. Effect of different phosphorus fertilizer rates on the number of spikes per plant.

3.5 Number of spikes per m^{-2}

Statistical analysis of the results indicates that increasing phosphorus application led to a higher number of spikes per unit area (Table 1). The highest spike density (185.778 spikes m^2) was recorded in the P_{120} treatment, which showed a statistically effect increase compared with other treatments and was categorized in group *a*. In contrast, the lowest spike density (151.667 spikes m^2) was observed in the control treatment (P_0), which was statistically grouped together with the P_{40} and P_{80} treatments in group *b*. This finding suggests that phosphorus application up to 80 kg/ha did not result in a significant increase in spike density (Figure 5).

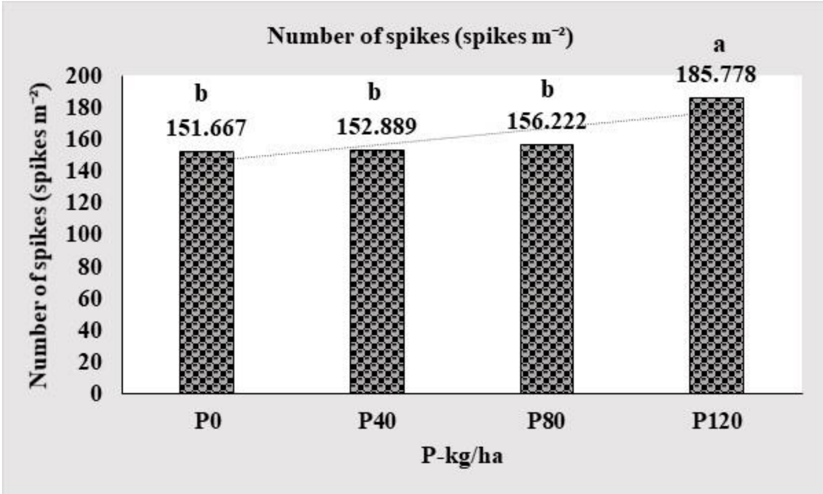

Figure 5. Effect of different phosphorus fertilizer rates on the number of spikes per m².

3.6 plant weight (m^2)

Statistical analysis of the results indicates that plant biomass increased with higher levels of phosphorus application (Table 1). The maximum plant weight (23.167 gr/m) was obtained in the P_{120} treatment, which showed a statistically significant increase compared with the other treatments. In contrast, the minimum plant weight (16.378 gr/m^2) was recorded in the control treatment (P_0), which was statistically distinct from the other treatments. Moreover, phosphorus application at levels of 40 and 80 kg/ha increased plant weight to 19.344 g and 20.344 gr/m^2, respectively, both of which were categorized in group *b* (Figure 6).

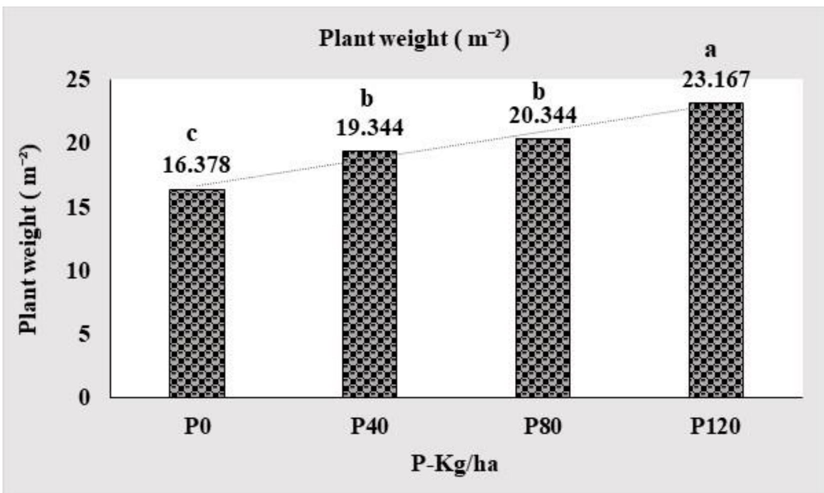

Figure 5. Effect of different phosphorus fertilizer rates on the plant weight (m^2)

3.7 Number 1000 Weight (gr)

Statistical analysis indicates that increasing phosphorus levels led to perceptible changes and, in certain instances, a significant increase in 1000-grain weight (Table 1). The maximum 1000-grain weight, averaging 43.767 g, was recorded in the P_{120} treatment. According to the statistical analysis, this treatment was categorized in level 'a,' demonstrating a significant increasing effect compared to other treatments. Conversely, the lowest 1000-grain weight were observed in the P_0 and P_{80} treatments, with averages of 41.133 g and 41.211 g, respectively; both were statistically grouped in level 'b.' The P_{40} treatment, with an average of 41.889 g, was placed in the 'ab' group, indicating that its differences from the P_0, P_{80}, and P_{120} treatments were less pronounced (Figure 7).

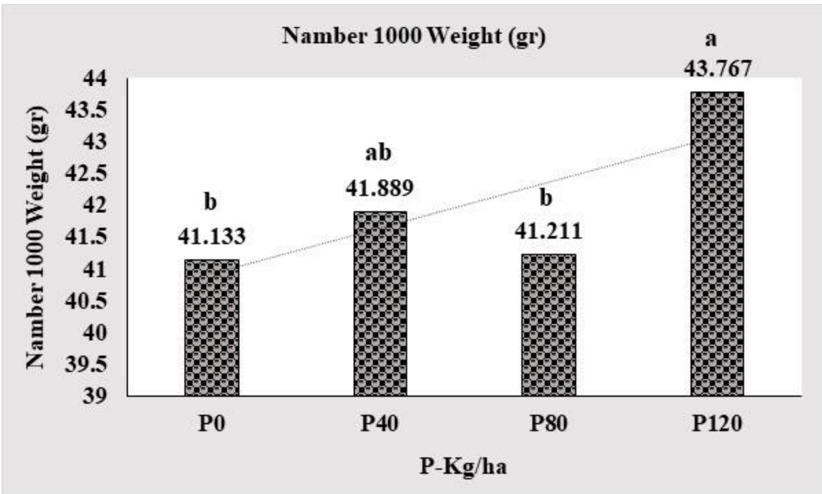

Figure 7. Effect of different phosphorus fertilizer rates on 1000-grain weight.

3.8 Spike length (cm)

Scientific and statistical analyses indicate that increasing phosphorus (P) levels significantly enhanced spike length (Table 1). Specifically, as fertilizer application increased from 0 to 120 kg/ha, spike length rose from 8.511 cm in the control group (P_0) to 9.689 cm at the P_{120} level (Table 1). Furthermore, the distinct statistical groupings (a, ab, b) demonstrate a positive correlation between phosphorus application levels and spike length (Figure 8).

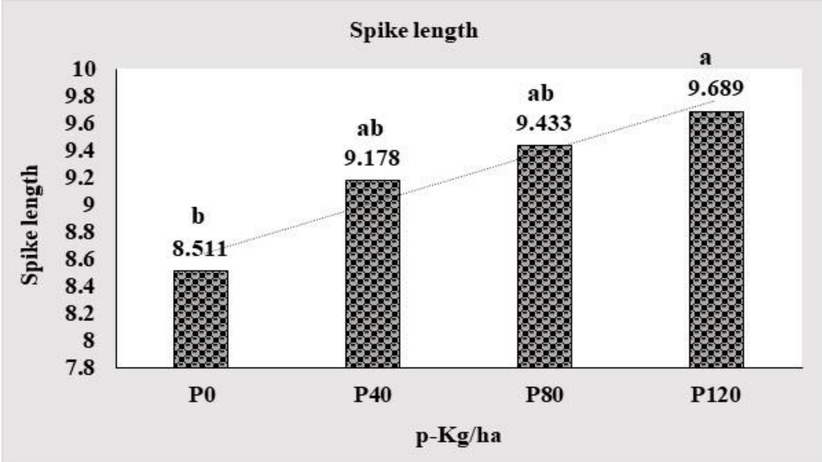

Figure 8. Effect of different phosphorus fertilizer rates on spike length (cm).

3.9 Biological weight

Biological yield in barley was Increasing effect by varying phosphorus rates (Table 1). The P_{120} treatment produced the maximum biological yield (471.222 kg ha^{-1}), while the lowest (245.333 kg ha^{-1}) was obtained from the P_0 treatment. Mean separation using different letters (a to d) confirms Increasing variations across all phosphorus levels. Such results highlight the effective role of phosphorus fertilization in promoting vegetative development and increasing dry matter production (Figure 10).

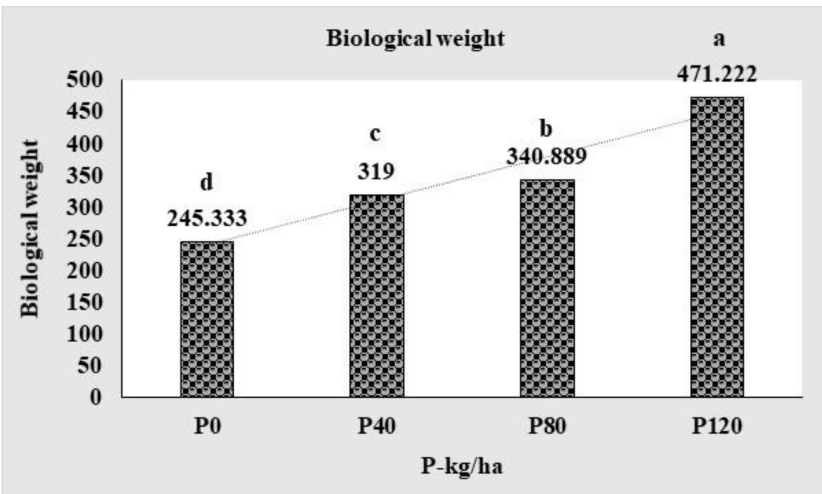

Figure 10. Biological yield (kg ha^{-1}) of barley as influenced by different phosphorus fertilizer rates.

3.10 Harvest Index (%)

The harvest index (HI) was Increasing effect by phosphorus fertilization levels (Table1). Raising P levels from 0 to 120 kg/ha led to a consistent increase in HI. Treatments P80 (151.982 %) and P_{120} (158.692 %) shared statistical group 'a', signifying that while they were superior to other treatments, the difference between them was negligible. The P_0 treatment yielded the minimum HI (103.83 %), categorized under group 'c', while P_{40} (133.299 %) occupied group 'b'. These results suggest that phosphorus application effectively optimizes the harvest index up to a threshold of 80 kg/ha, beyond which no Increasing effect improvement occurs (Figure 11).

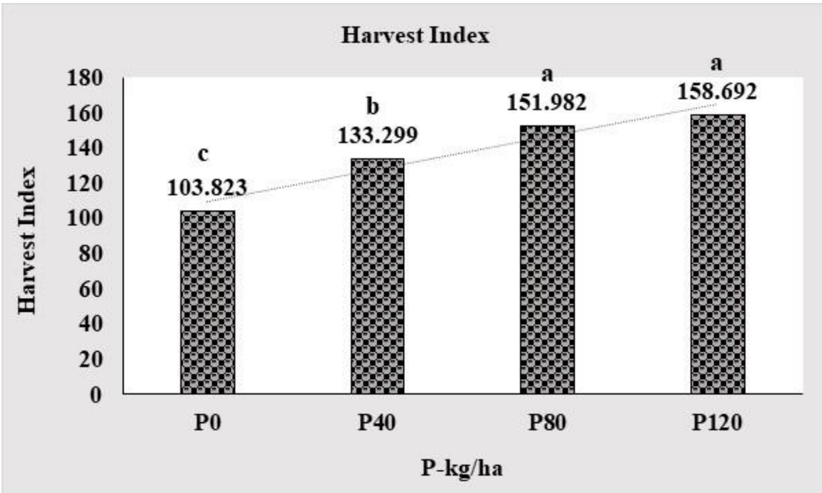

Figure 11. Harvest index (%) of barley as influenced by different phosphorus fertilizer rates.

Table 1. Measured traits of barley as influenced by different phosphorus fertilizer rates.

Treatment	Plant height (cm)	Number of tillers per m^2	Number of spikelet in a spike	Number of spikes per plant	Spike length
T1=P0	60.222	134.778	151.667	5.444	8.511
T2=P40	71.356	164.556	152.889	6.289	9.178
T3=P80	71.811	167.333	156.222	6.511	9.433
T4=P120	80.6	188	185.778	7.844	9.689
C.D.	0.028	0.07	0.353	0.089	0.093
SE(m)	4.361	13.315	10.376	0.634	0.326
SE(d)	6.168	18.83	14.675	0.896	0.46
C.V.	18.846	21.98	7.31	35.857	11.414

Treatment	Number of spikes per (m^{-2})	Plant weight (m^{-2})	Number 1000 Weight (gr)	Biological weight	Harvest Index
T1=P0	18.578	16.378	41.133	245.333	103.823
T2=P40	18.6	19.344	41.889	319	133.299
T3=P80	19.333	20.344	41.211	340.889	151.982
T4=P120	20.1	23.167	43.767	471.222	158.692
C.D.	0.091	0.122	0.436	0.005	0.557
SE(m)	0.677	1.906	1.261	39.127	29.179
SE(d)	0.957	2.696	1.784	55.335	41.265
C.V.	13.106	35.91	8.181	31.191	91.301

4. Discussion

Statistical analysis of the data revealed that the application of varying phosphorus (P) fertilizer levels had a significant impact on the morphological traits, yield components, and final grain yield of barley. Yield Components and Vegetative Growth The increase in the number of spikelets per spike as phosphorus levels rose, particularly at the 120 kg P/ha rate, aligns with findings reported by Singh et al. (2018) and Sharma et al. (2019). These researchers noted that phosphorus enhances yield components in cereals by promoting cell division and improving the differentiation of reproductive organs. The lack of significant differences between certain phosphorus levels observed in this study is consistent with Kumar et al. (2017), who attributed such patterns to relative soil phosphorus sufficiency and a plateau in plant response at intermediate application rates. Furthermore, the increase in the number of tillers per square meter in response to phosphorus application is in agreement with Ali et al. (2016) and Rasol et al. (2020). These authors reported that phosphorus significantly boosts vegetative growth and tillering capacity by promoting root system development and enhancing water and nutrient uptake. Regarding plant height, the significant increase observed, especially at the 120 kg/ha level, coincides with reports by Malik et al. (2015) and Yadav et al (2021). This height increment is attributed to improved root growth, enhanced nitrogen uptake, and the acceleration of physiological processes, including photosynthesis. Spike and Grain Parameters The increase in the number of spikes per plant and spikes per unit area with higher phosphorus rates is consistent with the results of Patel et al. (2018) and Choudhary et al. (2020). They argued that phosphorus plays a critical role in the conversion of vegetative tillers into fertile (reproductive) tillers, ultimately increasing the number of effective spikes contributing to yield. The significant rise in grain weight per square meter and grain weight per plant at the 120 kg P/ha level aligns with the findings of Ahmad et al. (2017) and Verma et al. (2019). These researchers confirmed the role of phosphorus in the translocation and accumulation of photosynthesis, enzymatic activity enhancement, and improved grain filling. While 1,000-grain weight showed an upward trend with increasing phosphorus, the differences between some levels were not statistically significant. This result matches the reports of Hussain et al. (2016) and Khan et al. (2020), who stated that 1,000-grain weight is more heavily influenced by the duration of the grain-filling period and the plant's physiological state, meaning increased phosphorus may not always result in statistically significant differences. Biological Yield and Harvest Index The increases in spike length and biological yield in response to phosphorus application are consistent with Singh & Kumar (2017) and Rahimi et al. (2021). They reported that higher dry matter production results from improved vegetative growth, increased leaf area, and enhanced photosynthetic efficiency under phosphorus fertilization. Finally, the increase in the harvest index (HI) at the 80 and 120 kg P/ha levels—which were placed in the same statistical group—concurs with Mahajan et al. (2018) and Zhang et al. (2020). These researchers emphasized that optimal phosphorus application facilitates better dry matter partitioning to economic organs and improves the efficiency of converting biomass into grain yield.

5. Conclusion

Based on the results of the statistical analyses, phosphorus application significantly influenced most growth parameters, yield components, and the final yield of barley. Increasing phosphorus levels, particularly up to 120 kg/ha, resulted in the enhancement of traits such as the number of spikelets per spike, plant height, number of spikes, grain weight, biological yield, and harvest index. Although no significant differences were observed between intermediate phosphorus levels for certain traits, the application of 120 kg/ha is generally recommended as the optimal rate for improving barley growth and yield under the climatic conditions of most barley-producing provinces.

6. Statements and Declarations

6.1 Competing interests

The author(s) declare no competing interests.

6.2 Data availability

Data will be available via request.

6.3 Ethics Approval

Not Applicable

6.4 Consent to participate/Consent to publish

Not Applicable

6.5 Funding

This research received no external funding.

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6.7 Author Contributions

Conceptualization, Q. and Q. F.; methodology, Q., Q. F., and H.; investigation, Q., Q.F., and H.; writing—original draft, Q. and Q. F.; writing—review & editing, Q. F. and H.; resources, H. and Q.; supervision, Q, Q.F., and H.

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