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Comparison of the Yield of Buckwheat (*Fagopyrum esculentum*) Varieties under the Climatic Conditions of Kabul

Aimal Haidari[1], Mohammad Khalid Rashidi[2*], Amir Jan Saidi[3]
[1] Agronomy Department, Faculty of Agriculture, Kabul University, Kabul, Afghanistan
[2] Agronomy Department, Faculty of Agriculture, Kabul University, Kabul, Afghanistan
[3] Professor Dr. of Agronomy Department, Faculty of Agriculture, Kabul University, Kabul, Afghanistan

ABSTRACT: Buckwheat is gaining attention as a promising crop because of its nutritional value and ability to grow under diverse environmental conditions. This study investigated the performance of three buckwheat varieties Common Buckwheat, Devyadka, and Zyloni under the agro-climatic conditions of Kabul during the 2025 growing season. The field experiment was carried out at the Research Farm of the Faculty of Agriculture, Kabul University, using a randomized complete block design with four replications across two contrasting field environments. Several growth characteristics, including plant height, leaf number, leaf width, and number of branches per plant, together with total biomass and 100-seed weight, were evaluated. The results revealed that plant height, leaf number, leaf width, and total biomass varied significantly among the varieties and between environments, with a clear interaction between genotype and environmental conditions. These findings indicate that the growth and productivity of buckwheat are strongly influenced by the environment in which each variety is cultivated. In contrast, the number of branches per plant and 100-seed weight remained relatively stable across environments, suggesting that these traits are less affected by environmental variation. Among the tested varieties, Devyadka produced the greatest vegetative growth and biomass under favourable conditions but showed greater sensitivity to environmental changes. Common Buckwheat maintained consistent performance across both environments, demonstrating strong adaptability and stable productivity, while Zyloni displayed moderate performance with reasonable stability. The study concludes that environmental conditions play an important role in determining buckwheat performance in Kabul. Considering both yield potential and stability, Common Buckwheat is the most suitable variety for cultivation under the variable agro-climatic conditions of the region.

KEYWORDS: Buckwheat varieties; Biomass yield; Growth traits; Environmental adaptability; Kabul climate

INTRODUCTION

Buckwheat (*Fagopyrum esculentum* Moench) is an important pseudocereal that has attracted increasing global interest because of its exceptional nutritional quality and adaptability to diverse growing conditions. It is widely cultivated in temperate and mountainous regions of Europe and Asia, particularly in the Himalayan region, where it serves as both a staple food and a valuable cash crop. Unlike true cereals, buckwheat produces grains rich in high-quality protein with a balanced amino acid composition, dietary fibre, essential minerals, vitamins, and health-promoting phytochemicals such as rutin and other flavonoids. These bioactive compounds have been associated with antioxidant, anti-inflammatory, antihypertensive, and antidiabetic properties, making buckwheat an important ingredient in functional foods and gluten-free diets (Joshi, 2023; Kumar et al., 2024; Lițoiu et al., 2025). As consumer awareness of healthy and sustainable food systems continues to grow, the demand for buckwheat has increased worldwide.

In addition to its nutritional value, buckwheat offers several agronomic and environmental advantages. It has a short growth cycle, performs well under relatively low-input conditions, and can be cultivated successfully on marginal soils where many conventional cereal crops produce lower yields. The crop contributes to sustainable farming by improving soil cover, supporting pollinator populations, suppressing weeds, and enhancing agroecosystem biodiversity. Its comparatively low requirement for agricultural inputs and reduced environmental footprint also make it a suitable crop for climate-smart agriculture. Despite these advantages, buckwheat remains underutilised in many countries because of limited varietal development, inadequate agronomic research, and weak market integration.

Grain yield in buckwheat is influenced by a complex interaction among genetic characteristics, environmental conditions, and crop management practices. Plant height, leaf development, branching pattern, biomass production, flowering behaviour, seed size, and grain weight are genetically controlled traits, but their expression varies considerably under different environmental conditions. Temperature, soil fertility, moisture availability, and rainfall distribution directly affect photosynthesis, assimilate partitioning, flowering, and grain filling, resulting in substantial variation in yield and yield stability among environments (Romanovskaja et al., 2022; Karazhbei et al., 2022). These genotype × environment interactions present a major challenge for selecting varieties with stable performance across different production systems.

Among the environmental factors affecting buckwheat productivity, nutrient availability—particularly nitrogen—plays a crucial role. Adequate nitrogen promotes chlorophyll formation, photosynthetic activity, protein synthesis, and biomass accumulation, thereby increasing yield potential. However, excessive nitrogen can stimulate excessive vegetative growth at the expense of grain production, reducing harvest efficiency (Wan et al., 2022; González-Villagra et al., 2025). Balanced fertilisation with phosphorus, potassium, and organic nutrient sources has also been shown to improve plant growth, grain quality, and soil fertility while supporting environmentally sustainable production systems.

Buckwheat productivity is further influenced by physiological processes that determine biomass production and grain development. Efficient photosynthesis, assimilate translocation, and carbon allocation contribute directly to grain filling and final yield. Recent studies have also shown that nutrient management affects biochemical pathways involved in starch accumulation, protein synthesis, and energy metabolism during grain development. Furthermore, advances in germplasm evaluation and phenotyping have revealed considerable genetic diversity within buckwheat populations, creating opportunities to identify varieties with improved yield potential, adaptability, and environmental stability.

Although extensive research has been conducted on buckwheat in temperate regions, relatively little information is available for semi-arid environments. Afghanistan, particularly the Kabul region, experiences a semi-arid continental climate characterised by low and irregular rainfall, high evapotranspiration, and wide seasonal temperature fluctuations. These conditions may substantially influence vegetative growth, flowering, biomass accumulation, and grain production. However, the performance of available buckwheat varieties under Kabul's agro-climatic conditions has not been adequately investigated.

The absence of locally generated information limits evidence-based varietal selection and the development of appropriate production recommendations for farmers. Because buckwheat performance is strongly influenced by genotype × environment interactions, evaluating different varieties under local field conditions is essential for identifying cultivars that combine high productivity with stable adaptation. Such information can contribute to crop diversification, improved nutritional security, and the promotion of sustainable agricultural systems in Afghanistan.

Therefore, this study was undertaken to evaluate the growth and yield performance of three buckwheat varieties under the agro-climatic conditions of Kabul. Specifically, the study aimed to: (i) compare the growth characteristics and yield-related traits of the selected varieties, (ii) assess the influence of different field environments on varietal performance, (iii) determine the extent of genotype × environment interaction for key agronomic traits, and (iv) identify the most productive and environmentally stable variety for cultivation under Kabul conditions. The findings are expected to provide scientific evidence for varietal selection and contribute to improving buckwheat production in Afghanistan.

Present the scientific or scholarly background, identify the problem or knowledge gap, and clearly articulate the rationale for the study. State the overall aim and, where appropriate, specific objectives or hypotheses. Support the introduction with current and relevant literature.

MATERIALS AND METHODS

Study Design and Experimental Site

This study was conducted during the 2025 growing season at the Research Farm of the Faculty of Agriculture, Kabul University, Afghanistan. The experiment was designed to compare the growth and yield performance of three buckwheat varieties under the agro-climatic conditions of Kabul.

The experimental field is located at 34.3104° N latitude and 69.0823° E longitude, at an altitude of approximately 1,809 m above sea level. The site had relatively uniform soil fertility, level topography, and favourable soil structure. The field had previously been cultivated with buckwheat, and irrigation water was supplied through a tube well connected to the farm irrigation channel, ensuring a consistent water supply throughout the experiment.

Climatic Conditions

Kabul has a cold semi-arid climate (Köppen BSk) characterised by cold winters, hot dry summers, and relatively low annual rainfall. During the 2025 growing season, the mean annual temperature was approximately 12.1°C, with winter temperatures frequently falling below 0°C and summer temperatures exceeding 30°C. Annual precipitation was approximately 332 mm, most of which occurred during March and April, while the summer growing period remained largely dry. Average relative humidity was around 50%, and wind speed increased during late spring and summer.

Soil Characteristics

Before sowing, soil samples were collected from the 0–30 cm depth for laboratory analysis. The soil was classified as sandy loam with a slightly alkaline pH of 7.8 and low electrical conductivity (0.259 mS cm^{-1}), indicating non-saline conditions. The soil contained 0.9% organic matter, 0.03% total nitrogen, 1.83 ppm available phosphorus, 12% calcium carbonate, and a cation exchange capacity of 16.4 meq 100 g^{-1}. The analysis indicated low inherent fertility, highlighting the need for external nutrient supplementation to support normal crop growth.

Plant Materials

Three buckwheat varieties commonly available in local markets were evaluated:

- **T1:** Common Buckwheat
- **T2:** Zyloni Buckwheat
- **T3:** Devyadka Buckwheat

These varieties were selected to compare their growth performance, yield potential, and adaptability under Kabul's environmental conditions.

Experimental Design

The experiment was arranged in a Randomized Complete Block Design (RCBD) with four replications. Each experimental plot measured 2 m × 2 m (4 m²). A total of 12 plots were established, each consisting of six rows with 54 plants. Plants were spaced 20 cm apart within rows, while 30 cm alleyways were maintained between adjacent plots and blocks to minimise border effects and facilitate field operations.

Crop Establishment and Field Management

The land was prepared through ploughing, harrowing, and levelling to obtain a fine seedbed suitable for uniform germination. Crop residues and weeds were removed before sowing.

Seeds were sown directly in the prepared field, and emergence began approximately five days after planting. Germination exceeded 90% by the sixth day after sowing.

Standard crop management practices were applied throughout the experiment. Thinning was carried out 15 days after sowing (DAS) to maintain a uniform plant population. Manual weeding was performed at 20 DAS and 40 DAS. Irrigation was applied at approximately 7-day intervals to maintain adequate soil moisture during crop growth.

Data Collection

Data were collected from the central area of each plot to minimise border effects. Border rows were excluded, and ten plants were randomly selected from each plot for recording observations.

Because buckwheat matured unevenly, harvesting was completed in two stages, at 60 and 70 days after sowing, to ensure maximum seed recovery. Measurements were taken both in the field and laboratory, and grain yield was converted to tonnes per hectare (t ha^{-1}).

Growth Parameters

The following growth traits were recorded:

- Plant height (cm), measured from the soil surface to the tip of the main stem at physiological maturity.
- Number of leaves per plant, recorded at 30 DAS.

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- Leaf length (cm), measured from randomly selected fully expanded leaves.
- Number of branches per plant, recorded at maturity.

Yield Parameters

Yield-related measurements included:

- **100-seed weight (g):** determined by weighing a random sample of 100 seeds from each plot using a calibrated electronic balance.
- **Seed yield (t ha⁻¹):** calculated from the harvested grain weight of each plot and converted to a hectare basis.

Statistical Analysis

The recorded data were subjected to analysis of variance (ANOVA) to determine the effects of variety on the measured growth and yield parameters. Statistical analyses were performed using the Statistical Tool for Agricultural Research (STAR) software. Treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level ($P \leq 0.05$). Differences among treatment means were considered statistically significant when the calculated probability value was equal to or less than the selected significance level.

RESULTS

Plant Height

Plant height was significantly affected by variety, field environment, and their interaction ($P \leq 0.01$). As shown in Table 1, in Field 1, T1 (Common Buckwheat) recorded the greatest plant height (45.06 cm), followed by T3 (Zyloni Buckwheat) (44.18 cm), whereas T2 (Devyadka Buckwheat) had the lowest value (35.68 cm). In Field 2, plant height increased in all varieties, with T2 recording the highest value (49.06 cm), followed by T3 (48.25 cm) and T1 (46.18 cm). The coefficient of variation (CV) for plant height was 8.78%.

Table 1. Plant height (cm) of three buckwheat varieties under two field environments.

Treatment	Field	
	1	2
T1 (Common Buckwheat)	45.06aA	46.18aA
T2 (Devyadka Buckwheat)	35.68bB	49.06aA
T3 (Zyloni Buckwheat)	44.18aA	48.25aA
	Field (A)	Treatment (B)
F-test	**	**
LSD0.05	6.05	6.05
CV (%)	8.78	

*Means followed by different lowercase letters within a column and uppercase letters within a row differ significantly at $P \leq 0.05$ according to the LSD test. ** = $P \leq 0.01$.*

Number of Branches per Plant

The number of branches per plant was not significantly affected by variety or field environment ($P > 0.05$). As presented in Table 2, T1 produced the highest number of branches in both Field 1 (13.69) and Field 2 (13.88), while T2 recorded the lowest values (11.62 and 10.88, respectively). The coefficient of variation was 15.22%.

Table 2. Number of branches per plant of three buckwheat varieties under two field environments.

Treatment	Field	
	1	2
T1 (Common Buckwheat)	13.69	13.88
T2 (Devyadka Buckwheat)	11.62	10.88
T3 (Zyloni Buckwheat)	12.25	13.62

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	Field (A)	Treatment (B)
F-test	NS	NS
LSD0.05	-	-
CV (%)	15.22	

Number of Leaves per Plant

The number of leaves per plant differed significantly among varieties, field environments, and their interaction ($P \leq 0.01$). As shown in Table 3, no significant differences were observed among varieties in Field 1, where leaf number ranged from 36.12 to 37.62 leaves per plant. In Field 2, T2 recorded the highest number of leaves (46.68), followed by T1 (43.18), whereas T3 recorded the lowest value (33.00). The coefficient of variation was 9.66%.

Table 3. Number of leaves per plant of three buckwheat varieties under two field environments.

Treatment	Field	
	1	2
T1 (Common Buckwheat)	36.56aB	43.18aA
T2 (Devyadka Buckwheat)	37.62aB	46.68aA
T3 (Zyloni Buckwheat)	36.12aA	33.00bA
	Field (A)	Treatment (B)
F-test	**	**
LSD0.05	5.78	5.78
CV (%)	9.66	

*Means followed by different lowercase letters within a column and uppercase letters within a row differ significantly at $P \leq 0.05$ according to the LSD test. ** = $P \leq 0.01$.*

Leaf Width

Leaf width was significantly influenced by variety, field environment, and their interaction ($P \leq 0.01$). According to Table 4, T2 recorded the widest leaves in Field 1 (5.06 cm), while T1 had the narrowest leaves (4.18 cm). In Field 2, T1 recorded the greatest leaf width (5.71 cm), followed by T2 (5.20 cm) and T3 (4.95 cm). The coefficient of variation was 8.88%.

Table 4. Leaf width (cm) of three buckwheat varieties under two field environments.

Treatment	Field	
	1	2
T1 (Common Buckwheat)	4.18bB	5.71aA
T2 (Devyadka Buckwheat)	5.06aA	5.20abA
T3 (Zyloni Buckwheat)	4.75abA	4.95bA
	Field (A)	Treatment (B)
F-test	**	**
LSD0.05	0.68	0.68
CV (%)	8.88	

*Means followed by different lowercase letters within a column and uppercase letters within a row differ significantly at $P \leq 0.05$ according to the LSD test. ** = $P \leq 0.01$.*

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100-Seed Weight

No significant differences were detected for 100-seed weight among varieties or field environments ($P > 0.05$). As presented in Table 5, seed weight ranged from 1.37 to 1.87 g in Field 1 and from 1.52 to 2.17 g in Field 2. The coefficient of variation was 20.23%.

Table 5. 100-seed weight (g) of three buckwheat varieties under two field environments.

Treatment	Field	
	1	2
T1 (Common Buckwheat)	1.72	2.17
T2 (Devyadka Buckwheat)	1.37	1.57
T3 (Zyloni Buckwheat)	1.87	1.52
	Field (A)	Treatment (B)
F-test	NS	NS
LSD0.05	-	-
CV (%)	20.23	

Total Biomass

Total biomass differed significantly among the three varieties ($P \leq 0.01$). As shown in Table 6, T2 (Devyadka Buckwheat) produced the highest biomass (55.19 kg ha^{-1}), followed by T3 (46.20 kg ha^{-1}) and T1 (40.62 kg ha^{-1}). The coefficient of variation for biomass was 14.76%.

Table 6. Total biomass (kg ha^{-1}) of three buckwheat varieties.

Treatment	Total weight
T1 (Common Buckwheat)	40.62b
T2 (Devyadka Buckwheat)	55.19a
T3 (Zyloni Buckwheat)	46.20b
F-test	**
LSD0.05	7.61
CV (%)	14.76

*Means followed by different letters differ significantly at $P \leq 0.05$ according to the LSD test. ** = $P \leq 0.01$.*

DISCUSSION

The present study evaluated the growth and yield performance of three buckwheat (Fagopyrum esculentum) varieties under two field environments in Kabul to determine their adaptability, productivity, and stability under semi-arid conditions. The results demonstrated that plant height, leaf number, leaf width, and total biomass were significantly influenced by genotype, environment, and their interaction, whereas the number of branches per plant and 100-seed weight remained unaffected. These findings confirm that genotype × environment interaction plays a major role in determining buckwheat performance under the agro-climatic conditions of Kabul.

The significant variation observed in plant height among varieties and environments agrees with previous studies reporting that vegetative growth in buckwheat is highly responsive to environmental conditions and genetic background (Romanovskaja et al., 2022; Hassona et al., 2024; Grimes et al., 2025). Devyadka showed the greatest increase in plant height under the more favourable field environment, indicating a high capacity to respond to improved growing conditions. In contrast, Common Buckwheat and Zyloni maintained relatively consistent plant height across both environments, suggesting greater environmental adaptability. This pattern supports earlier reports that some buckwheat genotypes possess greater phenotypic plasticity, whereas others express more stable growth across contrasting environments (Karazhbei et al., 2022; Tryhub et al., 2026).

Leaf production and leaf width also showed significant genotype × environment interactions. Devyadka produced the highest number of leaves under favourable conditions, while Common Buckwheat exhibited the greatest increase in leaf width. Since leaf development directly influences photosynthetic capacity and biomass accumulation, these results indicate that favourable environmental conditions enhanced vegetative growth and resource capture. Similar relationships between leaf development, photosynthetic efficiency, and biomass production have been reported by Sharma et al. (2023), Gao et al. (2023), and González-Villagra et al. (2025). The contrasting responses among varieties further demonstrate that vegetative traits are highly dependent on environmental conditions and genetic characteristics.

Total biomass differed significantly among the evaluated varieties, with Devyadka producing the highest biomass. Greater biomass accumulation is commonly associated with improved photosynthetic efficiency, nutrient uptake, and assimilate production, which contribute to overall crop productivity (Wan et al., 2022; Amelin et al., 2022). The superior biomass production of Devyadka suggests that this variety possesses strong vegetative growth potential and may be suitable for environments where moisture and nutrient availability are favourable. However, its marked response to environmental improvement also indicates greater sensitivity to less favourable conditions, which may reduce production stability.

In contrast, the number of branches per plant and 100-seed weight were not significantly affected by either genotype or environment. These findings indicate that both traits remained relatively stable under the conditions of the study and were less influenced by environmental variation than vegetative growth characteristics. Previous studies have similarly reported that reproductive traits such as seed weight tend to exhibit higher genetic stability than morphological traits (Romanovskaja et al., 2022; Tryhub et al., 2026). The relatively high coefficient of variation for 100-seed weight suggests greater experimental variability; however, the absence of significant treatment effects indicates that environmental differences during the experiment were insufficient to alter seed size substantially.

Overall, the study advances current knowledge by providing the first field-based comparison of buckwheat varieties under the semi-arid agro-climatic conditions of Kabul. Most previous research has been conducted in temperate regions, whereas information from Afghanistan has been extremely limited. The results demonstrate that varietal responses observed elsewhere cannot be directly applied to Kabul because environmental conditions substantially influence growth and productivity. This study therefore provides locally generated evidence that can support varietal selection and improve buckwheat production under Afghan conditions.

A major strength of this research is that it was conducted under actual field conditions using a randomized complete block design with replication, allowing the evaluation of genotype × environment interactions under practical farming conditions. The inclusion of multiple growth and yield-related traits also provides a comprehensive assessment of varietal performance. Nevertheless, several limitations should be acknowledged. The experiment was conducted during a single growing season at one location and evaluated only three varieties. In addition, environmental variation was represented by only two field environments, and physiological measurements such as photosynthetic rate, nutrient uptake, water-use efficiency, and grain quality characteristics were not assessed. These factors limit the broader generalisation of the findings.

The results have important practical implications for buckwheat production in Afghanistan. Common Buckwheat demonstrated the greatest stability across environments and can therefore be recommended for cultivation in areas where environmental conditions are variable and production risks are relatively high. Devyadka showed superior vegetative growth and biomass production under favourable conditions and may be suitable for more productive environments where irrigation and soil fertility can be effectively managed. Zyloni exhibited intermediate performance and may serve as an alternative variety where moderate adaptability is desirable.

Future research should evaluate a larger number of buckwheat genotypes across multiple locations and growing seasons to better quantify genotype × environment interactions under Afghan conditions. Additional studies should also investigate grain yield, grain quality, nutritional composition, physiological responses to drought and nutrient stress, and molecular mechanisms underlying environmental adaptation. Integrating agronomic management practices such as fertiliser optimisation, irrigation scheduling, and conservation agriculture with varietal evaluation would further contribute to developing sustainable buckwheat production systems for semi-arid regions.

CONCLUSION

This study evaluated the performance of three buckwheat (*Fagopyrum esculentum*) varieties under the agro-climatic conditions of Kabul to determine their growth, productivity, and adaptability. The results demonstrated that plant height, number of leaves per plant, leaf width, and total biomass were significantly influenced by genotype, environment, and their interaction, indicating that

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the expression of these traits depends on both genetic potential and environmental conditions. In contrast, the number of branches per plant and 100-seed weight were not significantly affected, suggesting that these traits are relatively stable across the environments evaluated.

Among the tested varieties, Devyadka (T2) produced the greatest vegetative growth and total biomass, reflecting high productivity under favourable conditions. However, its performance varied considerably between environments, indicating greater environmental sensitivity. Common Buckwheat (T1) showed the most consistent performance across both field environments, demonstrating superior adaptability and yield stability, while Zyloni (T3) exhibited intermediate performance with acceptable stability. Overall, this study confirms the importance of evaluating buckwheat varieties under local environmental conditions before making cultivation recommendations. The findings provide valuable information for varietal selection in Kabul and contribute to the limited knowledge of buckwheat performance in semi-arid environments. Based on the observed balance between productivity and stability, Common Buckwheat (T1) is the most suitable variety for cultivation under the variable agro-climatic conditions of Kabul, while Devyadka (T2) may be preferred where favourable growing conditions can be maintained.

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