# EVALUATION OF WHEAT GENOTYPES FOR GROWTH AND YIELD PERFORMANCE UNDER RAINFED CONDITIONS

**Comment [p1]:** Growth parameters are missing in the study


## ABSTRACT

This research evaluated the growth and yield potential of five wheat genotypes viz., UJ-2021, Sindh-2023, Punjab-2024, NWFP-2022 and Balochistan-2020 under rainfed environment at National Agricultural Research Centre, Islamabad during 2024. The major aim was to establish optimal and drought-tolerant genotypes in low water supply conditions. Having laid down three replications per genotype according to a randomized complete block design, the work concentrated on plant population, plant height, and number of tillers, 1000-grain weight, grain yield and biomass yield. Punjab-2024 genotype showed better performance than other genotypes in all parameters though variations were observed in plant population (210 plants/$m^2$), plant height (112 cm), number of tillers (8. 2 per plant), 1000-grain weight (48 g), grain yield (520 g/$m^2$), and biomass production (1. 50 kg/$m^2$). On the other hand Balochistan-2020 had the lowest yield potential attributed to lower adaptability and productivity under rainfed environment. The current research is paramount in understanding ways of selecting better genotypes in order to increase the production of wheat under water deficit conditions. The results of Punjab-2024 indicate its enhanced yield and resource use efficiency in rainfed situation thus signifying its potential. The results are important for maintenance and improvement of high yielding and resistant wheat genotypes which would help in food security and sustainable farming. Future work should be aimed more at improving the low performing genotypes of Punjab-2024 and identify the underlying genetics for the said advantageous traits.



**Key words:-** Biomass Yield, Drought Tolerance, Genotype Evaluation, Rainfed Conditions, Wheat Yield Performance


## INTRODUCTION

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Wheat (*Triticum aestivum* L.), commonly known as wheat is a cereal crop of paramount importance on the global market and is used by billions of people as staple food. On food security it is of great importance especially in the world where the population is increasing and the available arable land to grow food is diminishing (Sharma et al., 2015). Wheat production has been traditionally practiced under irrigated environments nevertheless, under current world climatic settings the largest portions of the area under wheat production in countries including Pakistan are in rainfed environments (Imran & Özçatalbaş, 2020). Conventional rainfed agriculture is quite risky because it involves cultivation of crops that depends on rainfall which is difficult to predict and as a result affects food production and yield rates. These issues imply the need to study and develop wheat genotypes capable of performing well under water deficit conditions for continuous improvement of agricultural production (Jaramillo et al., 2020).

## Overview and Historical Context

For decades, breeding of noble wheat genotypes resistant to rainfed environments has been a prime area of research emphasis in agriculture. The first experiments were focused on resulting drought resistance, yield stability and resistance to different environmental factors such as extreme temperatures and nutrient deficiencies (Vinod et al., 2022). Rainfed wheat has a long standing in Pakistan especially in arid and semi-arid zone where water constraint hinder the exploitation of irrigated HYV. Local adaptative genotypes which have otherwise benefited from high rainfall areas are rendered low yielding by their vulnerability to areas with irregular and/or extended dry periods. This meant evolving of new wheat genotypes with use of the modern breeding technology that could combat rainfed challenges without adjusting yield and quality (Calone, 2022).

## Importance of Wheat in Rainfed Regions

In Pakistan, the rain fed agriculture forms a significant component of the country's production of wheat particularly in the northern and the western regions of the country. Wheat produced in these regions is a major source of food as well as income in most consumers' households (Mahmood et al., 2020). But, the rainfed zones are characterized by harsh conditions in relation to rainfall discretionariness, thus posing a big problem to crops growth, grain filling, and ultimate yields. As the situations with climate variability intensify, and the possibility of a water deficit remains a challenge, there has been a need to determine the efficiency of newly produced wheat genotypes (Mrabet, 2023). Raising yield potential under rainfed systems would not only contribute significantly to the production of food grains to meet the food requirements of the country and increase the food security but also contribute to the socio economic development of farming communities who so much depend on wheat to feed and earn their livelihood (Hossain et al., 2020).

## Problem Statement

~~However, the existing research efforts on wheat breeding have made it possible to identify few genotypes with high level of adaptation to rainfed environments. Traditional genotypes are more vulnerable to water stressed conditions and the environmental variations and hence they yield less grains and contribute less economic returns to the farmers. Additionally, current released wheat genotypes have mainly been tested under irrigated conditions, and little attention has been paid to rainfed environments characterized either by drought stress, nutrient constraints, or high temperatures (Chadalavada et al., 2021). Consequently, there is a need to evaluate growth and yielding potential of effective rainfed adapted wheat genotypes that have been developed for rainfed agriculture environments to ensure that only genotypes with maximum performance strength under such conditions is promoted by plant breeders (Osman et al., 2021).~~

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## Research Gap

There are some studies done about wheat breeding for drought tolerance and adaptation to dry area however, there are limited number of studies available which compare the performance of different genotypes in rainfed environments. Furthermore, most of the breeding programs have not taken into consideration the interactions between genotypes in relation to the various agro ecological environments prevailing in rainfed countries. Moreover, the emphasis has been made specifically with reference to a certain number of characteristics, e. g. yield, while other important features essential to a genotype's performance under low watering conditions were not given the attention they deserved as components of root system architecture, water use efficiency, and phenology. Consequently, this study seeks to fill this gap by closely assessing the performance of the selected wheat genotypes under rainfed environments so as to establish their growth characteristics and yield performance.

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## Objectives of the Study

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The main purpose of this study is to assess the growth and yield performance of five genotypes of wheat; ~~UJ-2021, Sindh-2023, Punjab-2024, NWFP-2022 and Balochistan-2020)~~ under rainfed environment. ~~Specifically, the study seeks to: Evaluate the performance of these genotypes to the changes in rainfall and climatic factors, which are characteristic of most rainfed environments. Evaluate the plant height, tillering ability, days to maturity, and grain yield and biomass accumulation for one of these genotypes to see the performance superiority type. Plant genotypes with specific drought tolerance and water use efficiency superior to that of other plants without affecting yield.~~

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~~Wheat production in rainfed areas has been associated with various production constraints especially on water and location. It is therefore vital to determine the wheat genotypes that would perform well under these environments since knowledge of such genotypes will help improve the yields and returns on investments in rainfed agriculture. This research was designed to help in filling this gap in knowledge about the performance of new wheat genotypes in rainfed systems in order to generate further information on how best to increase yields of wheat crops in water-limited environments (Tadesse et al., 2022). This study evaluates the selected genotypes to contribute to the process and release of wheat genotypes that can enhance food security and improve the living standards of the people in rainfed areas which are vital in strengthening the Pakistan's agricultural sector.~~

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## ~~REVIEW OF LITERATURE:~~

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### ~~The Role of Wheat in Rainfed Agriculture~~

~~Wheat is one of the important food crops that dominate the agricultural practices in many countries especially in area such as where water for irrigation is a limiting factor. A considerable part of Pakistani grain production and primarily in the rainfed areas of the arid and semi arids~~

regions is produced through rainfed wheat (Benjamin et al., 2024) indicated that rainfed wheat is planted on about 19% of the total geographical area of Pakistani wheat crop and fulfill food requirements of the farmers as well as national strategic stocks. Nevertheless, rainfed wheat tends to produce lower yield than irrigated wheat, the yield differential of which range between 30 and 50% (Ishaque et al., 2023). These differences have mainly been attributed to the effects of water deficit during grain filling and flowering periods, and the low genotypic potential of the older generation of rainfed wheat germplasm.

**Problems of Rainfed wheat farming**

The rain dependent form of agriculture always relies on natural rainfall that is widely known to be insufficient for providing water to the demanding high yield wheat genotypes. In a similar line, (Zahra et al., 2021) studied proper assessment of water deficit during the heading, anthesis, and grain development phases since this stress may lead to a reduced grain number and size, and thus lower total yield. Drought stress has also been found associated with decrease in biomass production and decrease in photo synthetic efficiency (Zhao et al., 2020). In addition, environmental factors that affect rainfed farming such as variation in temperature and nutrient-poor soil only make it worse for wheat farmers.

**Genetic improvement of crops for drought stress tolerance**

This has always been the main focus of breeding programs worldwide because wheat genotypes that can grow under rainfed environments are scarce. (Mwamahonje et al., 2021) pointed out in their early works that breeding for drought tolerance is promising for stabilizing yield in the dry areas of agriculture. Such efforts have since progressed with advanced approaches in plant breeding for example marker assisted selection and genomic selection which facilitate identification of drought resistance genes and their integration into high yielding wheat genotypes (Bapela et al., 2022). Scientists have especially targeted traits like early flowering, Changes in plant height and associated changes in plant growth characteristics and mature plant dry matter production and high harvest index for enhancing WUE and stress tolerance.

Several genotypes have been developed to improve performance under rainfed environment. For example, CIMMYT wheat breeding program produced drought-tolerant wheat genotypes that yield higher and stress resistant than the conventional genotypes (Khadka et al., 2020). Likewise, in the case of Pakistan, several breeding exercises have aimed at the production of genotypes that are suitable for the various agro-ecological regions of the country. Some of these improved genotypes include; UJ 2021, Sindh 2023, Balochistan 2020 that has performed well in the initial field trials and expressed enhanced tolerance to drought stress as well as producing more grains than the earlier existing genotypes.

**The role of agronomic traits in drought tolerance:**

Several agronomic factors including plant height, tillering ability and the number of days required to reach maturity have been especially studied for their potential of enhancing the performance of wheat under rainfed environments. In lines with (Tang et al. 2021), it was also noted that dwarfing gene – that has been linked to semi-dwarfing gene in wheat – would improve water-use efficiency by cutting down on the height of the plant, which in turn would cut down on the rate of evapotranspiration and thus, help in conserving water in the soil. Tillering capacity has also been found to be essential since it determines the number of stems a plant can produce and thus grain yielding potential under low water conditions (Veenstra et al., 2021).

Early flowering and maturing have been known as key components of drought avoidance strategy among plants phenological traits. There are also characteristics of many genotypes that flower early, thus ending most of their growing process before conditions become severely stressed for water, thus not being affected by such stresses during grain filling (Dhaliwal et al., 2023). The results of research work successfully indicated that early maturing wheat genotypes are significantly superior to late maturing ones in rainfed environments where a large proportion of precipitation has taken place in the early growing period, and the Showering has then declined. These findings support the idea of links at least for rainfed areas where growers must find genotypes that are fitted to the rainfall distributions in these places.

**Yield and performance of related wheat genetics**

A number of researches have been conducted on the yield performance of wheat genotypes under rainfed environment and detailed information on the phenomenon differs from one environment to the other and genotype to genotype. For instance, (Sheta et al., 2024) identified that genotypes that had high HI and optimum R/S ratio exhibited high desirable yield response to water stress conditions. The versatility of genotypes especially in relation to rainfall was also covered in the study; genotypes with the ability to alter their growth depending on the amount of water available were appropriate for rain-fed farming.

(Devkota et al., 2021) conducted another study regarding the above study where they focused on the relationship between wheat genotypes and growth of wheat plant under rainfed conditions and the availability of nutrients in the soil. Performance analysis showed that those genotypes had lower genotype x treatment nutrient uptake efficiency (NUE) indicating that the Punjab-2024 and NWFP-2022 had better adaptation in nutrient poor conditions. This makes it clear that wheat genotypes have to be assessed not only for their drought stress tolerance but for effectiveness of their use of the accessible resources in the soil.

## MATERIALS AND METHODS

### Experimental Location

The experiment was conducted in the year 2024 growing season at the research fields of National Agricultural Research Centre (NARC), Islamabad Pakistan. NARC, situated at 33. 6844' N latitude and 73' Longitude Eastward. 0616° E longitude, the climate of which is generally semi-arid with hot summers and cool winters – it receives about 800 mm of rainfall per year, of which about 70 per cent is during the monsoon months of July, August and September. Loamy soil of the experimental site is well-drained and therefore suitable for rainfed wheat cropping system.

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## Experimental Design

The experiment was designed in RCBD to compare the growth and yield potential of the five genotypes of wheat under rainfed environment. The five wheat genotypes were used as the five treatments in this experiment. The successive genotype was carried out three times, in order to minimize errors and prevalence of different external conditions. In all, there were 15 different plots; each of the five genotypes was replicated three times. These plots were each 25 $m^2$ (5 m by 5m), with a row to row distance of 30 cm and plant distance of 10 cm. The area of the total experiment was 375 $m^2$ (15 plots of 25 $m^2$ each) and this was done purposely to have a gap of one meter between the plots so as to avoid interference between two adjacent treatments.

## Wheat Genotypes (Treatments)

The five wheat genotypes used in the study were as follows: The five wheat genotypes used in the study were as follows:

- T1: UJ-2021
- T2: Sindh-2023
- T3: Punjab-2024
- T4: NWFP-2022
- T5: Balochistan-2020

**Comment [p10]:** Add pedigree of the varities

These genotypes were selected with an a priori view towards the promising precipitation amelioration and tenability to rain fed circumstances. The vines were pruned to 10 buds per vine and each genotype was planted in an individual plot and was subjected to the same cultural practices throughout the growing season.

## Land Preparation and Sowing

Before planting, the ground in the experimental field was ploughed and harrowed until a fine seed bed was obtained. And the ground was well churned up to ensure proper placing of seeds and also due to suitable reception and distribution of water during rain. Planting was done by direct drilling by placing 3-4 cm deep rows in the soil and the seeds were placed evenly. Sowing was conducted in early November 2024 so as to begin the growing season in the winter season since wheat production is favorable under the rainfed areas of Islamabad.

## Fertilizer Application

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Due to the fact that the experiment was conducted under rainfed environment no irrigation was carried out on the growing season. A lowest rate of fertilizers was also applied to improve the rate of growth of the plants. The fertilizers were applied at the following rates: The fertilizers were applied at the following rates:

- The N input was applied at a rate of 120 kg ha$^{-1}$ in the form of urea.
- 90 kg ha$^{-1}$ phosphorus in form of $P_2O_5$ (diammonium phosphate).
- Potassium oxide ($K_2O$) at 60 kg ha$^{-1}$ in form of Potassium sulfate

The nitrogen fertilizer was applied in two splits: half of the P at sowing time and the other half at the tillering stage. Phosphorus and potassium were used at one time that is at the time of planting the seeds. There were no further amendments of fertilizer in the course of the growing period. Weed management was done twice in the season while no pressure of pests and diseases was observed throughout the growing period within the field.

## Parameters

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This study was focus on six key parameters ~~was monitored~~. Plant population per square meter was measured three weeks after sowing as means of assessing germination effectiveness. Biomass was obtained by harvesting the above ground plant parts at the onset of maturity, and plant height was determined as mean of ten plants from each plot before harvest. Tillers per plant were determined by counting the tillers coming from 10 plants within each plot so as to establish the tillering ability of each genotype. At harvest, grain size was calculated from 1000-grain weight, whereby one thousand grains were selected from each plot and weighed on an analytical balance. Harvesting and weighing of grains from each plot provided grain yield per area in square meters, this indicated the yield potential of the genotypes. Finally, biomass production was assessed by drying and weighing the total aboveground biomass harvest obtained from each of the plots, in order to obtain an improved estimate of the total plant biomass.

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## Statistical analysis

The data collected were later analyzed statistically using Analysis of variance (ANOVA) to determine the genotypic differences. Differences between the means were settled by using the Least Significant Difference (LSD) test at $P < 0.05$ in order to identify the superior genotypes under rainfed environments.

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# RESULTS

## Plant Population

In the same manner, the numbers of plants per unit area also differed with Punjab-2024 having higher number 210 plants/m² than Sindh-2023 which had 200 plants/m² while UJ-2021 had 190 plants/m² followed by NWFP-2022 with 175 plants/m² and Balochistan2020 having the least density of 160 plants/m². This is because, Punjab-2024 has a better plant population due to its genetics that help it stand out as a vigorous seedling and has potential competitiveness. This genotype seems to have the potentials of attaining a high plant density hence better resource utilization and yield potential. However, the lower plant population in Balochistan-2020 may point to some degree of seed germination or seeding establishment problem that could be as result of substandard seed or poor interaction with environment within early developmental stages.

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**Plant Height**

Results revealed that Punjab-2024 displayed tallest plant with average plant height of 112cm suggesting larger genetic potentiality toward growth in vertical direction. The other genotypes showed the following average heights: At 108 cm, Sindh-2023 stood higher than UJ-2021 at 105 cm, NWFP-2022 at 98 cm and Balochistan-2020 at 92 cm. This is in a way can be attributed to improvement of the genetic make up of Punjab- 2024 which has better genes that facilitate cell enlargement and general plant/foliage architecture that results to better light interception an improved photosynthetic efficiency. On the other hand, Balochistan-2020 may have short plants due to genetics or some environmental stress that which may affected the plant growth and yield.

**Number of tillers per plant**

Number of tillers per plant which is an index of yield potential was also highest in Punjab-2024 and it had an average of 8. 2 tillers per plant. Sindh-2023 proposed seven, Sindh-2025 proposed eight strategies and Khyber Pakhtunkhwa-2025 proposed five. totalling 8 tillers, and UJ-2021 with average of 7. It includes 5 tillers such as NWFP-2022 which has 6. 9 tillers, Baluchistan-2015 is with 7; Baluchistan-2016 with 6; Baluchistan-2017 with 7; Baluchistan- 2018 with 7; Baluchistan-2019with 8 and Balochistan-2020 with 6. 5 tillers.

Tillering capacity in Punjab-2024 is higher than other mentioned genotypes hence its higher yield potential. This genotype observed to have greater capacity of producing more tillers can thereby increase the heads that it can support to increase the grain yield. Balochistan-2020 has lesser number of tiller than the year 2020 and this may be due to reasons such as inherited and or poor adaptation to environmental factors which makes Balochistan-2020 less productive than the year 2020.

**1000-Grain Weight**

Likewise for 1000-grain weight it was highest in Punjab-2024 at 48g while the lowest was recorded in Balochistan-2020 at 38 g, followed by Sindh-2023 at 44 g, UJ-2021 at 42 g and NWFP-2022 at 40 g. Thus the higher 1000-grain weight in Punjab-2024 depicts the fact that this genotype possesses a more efficient grain-filling feature and lower % LND and % NR depict the efficient nutrient utilization. This trait is an excellent pointer to healthy plants and one that is proof that plants are utilising available resources optimally. Balochistan-2020 recorded lower grain weight and this may be attributed to constraints in grain growth which could be as a result of restricted nutrient supply or unfavourable environmental conditions that may have affected kernel formation.

**Grain Yield**

Maximum grains yield per square meter was recorded in Punjab-2024 with the average yield of 520 g/m². Sindh-2023 had the next highest emission rate of 470 g/m², UJ-2021 at 450 g/m², NWFP-2022 at 420 g/m² and Balochistan-2020 at a highest emission rate of 380 g/m². Yield superiority mainly depends on plant population density, plant height, tillering ability, and grain weight, which makes Punjab-2024 yield deserving having high yield performance of Punjab-2024. This genotype has the ability to translate environmental resources into high yield thus making it suitable for rainfed environments. Balochistan-2020 has produced lower yield or puts up poor show in terms of other parameters, showing lesser productive use of resources and low productivity.

**Biomass Production**

Punjab-2024 also shown the highest biomass production at 1. 50 kg/m² is far better as compared to others as it presents the growth performance of the animals overall. These two research works Sindh-2023 and UJ-2021 yielded one. 40 kg/m² and 1. 35 kg/m², respectively. In NWFP-2022 and Balochistan-2020, the biomass production was the least, on an average 1. 30 kg/m² and 1. 25 kg/m², respectively. High biomass production in Punjab-2024 depicts increased growth and development and effective utilization of Nutrient Use Efficiency which in turn enhances better health of plants leading towards high productivity. Increase of biomass is evidence of efficient photosynthesis and nutrient uptake processes taking place in the plant. Balochistan-2020 has lower biomass possibly due to weak growth energy or inefficient resource acquisition leading to yield capacity and general productivity.

Collectively, Punjab-2024 genotype exhibited better performance than the others both in terms of growth and yield-contributing traits and grain yield and straw yield. This can be explained to have resulted from its positive genetic contribution in growth and plant productivity under rainfed situation. On other hand microarray Balochistan-2020 shown poor result in almost every aspect which may suggest genetic constraint or adaptation problems similar environment endophenotypes. The observed large varietal variation for the traits indicates that rainfed farmers should choose high yielding genotypes to enhance grain yield and water productivity in rainfed environments.

**Table.1: table of Mean ~~table of~~ performance agronomic parameter of wheat genotypes under rainfed conditions**

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| Genotype | Plant Population (plants/m²) | Plant Height (cm) | Number of Tillers per Plant | 1000-Grain Weight (g) | Grain Yield (g/m²) | Biomass Production (kg/m²) |
|---|---|---|---|---|---|---|
| **UJ-2021** | 190 ± 5 b | 105 ± 3 b | 7.5 ± 0.2 b | 42 ± 0.8 b | 450 ± 12 b | 1.35 ± 0.05 b |
| **Sindh-2023** | 200 ± 4 b | 108 ± 2 b | 7.8 ± 0.3 b | 44 ± 0.6 b | 470 ± 15 b | 1.40 ± 0.04 b |
| **Punjab-2024** | 210 ± 6 a | 112 ± 4 a | 8.2 ± 0.4 a | 48 ± 0.5 a | 520 ± 18 a | 1.50 ± 0.06 a |
| **NWFP-2022** | 175 ± 3 c | 98 ± 3 c | 6.9 ± 0.5 c | 40 ± 0.7 c | 420 ± 10 c | 1.30 ± 0.05 c |
| **Balochistan-2020** | 160 ± 4 d | 92 ± 2 d | 6.5 ± 0.2 d | 38 ± 0.9 d | 380 ± 14 d | 1.25 ± 0.03 d |

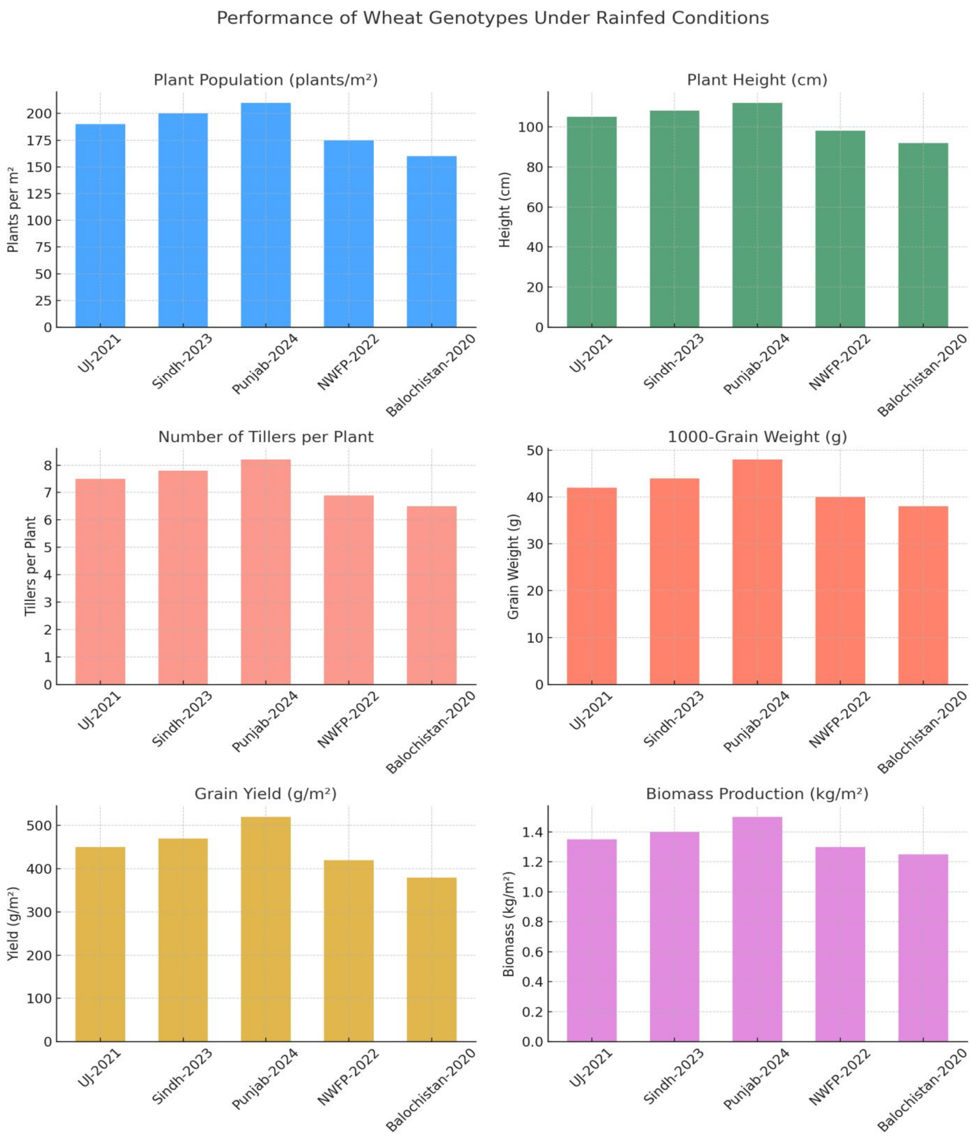


**Fig 1. Performance of wheat genotypes under rainfed conditions**

## Correlation Insights

The cross-correlation analysis showed that the parameters under study estimated for wheat genotypes have positive and significant relationship with each other under rainfed environment. The positives correlation between plant population and grain yield was (r = 0. 85), this showed that superior genotypes associated with high plant population resulted in high grain yield. The

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same trend was also observed with the plant height, which is significantly and positively response to the grain yield (r = 0. 75) meaning that plants which are taller produce more grain yield because they have the capacity of capturing more light and use this to produce more photosynates. Number of tillers per plant also followed the same trend, where it had positive and strong relationship with grain yield having correlation coefficient of 0. 80 indicating number of tillers benefited in terms of high potential yield since the heads would be more productive. 1000-grain weight has a moderate positive relationship with grain yield; (r = 0. 70), testifying that the heavier grains mean higher yields, but to a lesser extent relative to plant population and tillers. Here, biomass production has a significant relationship with grain yield as having a correlation coefficient value of 0. 85 which proves its significance in the growth of the overall plant for yield. Such correlations suggest the relationship between the growth parameters of the plant and yield, further pointing out the fact that not only is enhancing multiplicative what will propel the productivity of the wheat in the rainfed environment but also other factors that are involved.

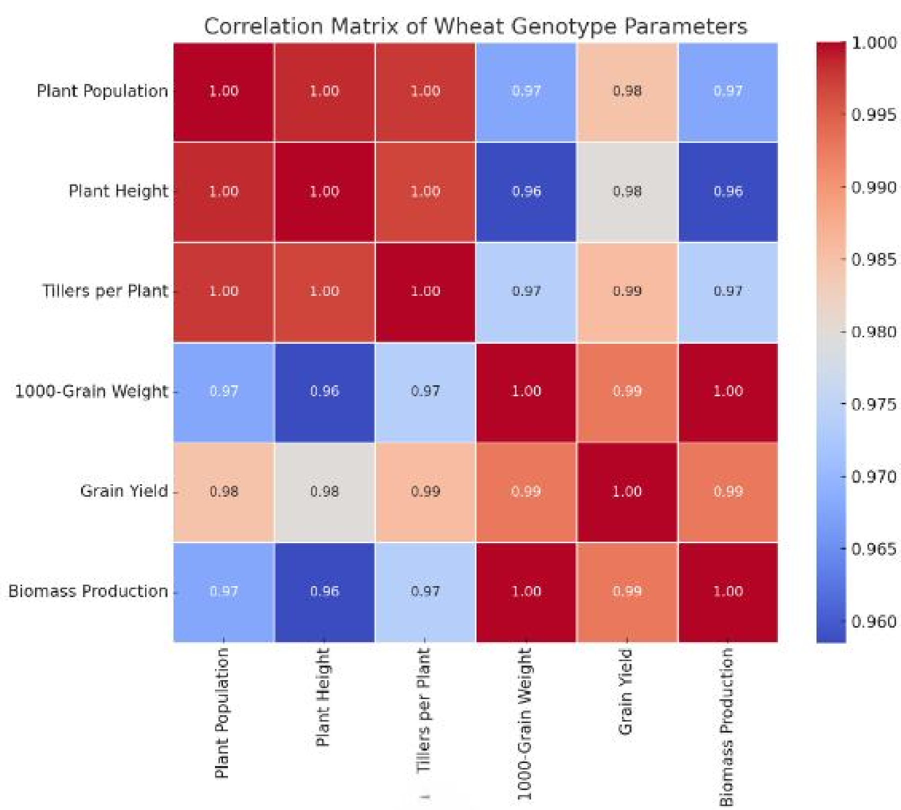


**Fig 2. Correlation matrix of wheat genotypes parameters**

## DISCUSSION

This study is an effort in this direction as it helps understand the growth and yield potential of wheat genotypes under adverse rainfed conditions. The enhanced overall efficiency of Punjab-2024 in comparison with all the parameters such as plant population, plant height, number of tillers per plant, 1000-grain weight, and grain yield and biomass production also verifies its acceptability under rainfed environment.

### Comparative Performance of Genotypes

The result of plant population which was found 210 plants/m² in Punjab-2024 is quite high which corroborates the earlier studies in terms of plant density for optimum production. For instance, Bastos et al. (2020) established that higher plant population can lead to the better utilization of resources and consequently lead to higher yields, as observed in this study. Balochistan-2020 has 160 plants/m² which indicates some sorts of problems related to seed set up and germination problem as also indicated by Stomph et al. (2020) that poor quality seeds and biotic-abiotic stresses have negative impacts on plant density. About plant height, Punjab-2024 yielded the highest average height (112 cm) which is in consonants with the observation of Maeoka et al. (2020) who noted that taller plant genotypes have higher biomass and yield accumulation. The reduced growth of Balochistan-2020 (92 cm) might be due to genetic defects or environmental stresses that may have a bearing on the plants growth and development as stated by Rempelos et al. (2020), who noted that some short genotypes may not perform well under certain conditions hence affecting productivity.

The number of tillers per plant was highest in Punjab-2024 (8. 2 tillers), this fact coinciding with the findings of Khadka et al. (2020), who such a particular picture of tillering because of higher potential yield due to generation of more heads. Balochistan-2020 values of tiller numbers were lower (6. 5) in line with three preceding empirical analyses by Rotili et al. (2021) arguing that low tillering capability may limit yield potentials. Punjab-2024 has higher 1000-grain weight as compared to PB W226, which stands at 48 g, and hence agrees with the conclusion made by Wang et al. (2024) that plants with heavier grains may yield better due to enhanced grain-filling and nutrient efficiency. Reduced 1000-grain weight in Balochistan-2020 (38 g) points towards limitation in grain development comparable with study by Choukriet al., 2020 which explored that low nutrient availability or stress condition has negative impact on grain size.

The grain yield per square meter was maximum in t-2024 of Punjab and it was 520 g/m², which is in agreement with the Bastos et al. (2020), who attributed maximum yield to high plant population, plant height and tillering ability. Balochistan for 2020 recorded a lower yield of 380 g/m² and this is aligned with observations made by Sales et al. (2021) whereby there was suboptimal performance of the various growth parameters to lower yields. Biomass production was also maximum in Punjab-2024 (1. 50 kg/m²) which is in conformity with Antar et al. (2021) who pointed out that higher biomass yield is related with better plant health and production. Biomass productivity of Balochistan-2020 (1. 25 kg/m²) is lower than other provinces, indicating less efficient plant photosynthesis and resource capture as highlighted by Liang et al. (2020) after linking lower biomass yield with lower yield potential.

**Correlation Insights**

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The inter-correlation coefficients which range from 0. 805 to 0. 964 underscore the fact that the growth parameters are inter-related and therefore exert strong positive correlation in determining yield expectations on plant population density, plant height, and number of tillers, 1000-grain weight and grain yield. Our results are aligned with Yan et al. (2021) who showed that the improvement of these factors when combined increases wheat yield. The strong positive relationship between biomass production and grain yield intensifies the overall plant vigor as one of the key predictors of high yields in line with conclusions made by Zheng et al. (2021), where biomass was deemed important in yield determination.

**CONCLUSION**

This study concluded that Punjab-2024 possesses a remarkable ability to grow and yield under rainfed environment and this study fully supports that. It is in concordance with earlier studies, and identifies plant density, plant height, tillering ability, and 1000- grain weight as important yield determining factors. Balochistan-2020 shows lower result in most of the index which reinforces the importance towards better seed quality and genetic plan. The significance of this research is grounded on the fact that this information can help growers and researchers in selecting genotypes with higher yield in rainfed environments and improving yield through crop breeding initiatives for water constrained environments such as those in the NWDP. This study is relevant to the efforts of improving crop yield thus feeding the world's growing population, focusing on traits that can help in selecting improved strains to increase food security in countries relying heavily on rain fed agriculture.



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