scientific reports

OPEN

Impact of different priming and sowing techniques in combination with different seed rates on wheat growth and yield

Samiullah Khan Ranazai[1]✉, Muhammad Sadiq[1], Muhammad Safdar Baloch[1], Huma Qureshi[2]✉, Tauseef Anwar[3]✉, Abdullah A. Alarfaj[4] & Mohammad Javed Ansari[5]

Wheat (*Triticum aestivum* L.) is a staple crop of immense economic importance, especially in the agronomic context of Dera Ismail Khan, Khyber Pakhtunkhwa (KPK), Pakistan. Understanding the effects of various agronomic practices, such as priming techniques, sowing methods, and seed rates, on wheat yield and growth is crucial for optimizing production and ensuring regional food security. To study the effects of priming and sowing techniques in combination with seed rates on short (Israr Shaheed) and long (Gomal) duration, three experiments were conducted at the agronomic research site of Gomal University, Dera Ismail Khan, Pakistan, wheat varieties. In the first experiment, various priming techniques were used. Among different techniques used Farmyard manure priming produced the tallest plants at 111.3 and 125.3 cm, the maximum number of tillers (335.7 and 345.0 m^{-2}), longest spikes (8.6 and 7.6 cm), maximum spikelets (27.2 and 31.0 spike^{-1}), maximum number of grains (45.5 and 48.7 spike^{-1}), maximum grain yield (4.4 and 4.6 t ha^{-1}) and maximum harvest index (38.7 and 41.5%) respectively for Israr Shaheed and Gomal. Conversely, compost manure produced heavier grains than other interactions (49.2 and 42.3 g) while sodium chloride showed the maximum biological yield (12.4 and 11.8 t ha^{-1}) for Israr Shaheed and Gomal correspondingly. In 2nd experiment, different sowing methods were tested on two wheat varieties Israr Shaheed and Gomal. Dry sowing followed by flooding produced tallest plants measuring (105.5 and 101.7 cm), maximum number of tillers (398.2 and 406.7 m^{-2}), longest spikes (8.3 and 7.2 cm), maximum spikelets (29.8 and 35.5 spike^{-1}), maximum number of grains (54.3 and 51.6 spike^{-1}) and maximum grain yield (4.3 and 4.6 t ha^{-1}) respectively for Israr Shaheed and Gomal. Israr Shaheed and Gomal showed maximum 1000-grain weights (45.3 and 45.0 g) in sprouted seeding in flooded fields respectively. The highest biological yield (13.6 t ha-1) was in dry seed in the flooded field while the maximum harvest index (33.5 and 33.9%) was recorded in soaked seed followed by flooding for Israr Shaheed and Gomal. In the last experiment, different seed rates were studied. The results showed that plants grown with seed rate 150 kg ha^{-1} showed the tallest plants at 111.0 and 111.7 cm, maximum number of tillers (411.6 and 408.2 m^{-2}), longest spikes (7.8 and 7.7 cm), maximum spikelets (34.3 and 34.3 spike^{-1}), maximum number of grains (50.8 and 47.2 spike^{-1}), maximum grain yield (4.6 and 4.5 t ha^{-1}) and maximum harvest index (38.4 and 36.7%) respectively for Israr Shaheed and Gomal. The maximum number of 1000-grains weight (g) was found on 200 and 250 kg ha^{-1} for Israr Shaheed and Goma-8, respectively giving 45.2 g while biological yield was the highest in 175 kg ha^{-1} respectively. Conclusively, the results indicated that yield and yield attributes in wheat were enhanced up to 150 kg ha^{-1} seed rate when interacted with farmyard manure priming along with dry sowing of seed followed by flooding. Future research should explore the integration of advanced irrigation techniques and nutrient management practices to further enhance wheat productivity in the Dera Ismail Khan region.

Keywords Biological yield, Farmyard manure, Grain yield, Irrigation techniques, Seed rate effects

[1]Department of Agronomy, Faculty of Agriculture, Gomal University, Dera Ismail Khan-29050, Khyber Pakhtunkhwa, Pakistan. [2]Department of Botany, University of Chakwal, Chakwal 48800, Pakistan. [3]Department of Botany, The Islamia University of Bahawalpur, Bahawalpur 63100, Pakistan. [4]Department of Botany and Microbiology, College of Science, King Saud University, Riyadh 11451, Saudi Arabia. [5]Department of Botany, Hindu College (Mahatma

Jyotiba Phule Rohilkhand University, Bareilly-244001), Moradabad, India. ✉email: samikhanranazai@gmail.com; huma.qureshi@uoc.edu.pk; tauseef.anwar@iub.edu.pk

Wheat (*Triticum aestivum*L.) is one of the most significant cereal crops globally, not only for its nutritional value but also for its economic importance. As a staple food in many countries, including Pakistan, wheat plays a pivotal role in ensuring food security. In Pakistan, 12.55% of households' monthly income is spent on wheat flour, with the per capita wheat consumption reaching 118 kg per year, compared to an annual production of 131 kg per capita[1]. The productivity and yield of wheat directly affect its availability, which has implications for national and household food security. Variations in wheat supply impact consumers, farmers, and all those dependent on agriculture, either directly or indirectly[2].

In recent years, Pakistan has faced challenges in maintaining wheat productivity. In the 2021-22 growing season, wheat was sown on 8,976 thousand hectares, yet production decreased by 3.9%, amounting to 27.464 million tons, a 2.1% yield decline compared to the previous year[3,4]. Multiple factors contribute to this low productivity, but a significant reason is farmers' reluctance to adopt recommended production technologies, such as optimal seed rates, fertilizer applications, and appropriate planting techniques.

One critical factor influencing wheat yield is the seed rate. An optimal seed rate is essential for achieving adequate plant density, while a suboptimal rate can either reduce plant density or increase competition among plants, both of which negatively impact yield[5]. Studies like that of Seleiman et al. showed that increasing seed rates (250, 300, 350, and 400 gm^{-2}) led to increased wheat yield, although it also caused a reduction in grain weight[6]. Similarly, Iqbal et al. demonstrated that using a seed rate of 150 kg ha^{-1} optimized various yield-contributing factors, resulting in a yield of 4.2 t ha^{-1}[7].

In addition to seed rate, planting methods significantly influence wheat productivity. Research by Chaudhary et al. showed that bed planting produced 13% more yield than traditional broadcast and drill sowing methods[8]. Given the critical role of seed in crop production, proper stand establishment, which depends on optimal seed germination and seedling vigor, is essential. Environmental and abiotic stressors often negatively affect germination, leading to subpar crop yields. Priming is a simple and effective method to overcome these restrictions by promoting seed germination through regulated hydration and drying processes that improve germination efficiency[9]. Seed priming can reduce fertilizer use, synchronize seed germination, and enhance crop production in an environmentally sustainable manner[10].

Triticum aestivum, the common wheat, has been the subject of extensive research and debate for decades. Hexaploid wheat, the most common form, originated from the crossing of tetraploid wheat (*T. turgidum*) and diploid *Aegilops tauchii* var. *strangulata*[11]. Archaeological research suggests that wheat originated in the Fertile Crescent around 8,000 to 10,000 years ago[12,13]. While *T. aegilopoides* is widely cultivated in the Middle East, *T. monococcum*, or Einkorn wheat, is grown on a smaller scale[14].

In Pakistan, wheat remains a vital crop, but yields have been significantly affected by farmers' reluctance to adopt modern agricultural technologies. One key challenge is achieving an optimal crop stand, which is influenced by seed rate and planting methods. The current study aims to improve the germinability of two wheat varieties through priming techniques and to determine the optimal seed rate and planting method for clayey soils under the arid climate of Dera Ismail Khan. This research is crucial for identifying strategies to enhance wheat yield and ensure food security in regions with challenging growing conditions.

Materials and methods

Site description

The research was conducted at the Agronomy research area of Gomal University, D.I. Khan, during the Rabi seasons of 2017, 2018, and 2019. The experimental site is characterized by a semi-arid climate with hot summers and mild winters. Meteorological data recorded during the study showed average temperatures ranging from 12 °C to 24 °C during the Rabi season, with an annual rainfall of approximately 250–300 mm, primarily concentrated during the monsoon period. Initial soil properties at the experimental site indicated a sandy loam texture with a slightly alkaline pH (7.5–8.0), moderate organic matter content, and average nutrient availability. The experiments tested two wheat varieties: Israr Shaheed (a short-duration variety) and Gomal (a long-duration variety). The seeds of Israr Shaheed and Gomal wheat varieties were sourced from the Cereal Crops Research Institute (CCRI), Pirsabak, Nowshera, Pakistan. These varieties were selected to evaluate their response to different seed rates, sowing methods, and priming techniques under the agroecological conditions of the research area.

Treatments and design

In 1st experiment, the influence of different priming techniques on wheat crop growth and yield was studied. Following priming treatments were studied in the experiments including T_1: Control, T_2: Tap water (primed for 2 h), T_3: Sewage water (primed for 3 h), T_4: Farmyard manure (primed for 6 h), T_5: Compost manure (primed for 8 h), T_6: Poultry manure (primed for 8 h), T_7: Press mud (primed for 12 h) and T_8: Sodium chloride.

In 2nd experiment, sowing techniques and wheat performance under the agroecology of Dera Ismail Khan, KPK, Pakistan were studied. The following treatments were studied in the experiments including, T_1: Normal sowing technique (Normal sowing technique involved sowing seeds in prepared dry soil using a seed drill, ensuring they are planted at a consistent depth and spacing), T_2: Dry seed in a flooded field (the field was flooded, and the dry seeds were then scattered over the water-covered soil through broadcast method), T_3: Dry seed drill method (Drill Method), T_4: Sprouted seeding in a flooded field (Broadcast Method), T_5: Soaked seeding in a flooded field (Drill Method) and T_6: Soaked seed followed by flooding (Drill Method).

In 3rd experiment, different seeding densities' effect on wheat crop growth and yield was studied. Following treatments were studied in the experiments including, T_1: 100 kg ha^{-1}, T_2: 125 kg ha^{-1}, T_3: 150 kg ha^{-1}, T_4: 175 kg ha^{-1}, T_5: 200 kg ha^{-1}, T_6: 225 kg ha^{-1} and T_7: 250 kg ha^{-1}. A randomized complete block design was used for the research. All experiments were conducted in three replications with a plot area of 6 m^2, maintaining 30 cm and 10 cm distances between plants and rows, respectively.

Intercultural operation/ agronomic management technique

Throughout the experiments, standard agronomic practices were followed to ensure optimal growth conditions for both wheat varieties, Israr Shaheed and Gomal. The fields were prepared using thorough plowing, followed by harrowing to achieve a fine tilth. The seedbed was leveled before sowing to ensure uniform seed distribution and proper water management. Fertilizer application was based on soil test results, with a recommended dose of nitrogen (N), phosphorus (P), and potassium (K) applied at rates of 120:90:60 kg ha^{-1}, respectively. Nitrogen was applied in split doses, with half at sowing and the remaining half at the tillering stage. Phosphorus and potassium were applied as basal doses at sowing. Irrigation was provided at critical growth stages, including tillering, booting, and grain filling, with additional waterings depending on rainfall patterns during the season. Water was managed carefully to prevent both waterlogging and drought stress. Weed control was carried out through manual weeding at regular intervals, particularly during the early growth stages, to reduce competition for nutrients, water, and light. A pre-emergence herbicide (Pendimethalin) was applied at a rate of 1.25 kg ha^{-1} to manage early germinating weeds, followed by post-emergence herbicide applications as needed. Pest and disease management included regular field monitoring for common wheat pests (e.g., aphids and armyworms) and diseases (e.g., rust and blight). Insecticides and fungicides were applied as necessary to minimize crop loss, following integrated pest management (IPM) principles to reduce pesticide use and promote sustainable agriculture. During the growth period, plots were also inspected for soil moisture conditions and nutrient deficiency symptoms, with corrective actions taken as required (e.g., supplemental foliar feeding in cases of nutrient stress).

Yield parameters

A measuring tape was used to measure the plant heights of both varieties viz. Israr Shaheed and Gomal. For this purpose, we measured a sample of ten plants from the base to the tip. We obtained average results for each treatment by adding the heights of ten plants and dividing them by 10. In each plot, a square meter area was chosen randomly and in each treatment's number of stems and tillers (m^{-2}) was counted. We measured spike length in centimeters from a sample (10 plants) and then averaged the results for each treatment. To determine the mean results for each treatment, we counted number of spikelets (spike^{-1}) in each spike in ten plants. Randomly, ten plants were chosen as a sample and their number of grains (spike^{-1}) was counted in each spike and averaged. We counted the weight of 1000 grains (gm) in each treatment, and then they were weighed on an electronic balance. The yield of grain (kg ha^{-1}) was obtained from each plot and the obtained results were converted into (kg ha^{-1}) through the given formula:

$$Grain\ yield\ \left(kg\ ha^{-1}\right) = \frac{Grain\ yield\ \left(g\ plot^{-1}\right)}{6} \times\ 10$$

From each plot, the biological yield (kg ha^{-1}) was obtained, and the results were collected into kg ha^{-1} through the given formula:

$$Biological\ yield\ \left(kg\ ha^{-1}\right) = \frac{Biological\ yield\ \left(g\ plot^{-1}\right)}{6} \times\ 10$$

The given formula was used for obtaining the harvest index (%age):

$$Harvest\ index\ (\%) = \frac{Economic\ yield}{Biological\ yield} \times\ 100$$

Statistical analysis

The variance technique was analyzed statistically for the data obtained in all the experiments. For the comparison of means at a 5% probability level, the Least Significant Difference (LSD) test was applied using Statistix 10 (Analytical Software, Tallahassee, FL, USA; www.statistix.com).

Results

Effect of different priming techniques on the growth and yield of wheat crop

The results of the study on the effect of different priming techniques on the growth and yield of wheat crops are summarized in Table 1. For the variety Israr Shaheed, the highest plant height was recorded in the treatment with farmyard manure priming (T4), measuring 111.3 ± 6.5 cm, which was significantly greater than the other treatments. In contrast, the lowest plant height of 89.8 ± 4.9 cm was observed in T5. The Gomal variety exhibited a similar trend, with the tallest plants also found in T4 (125.3 ± 5.2 cm) and the shortest in T3 (102.7 ± 2.3 cm), emphasizing the positive impact of farmyard manure on plant growth.

In terms of the number of tillers, Israr Shaheed produced the most tillers per square meter in T4 (335.7 ± 20.7), significantly outperforming other treatments, with T7 recording the lowest count of 277.0 ± 9.4. The Gomal variety showed a comparable pattern, where the highest tiller count was also observed in T4 (345.0 ± 22.2), while T3 produced the least (288.7 ± 1.4). These findings suggest that farmyard manure priming effectively enhances tiller development in both wheat varieties.

Parameters	Variety	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	CV(%)
Plant height (cm)	Israr Shaheed	94.1 ± 3.5 b	99.0 ± 5.6 ab	96.2 ± 4.0 ab	111.3 ± 6.5 a	89.8 ± 4.9 c	106.3 ± 9.4 ab	89.3 ± 3.7 c	101.2 ± 1.6 ab	5.6
	Gomal	104.2 ± 1.2 cd	114.8 ± 4.9 b	102.7 ± 2.3 d	125.3 ± 5.2 a	101.7 ± 0.9 d	111.8 ± 11.9 bc	95.8 ± 1.2 e	104.8 ± 3.1 cd	4.8
Number of tillers (m-^{2})	Israr Shaheed	282.0 ± 19.8 d	310.8 ± 9.2 bc	298.7 ± 21.7 c	335.7 ± 20.7 a	289.2 ± 22.8 cd	328.5 ± 19.6 ab	277.0 ± 9.4 d	313.3 ± 4.7 bc	7.4
	Gomal	297.3 ± 6.6 de	321.3 ± 17.4 bc	288.7 ± 1.4 e	345.0 ± 22.2 a	299.7 ± 4.2 cd	320.3 ± 9.9 bc	295.5 ± 9.2 de	312.0 ± 2.4 bcd	6.2
Spike length (cm)	Israr Shaheed	5.6 ± 1.0 c	6.5 ± 0.9 b	5.8 ± 0.3 c	8.6 ± 0.4 a	5.9 ± 0.1 c	7.6 ± 0.3 ab	5.4 ± 0.9 c	5.5 ± 0.1 c	10.3
	Gomal	5.4 ± 0.4 d	6.6 ± 0.7 b	5.2 ± 0.1 d	7.6 ± 0.3 a	5.4 ± 0.4 d	6.1 ± 0.6 c	5.5 ± 0.4 d	5.8 ± 0.3 c	8.7
Number of spikelets (spike-^{1})	Israr Shaheed	18.5 ± 0.7 e	21.7 ± 0.9 d	18.3 ± 0.1 e	27.2 ± 0.7 a	20.5 ± 1.1 d	24.0 ± 0.9 b	20.0 ± 0.9 d	22.7 ± 0.9 c	9.2
	Gomal	22.3 ± 1.9 d	25.0 ± 0.5 c	19.3 ± 0.9 e	31.0 ± 0.1 a	25.8 ± 0.7 c	30.0 ± 0.5 ab	23.0 ± 1.9 d	26.0 ± 0.9 bc	9.0
Number of grains (spike-^{1})	Israr Shaheed	24.3 ± 0.9 e	37.8 ± 0.2 c	26.0 ± 1.4 e	45.5 ± 0.02 a	35.7 ± 0.9 cd	40.8 ± 0.7 b	32.5 ± 0.7 d	38.3 ± 0.9 bc	11.1
	Gomal	28.2 ± 2.6 e	41.3 ± 0.9 b	28.0 ± 0.5 e	48.7 ± 0.5 a	34.8 ± 4.0 cd	45.0 ± 0.4 ab	31.0 ± 3.3 de	33.7 ± 1.9 de	10.3
1000-grains weight (g)	Israr Shaheed	29.2 ± 0.2 e	35.7 ± 0.2 c	31.8 ± 0.5 d	32.5 ± 0.6 d	49.2 ± 0.1 a	32.2 ± 0.4 d	39.9 ± 1.1 b	32.6 ± 0.1 d	6.2
	Gomal	32.2 ± 1.3 d	35.5 ± 1.9 c	35.6 ± 0.7 c	35.6 ± 3.5 c	42.3 ± 0.2 a	32.9 ± 0.6 d	34.2 ± 1.5 cd	36.4 ± 1.3 bc	4.9
Grain yield (t ha-^{1})	Israr Shaheed	2.7 ± 0.1 d	3.7 ± 0.1 b	2.0 ± 0.1 e	4.4 ± 0.1 a	3.5 ± 0.1 bc	4.1 ± 0.1 a	3.2 ± 0.1 cd	3.8 ± 0.1 b	9.3
	Gomal	2.9 ± 0.1 d	3.8 ± 0.1 b	3.2 ± 0.3 cd	4.6 ± 0.1 a	3.7 ± 0.1 b	4.4 ± 0.2 a	3.3 ± 0.1 c	3.7 ± 0.1 b	7.1
Biological yield (t ha-^{1})	Israr Shaheed	8.8 ± 0.3 e	10.9 ± 0.5 bc	10.4 ± 0.4 cd	11.8 ± 0.4 a	10.5 ± 0.6 cd	11.6 ± 0.2 ab	11.5 ± 0.2 ab	12.4 ± 0.8 a	7.5
	Gomal	9.3 ± 0.1 e	11.5 ± 0.1 bc	11.4 ± 0.5 bc	11.3 ± 0.5 bc	11.4 ± 0.5 bc	11.3 ± 0.3 bc	9.7 ± 0.2 d	11.8 ± 0.7 ab	5.9
Harvest index (%)	Israr Shaheed	31.1 ± 0.6 cd	34.4 ± 2.4 bc	27.7 ± 0.2 e	38.7 ± 2.3 a	33.2 ± 1.5 bc	36.0 ± 0.9 ab	28.4 ± 0.1 de	32.4 ± 0.2 c	9.2
	Gomal	31.9 ± 0.8 cd	34.1 ± 0.3 bc	27.9 ± 1.5 e	41.5 ± 2.6 a	32.7 ± 2.7 c	39.9 ± 0.4 ab	34.2 ± 1.4 bc	31.9 ± 1.9 cd	8.3

Table 1. Effect of different priming techniques on the growth and yield of wheat crop. *Different letters in each row indicate significant differences among treatments at $P < 0.05$. T_1: Control, T_2: Tap water (primed for 2 hours), T_3: Sewage water (primed for 3 hours), T_4: Farmyard manure (primed for 6 hours), T_5: Compost manure (primed for 8 hours), T_6: Poultry manure (primed for 8 hours), T_7: Pressed mud (primed for 12 hours) and T_8: Sodium chloride.

Spike length, another important growth parameter, was the longest in Israr Shaheed with T4 (8.6 ± 0.4 cm), while the control treatment (T1) yielded the shortest spikes at 5.6 ± 1.0 cm. Gomal demonstrated a similar trend, with the maximum spike length also in T4 (7.6 ± 0.3 cm) and the minimum in T3 (5.2 ± 0.1 cm). Additionally, the number of spikelets per spike was significantly highest in Israr Shaheed for T4 (27.2 ± 0.7), compared to the control T1 (18.5 ± 0.7). In Gomal, T4 again resulted in the most spikelets (31.0 ± 0.1), while T3 showed the lowest count (19.3 ± 0.9).

Regarding grain development, Israr Shaheed had the highest number of grains per spike in T4 (45.5 ± 0.02), significantly higher than the control T1 (24.3 ± 0.9). Similarly, Gomal exhibited a maximum of 48.7 ± 0.5 grains per spike in T4, with the minimum found in T1 (28.2 ± 2.6). The thousand-grain weight for Israr Shaheed was heaviest in T5 (49.2 ± 0.1 g), while the lowest weight of 29.2 ± 0.2 g was recorded in T1. Gomal's highest grain weight was also in T5 (42.3 ± 0.2 g), contrasting with the minimum of 32.2 ± 1.3 g in T1.

In terms of yield, the grain yield for Israr Shaheed was highest in T4 (4.4 ± 0.1 t ha^{-1}) and lowest in T3 (2.0 ± 0.1 t ha^{-1}). Gomal similarly showed a maximum yield of 4.6 ± 0.1 t ha^{-1} in T4 and a minimum of 2.9 ± 0.1 t ha^{-1} in T1. Biological yield followed a similar pattern, with Israr Shaheed achieving the highest yield in T4 (11.8 ± 0.4 t ha^{-1}) and the lowest in T1 (8.8 ± 0.3 t ha^{-1}). Gomal's biological yield also peaked in T4 (11.3 ± 0.5 t ha^{-1}) and was lowest in T1 (9.3 ± 0.1 t ha^{-1}).

Finally, the harvest index was significantly highest in Israr Shaheed for T4 (38.7 ± 2.3%), while T3 showed the lowest index at 27.7 ± 0.2%. Gomal exhibited a similar trend, with the highest harvest index in T4 (41.5 ± 2.6%) and the lowest in T3 (27.9 ± 1.5%). Overall, farmyard manure priming (T4) consistently resulted in the best growth and yield parameters for both wheat varieties, demonstrating its efficacy compared to other treatments.

Effect of sowing techniques on the performance of short and long-duration wheat varieties under the agro-ecology of D.I. Khan, KPK, Pakistan

The results presented in Table 2 illustrate the effects of various sowing techniques on the performance of short and long-duration wheat varieties, Israr Shaheed and Gomal, under the agroecological conditions of D. I. Khan, KPK, Pakistan.

In terms of plant height, significant variations were observed across the different treatments. The tallest plants of Israr Shaheed were recorded with the dry seed drill method (T3), measuring 105.5 cm, closely followed by the dry seed in the flooded field (T2) at 100.5 cm. Similarly, Gomal achieved a maximum height of 101.7 cm with the dry seed drill method. Conversely, the shortest plants for both varieties were measured with the soaked seeding in flooded fields (T5), at 93.3 cm for Gomal and 93.9 cm for Israr Shaheed. These findings highlight the efficacy of modern sowing techniques in promoting plant growth.

The number of tillers per square meter also varied significantly among treatments. Israr Shaheed showed the highest tiller count of 398.2 in response to the dry seed drill method (T3), while Gomal exhibited a maximum of 406.7 under the same treatment. In contrast, the conventional sowing method (T1) resulted in the lowest tiller counts for both varieties.

Parameters	Variety	T_1	T_2	T_3	T_4	T_5	T_6	CV (%)
Plant height (cm)	Israr Shaheed	91.5 ± 1.1 c	100.5 ± 5.1 ab	105.5 ± 4.5 a	93.9 ± 3.8 bc	94.1 ± 3.2 bc	95.3 ± 2.2 bc	3.7
	Gomal	90.7 ± 0.9 c	96.3 ± 0.9 b	101.7 ± 0.9 a	93.5 ± 4.0 bc	93.3 ± 5.1 bc	94.3 ± 1.4 b	3.1
Number of tillers (m-^{2})	Israr Shaheed	336.8 ± 10.1 c	385.0 ± 3.8 a	398.2 ± 2.1 a	335.0 ± 4.7 c	339.3 ± 15.6 bc	362.3 ± 0.1 b	4.7
	Gomal	338.0 ± 0.1 c	396.5 ± 2.1 ab	406.7 ± 3.3 a	347.2 ± 6.4 bc	342.8 ± 13.9 c	370.2 ± 1.6 b	5.3
Spike length (cm)	Israr Shaheed	5.9 ± 0.1 d	7.9 ± 0.1 ab	8.3 ± 0.2 a	6.3 ± 0.1 cd	6.2 ± 0.5 cd	6.9 ± 0.5 bc	8.2
	Gomal	6.1 ± 0.1 cd	7.5 ± 0.1 ab	8.2 ± 0.2 a	6.2 ± 0.1 cd	6.3 ± 0.3 cd	6.8 ± 0.9 bc	7.6
Number of spikelets (spike-^{1})	Israr Shaheed	23.7 ± 0.5 c	26.9 ± 0.5 b	29.8 ± 0.2 a	23.5 ± 0.7 c	23.3 ± 0.9 c	25.3 ± 0.5 b	9.4
	Gomal	26.7 ± 2.3 c	30.3 ± 0.4 b	35.5 ± 0.7 a	22.8 ± 0.7 d	23.0 ± 1.4 d	24.3 ± 0.1 cd	8.7
Number of grains (spike-^{1})	Israr Shaheed	37.8 ± 1.2 cd	44.8 ± 1.2 b	54.3 ± 4.7 a	37.5 ± 0.7 d	37.2 ± 0.7 d	40.9 ± 0.4 bc	10.3
	Gomal	35.9 ± 2.5 d	44.2 ± 0.7 bc	51.6 ± 0.9 a	38.4 ± 0.5 cd	35.4 ± 1.9 d	39.9 ± 0.8 c	9.1
1000-grains weight (g)	Israr Shaheed	31.8 ± 3.7 d	35.3 ± 1.8 c	31.9 ± 4.5 d	45.3 ± 1.9 a	40.4 ± 1.0 b	35.4 ± 5.1 c	11.7
	Gomal	30.8 ± 1.0 e	34.9 ± 2.3 d	32.3 ± 6.0 e	45.0 ± 1.3 a	39.3 ± 0.9 b	33.3 ± 2.9 cd	10.2
Grain yield (t ha-^{1})	Israr Shaheed	3.4 ± 0.1 d	4.1 ± 0.1 b	4.3 ± 0.1 a	3.8 ± 0.1 c	3.7 ± 0.1 c	3.9 ± 0.1 bc	7.1
	Gomal	3.6 ± 0.1 c	4.1 ± 0.1 b	4.6 ± 0.1 a	3.7 ± 0.1 c	3.6 ± 0.1 c	3.9 ± 0.1 bc	6.8
Biological yield (t ha-^{1})	Israr Shaheed	12.9 ± 1.3 bc	13.6 ± 0.3 a	12.9 ± 0.1 b	13.3 ± 0.4 a	11.9 ± 0.1 c	12.5 ± 0.1 b	7.8
	Gomal	14.2 ± 1.3 a	13.6 ± 0.3 ab	13.6 ± 0.1 ab	12.7 ± 0.4 bc	12.6 ± 0.1 c	12.6 ± 0.3 c	6.4
Harvest index (%)	Israr Shaheed	26.9 ± 3.5 d	29.7 ± 0.2 c	32.0 ± 2.7 b	28.9 ± 0.2 c	31.4 ± 1.6 b	33.5 ± 2.7 a	9.8
	Gomal	26.3 ± 3.5 d	29.9 ± 2.7 c	31.7 ± 5.8 b	30.3 ± 2.1 bc	28.9 ± 0.1 c	33.9 ± 4.4 a	10.1

Table 2. The sowing techniques' effect on short and long-duration wheat varieties performance under the agro-ecology of D. I. Khan, KPK, Pakistan. *Different letters in each row indicate significant differences among treatments at $P < 0.05$. T_1: Normal sowing technique, T_2: Dry seed in the flooded field (Broadcast Method), T_3: Dry seed drill method (Drill Method), T_4: Sprouted seeding in the flooded field (Broadcast Method), T_5: Soaked seeding in the flooded field (Drill Method) and T_6: Soaked seed followed by flooding (Drill Method).

When examining spike length, Israr Shaheed achieved its longest spikes (8.3 cm) using the dry seed drill method (T3), while Gomal also performed well with a spike length of 8.2 cm under the same treatment. The soaked seeding techniques led to shorter spikes for both varieties, underscoring the advantages of dry-sowing methods for spike development.

The number of spikelets per spike revealed that Israr Shaheed had the highest count (29.8) with the dry seed drill method (T3), while Gomal recorded its maximum spikelets (35.5) under the same treatment. Soaked seeding methods resulted in significantly fewer spikelets.

In terms of grains per spike, Israr Shaheed produced the highest count (54.3) with the dry seed drill method (T3), while Gomal also performed best with this method, yielding 51.6 grains per spike. The soaked seed treatments, however, resulted in fewer grains, emphasizing the positive influence of improved sowing techniques on grain production. The 1000-grain weight showed that Israr Shaheed had its heaviest seeds (45.3 g) with the sprouted seeding method (T4), whereas Gomal reached its peak weight (45.0 g) under the same treatment. In contrast, the lightest seeds for both varieties were recorded with the dry seed drill method (T3). This variation in grain weight highlights how different management practices can significantly impact seed quality.

Grain yields were notably affected by sowing techniques, with Israr Shaheed achieving the highest yield (4.3 t ha^{-1}) under the dry seed drill method (T3) and Gomal reaching its maximum yield (4.6 t ha^{-1}) using the same technique. The conventional method (T1) resulted in the lowest grain yields for both varieties, indicating that modern sowing practices can enhance agricultural productivity. Finally, the biological yield showed significant differences among treatments. Israr Shaheed recorded its highest biological yield (13.6 t ha^{-1}) under the soaked seed followed by the flooding method (T5), while Gomal's maximum biological yield (14.2 t ha^{-1}) was noted with normal sowing techniques (T1). The harvest index also varied, with Israr Shaheed achieving the highest index (33.5%) under soaked seed followed by flooding (T6), and Gomal showing its best harvest index (33.9%) with the same treatment.

Effect of various seeding densities on the growth and yield of wheat crop

The study results, as shown in Table 3, reveal that different seeding densities significantly influenced the growth and yield of both the Israr Shaheed and Gomal wheat varieties. Plant height peaked at 150 kg ha^{-1} for both varieties, with Israr Shaheed reaching 111.0 cm and Gomal 111.7 cm. However, at the highest density (250 kg ha^{-1}), plant height decreased significantly for both varieties, indicating that higher seeding rates negatively impacted growth.

The number of tillers per square meter also followed a similar trend, with the highest tiller count observed at 150 kg ha^{-1} (411.6 for Israr Shaheed and 408.2 for Gomal). As the seeding density increased, the number of tillers declined, especially at 250 kg ha^{-1}, where the lowest values were recorded. Spike length was maximized at 150 kg ha^{-1} for both varieties but decreased at higher densities.

Number of spikelets and grains per spike was highest at 150 kg ha^{-1}, with Israr Shaheed and Gomal producing 34.3 spikelets and around 50 grains per spike, respectively. Higher seeding densities led to a notable decline in these parameters, particularly at 250 kg ha^{-1}. Grain yield was significantly affected by seeding density, with the

Parameters	Variety	T_1	T_2	T_3	T_4	T_5	T_6	T_7	CV (%)
Plant height (cm)	Israr Shaheed	100.2 ± 4.9 bc	105.7 ± 3.3 ab	111.0 ± 0.1 a	105.3 ± 1.9 ab	102.5 ± 4.0 abc	99.7 ± 3.3 bc	98.0 ± 0.1 c	3.9
	Gomal	105.8 ± 7.9 ab	104.2 ± 3.1 ab	111.7 ± 4.2 a	104.5 ± 3.1 ab	103.7 ± 4.7 ab	99.5 ± 3.1 bc	96.5 ± 0.7 c	5.0
Number of tillers (m-²)	Israr Shaheed	384.5 ± 2.1 b	398.5 ± 2.1 ab	411.6 ± 3.8 a	356.0 ± 3.8 c	325.0 ± 2.8 d	320.8 ± 7.8 d	294.5 ± 7.3 e	7.8
	Gomal	374.4 ± 10.9 b	398.2 ± 3.1 ab	408.2 ± 3.1 a	355.0 ± 22.1 c	327.8 ± 21.4 d	306.8 ± 0.7 e	300.7 ± 5.6 e	8.5
Spike length (cm)	Israr Shaheed	7.3 ± 0.3 abc	7.6 ± 0.3 ab	7.8 ± 0.5 a	7.2 ± 0.5 bc	7.1 ± 0.2 bc	7.3 ± 0.6 abc	6.9 ± 0.5 c	5.9
	Gomal	7.7 ± 0.2 a	7.8 ± 0.1 a	7.7 ± 0.4 a	7.0 ± 0.4 bc	7.2 ± 0.3 b	7.2 ± 0.2 b	6.9 ± 0.6 c	5.2
Number of spikelets (spike-¹)	Israr Shaheed	30.3 ± 2.4 b	32.2 ± 0.7 ab	34.3 ± 1.9 a	23.3 ± 0.9 d	23.7 ± 0.5 d	22.3 ± 3.3 d	20.2 ± 4.4 e	10.7
	Gomal	29.3 ± 1.4 bc	32.9 ± 0.9 ab	34.3 ± 0.5 a	23.9 ± 0.9 d	24.2 ± 1.6 d	22.7 ± 0.5 d	21.4 ± 3.1 e	9.9
Number of grains (spike-¹)	Israr Shaheed	45.5 ± 2.6 b	47.8 ± 0.7 ab	50.8 ± 1.7 a	35.2 ± 2.6 c	31.3 ± 0.1 d	29.0 ± 1.4 de	31.3 ± 4.2 d	12.1
	Gomal	42.9 ± 6.1 bc	45.5 ± 2.5 b	47.2 ± 2.6 ab	33.0 ± 2.8 d	30.3 ± 2.8 d	30.5 ± 2.1 d	31.5 ± 6.8 d	13.7
1000-grains weight (g)	Israr Shaheed	32.3 ± 3.8 e	30.3 ± 0.1 e	31.0 ± 1.4 e	38.3 ± 1.9 c	45.2 ± 0.7 a	43.9 ± 2.4 ab	43.9 ± 4.7 ab	10.1
	Gomal	33.7 ± 1.4 d	29.2 ± 1.2 e	28.0 ± 4.2 e	40.7 ± 0.1 bc	39.2 ± 0.7 c	40.3 ± 1.9 bc	45.2 ± 5.4 a	11.2
Grain yield (t ha-¹)	Israr Shaheed	4.3 ± 0.1 b	4.6 ± 0.1 a	4.6 ± 0.1 a	3.7 ± 0.02 c	3.4 ± 0.1 d	3.2 ± 0.1 de	2.7 ± 0.1 e	8.6
	Gomal	4.3 ± 0.1 b	4.4 ± 0.2 ab	4.5 ± 0.1 a	3.7 ± 0.2 c	3.4 ± 0.1 d	3.2 ± 0.1 de	2.9 ± 0.1 e	8.3
Biological yield (t ha-¹)	Israr Shaheed	12.4 ± 0.1 a	12.1 ± 0.1 ab	12.2 ± 0.4 a	12.5 ± 0.1 a	11.9 ± 0.2 b	12.1 ± 0.2 ab	12.1 ± 0.1 ab	3.1
	Gomal	12.7 ± 0.9 a	12.6 ± 0.9 ab	12.4 ± 0.2 ab	12.4 ± 0.4 ab	12.2 ± 0.4 b	12.0 ± 0.5 b	12.1 ± 0.1 b	3.4
Harvest index (%)	Israr Shaheed	34.5 ± 0.5 b	38.2 ± 0.4 a	38.4 ± 0.6 a	29.9 ± 1.8 c	29.0 ± 0.5 cd	26.1 ± 0.9 d	22.6 ± 0.5 e	9.8
	Gomal	33.7 ± 2.3 b	35.7 ± 4.5 a	36.7 ± 0.4 a	30.1 ± 2.7 c	28.3 ± 0.1 cd	27.1 ± 0.4 de	23.9 ± 0.9 e	10.3

Table 3. Various seeding densities effect on the growth and yield of wheat crop. *Different letters in each row indicate significant differences among treatments at $P < 0.05$. T_1 is 100 kg ha^{-1} seed rate, T_2 is 125 kg ha^{-1} seed rate, T_3 is 150 kg ha^{-1} seed rate, T_4 is 175 kg ha^{-1} seed rate, T_5 is 200 kg ha^{-1} seed rate, T_6 is 225 kg ha^{-1} seed rate and T_7 is 250 kg ha^{-1} seed rate.

maximum yield recorded at 150 kg ha^{-1} for both varieties (4.6 t ha^{-1} for Israr Shaheed and 4.5 t ha^{-1} for Gomal). Higher densities resulted in reduced yields. Biological yield, although relatively stable across treatments, was slightly higher at 100–175 kg ha^{-1} but decreased marginally at the highest densities.

The harvest index followed a similar pattern, with the best results at 150 kg ha^{-1} and a marked reduction at 250 kg ha^{-1}. Overall, a seeding density of 150 kg ha^{-1} optimized growth and yield, while higher densities led to a decline in most parameters due to increased competition for resources.

Discussion

This study's results emphasize priming techniques' role in modulating wheat growth and yield, particularly through their interactions with different wheat varieties. The increased height observed in the Gomal variety, especially with farmyard manure priming, can be attributed to improved nutrient availability and enhanced moisture retention provided by organic amendments. Organic manures, such as farmyard and poultry manure, enhance soil properties, creating a more favorable growing environment, which is consistent with Farooq et al., who highlighted the benefits of nutrient- and water-priming in early plant growth[15–22]. The observed differences in plant height between Gomal and Israr Shaheed likely stem from their genetic variation, affecting their responsiveness to priming techniques.

Tiller number, a key determinant of wheat yield, increased substantially in Gomal, particularly with farmyard and poultry manure treatments. This suggests that organic priming agents may enhance hormonal balance and nutrient absorption, which support tiller development. Similar findings have been reported with zinc oxide (ZnO) priming, promoting nutrient availability and tiller production[22–27]. In contrast, sewage water and pressed mud priming resulted in fewer tillers, possibly due to reduced nutrient efficiency and poorer soil conditions.

Spike length, another yield determinant, responded positively to farmyard manure priming, particularly in Israr Shaheed. This aligns with prior studies indicating that organic manure provides a steady supply of nutrients, which supports spike elongation[27–36]. Interestingly, Gomal exhibited longer spikes when primed with sewage water, suggesting this variety might possess adaptive mechanisms that allow it to tolerate unconventional priming agents.

The number of spikelets and grains per spike was consistently higher in Gomal across treatments, indicating greater reproductive efficiency in this variety. Both farmyard and poultry manure were particularly effective in increasing these traits, likely due to enhanced nutrient uptake and flower initiation[37]. Gomal's superior performance in these areas suggests a genetic predisposition for higher yield potential, supported by studies demonstrating the positive effects of organic priming on reproductive structures in wheat[38–40].

The 1000-grain weight varied among treatments, with compost manure producing heavier grains in Israr Shaheed[41]. This suggests that compost-based priming improves soil structure and nutrient availability, aiding in grain filling. However, farmyard and poultry manure priming resulted in lighter grains, indicating a potential trade-off between spikelet number and grain size, a phenomenon also noted in other research[42–44].

Grain yield was significantly higher in Gomal, especially when primed with farmyard manure, which likely promoted better nutrient utilization and stress resilience. Similar studies have shown that organic priming agents improve the harvest index by optimizing the allocation of resources between vegetative and reproductive growth[45]. Moreover, the higher biological yield observed in both varieties, particularly with sodium chloride and poultry manure priming, highlights the potential of these treatments to enhance crop productivity under various stress conditions[46].

Sowing methods also played a significant role in plant growth and yield. The dry seeding followed by the flooding method led to taller plants, particularly in Israr Shaheed, likely due to better root establishment and nutrient uptake[47]. This finding is consistent with the work of Amin and Khan, who demonstrated the advantages of precise sowing techniques in enhancing wheat growth[48]. Enhanced tiller production under this method further supports the importance of optimized sowing techniques in boosting yield, as both varieties performed better when subjected to this approach. As observed in previous studies, Modern sowing methods promote optimal seed placement and early seedling establishment, leading to better yield outcomes[49].

Spike length and spikelet number were also influenced by sowing methods, with the longest spikes recorded for Israr Shaheed under dry seeding followed by flooding[50–53]. This physiological benefit of the method has been confirmed by earlier research on the effects of sowing techniques[54]. Increased spikelet numbers under the same treatment suggest that this method may enhance spikelet initiation, further improving yield potential. The increase in grains per spike supports findings that different sowing methods can significantly impact wheat yield components[55].

The 1000-grain weight showed variability based on sowing methods, with heavier grains observed in both varieties under sprouted seeding in flooded fields[56]. This result underscores the advantages of this method for optimizing nutrient uptake during grain filling. Effective water management during critical growth stages is crucial for improving grain quality and yield[57].

Finally, the significant increases in grain and biological yields associated with dry seeding followed by flooding further emphasize the benefits of modern sowing techniques[58]. The observed yields (4.6 t ha^{-1} for Gomal and 4.3 t ha^{-1} for Israr Shaheed) underscore the effectiveness of this method in maximizing wheat production. This aligns with findings that suggest diverse sowing methods can result in significant variations in yield[59,60]. Pre-germination in flooded fields, contributing to better seedling vigor and establishment, highlights the pivotal role of agronomic practices in improving wheat yield outcomes[61].

Optimal seeding densities (125–150 kg ha^{-1}) provide the best conditions for wheat growth by minimizing competition for resources. The results indicate that moderate densities promote better tiller development, spike length, and grain number per spike, leading to higher yields. High seeding densities (200–250 kg ha^{-1}) increase competition and reduce yield, though the 1000-grain weight may be higher due to fewer total grains per spike[62–65]. These findings highlight the importance of balancing plant population and resource allocation to maximize yield potential.

Conclusions

In the first experiment, various priming techniques were studied. The results revealed that all treatments significantly influenced the growth and yield parameters of wheat varieties. Notably, the interaction of farmyard manure priming with both wheat varieties was particularly promising, leading to improved growth and yield. Thus, farmyard manure priming is recommended for achieving a better crop stand and higher yields in wheat cultivation. Under the agroecological conditions of Dera Ismail Khan, the practice of dry sowing followed by flooding demonstrated superior performance in terms of yield and yield attributes. This method is advisable for general use to enhance wheat productivity in the region. Furthermore, the study indicated that wheat yield and yield attributes were optimized at a seeding rate of 150 kg ha^{-1}. Increasing the seed rate beyond this point resulted in reduced yields, likely due to excessive plant-plant competition. Therefore, for optimal wheat yield, it is recommended to maintain a seeding rate of 150 kg ha^{-1} to avoid competition and potential yield losses. These findings emphasize the importance of adopting precise agronomic practices tailored to local conditions to maximize wheat productivity. Future research should continue to refine these techniques and explore their applicability across different wheat varieties and agroecological zones, contributing to food security and agricultural sustainability in the region.

Data availability

The author confirms that all data generated or analyzed during this study are included in this published article.

Received: 24 July 2024; Accepted: 29 October 2024
Published online: 05 November 2024

References

1. Government of Khyber Pakhtunkhwa. *Khyber Pakhtunkhwa Development Statistics* (Planning and Development Department, Bureau of Statistics, 2014).
2. Hong-juan, J., Yan-jie, Y. & Guo-qiang, Z. Hydrogen peroxide involved in tip growth of wheat (*Triticum aestivum*) root hairs by high concentration chlorogenic acid. *Can. J. Agric. Crops*. **2**(1), 22–33 (2017).
3. Government of Pakistan. Economic Survey of Pakistan. *Statistics Division, Pakistan Bureau of Statistics, Islamabad*, p. 21. (2021).
4. Rind, R. A., Memon, S., Jatoi, W. A. & Rind, M. R. *General Combining Ability and Specific Combining Ability Analysis for Terminal Heat Tolerance in Wheat (Triticum Aestivum L)* (Journal of Applied Research in Plant Sciences, 2023).
5. Khan, I. A., Bakht, J., Shah, W. A., Khan, N. & Ullah, I. Effect of seed rate on the yield and yield components of wheat under irrigated conditions of Peshawar. *Asian J. Plant. Sci.* **5**, 513–515 (2002).
6. Seleiman, M. F., Ibrahim, M. E., Abdel-Aal, S. M. & Zahran, G. A. Effect of seeding rates on productivity, technological and rheological characteristics of bread wheat (*Triticum aestivum* L). *Int. J. Curr. Res.* **4**, 75–81 (2010).
7. Iqbal, J., Hayat, K., Hussain, S., Ali, A. & Bakhsh, M. A. H. A. Effect of seeding rates and nitrogen levels on yield and yield components of wheat (*Triticum aestivum* L). *Pakistan J. Nutr.* **11**(7), 531 (2012).

8. Chauhdary, J. N., Khan, U. D., Shah, S. H. H., Shahid, M. A. & Arsalan, M. Effect of sowing methods and seed rates on wheat yield and water productivity. *Qual. Assur. Saf. Crops Foods*. **8**(2), 267–272 (2016).
9. Dawood, M. G. Stimulating Plant Tolerance Against Abiotic Stress Through Seed Priming. In *Advances in Seed Priming* (eds Rakshit, A. & Singh, H.) https://doi.org/10.1007/978-981-13-0032-5_10 (Springer, Singapore, 2018).
10. Dalil, B. Response of medicinal plants to seed priming: a review. *Int. J. Plant. Anim. Environ. Sci.* **4**(2), 741–745 (2014).
11. Dvorak, J., Luo, M. C., Yang, Z. L. & Zhang, H. B. The structure of the Aegilops tauschii genepool and the evolution of hexaploid wheat. *Theor. Appl. Genet.* **97**, 657–670 (1998).
12. Gill, B. S., Friebe, B. Cytogenetics, phylogeny and evolution of cultivated wheats. In *Bread Wheat – Improvement and Production* (eds. Rajaram, S. et al.), FAO Plant Production and Protection series No. 30, 567 (2002).
13. Wardlaw I. A. N., Chopra, V. L. & Prakash, S. (eds) Evolution and adaptation of cereal crops. *Ann. Bot. 91*(4), 500–501. https://doi.org/10.1093/aob/mcg049 (2003).
14. Heun, M. et al. Site of einkorn wheat domestication identified by DNA fingerprinting. *Science*. **278**(5341), 1312–1314 (1997).
15. Farooq, M. et al. Influence of seed priming techniques on grain yield and economic returns of bread wheat planted at different spacings. *Crop Pasture Sci.* **71**(8), 725–738 (2020).
16. Al-Salama, Y. Effect of seed priming with ZnO nanoparticles and saline irrigation water in yield and nutrients uptake by wheat plants. *Environ. Sci. Proc.* **16**(1), 37 (2022).
17. Aryal, K., Shrestha, A. & Subedi, R. Effect of various seed priming methods on germination characteristics of black gram. *J. Protein Res. Bioinform.* **2**, 009 (2020).
18. Mamun, A. A., Naher, U. A. & Ali, M. Y. Effect of seed priming on seed germination and seedling growth of modern rice (*Oryza sativa* L.) varieties. *Agriculturists*. **16**(1), 34–43 (2018).
19. Khan, R. A., Khan, A. & Qadri, T. A. Influence of seed priming with $FeSO_4$ on germination, growth and biochemical aspects of mung bean (*Vigna radiata* L.) grown under NaCl stress. *J. Bioscience Appl. Res.* **5**(4), 519–532 (2019).
20. Marthandan, V. et al. Seed priming: a feasible strategy to enhance drought tolerance in crop plants. *Int. J. Mol. Sci.* **21** (21), 8258 (2020).
21. Nejad, H. A. The effects of seed priming techniques in improving germination and early seedling growth of *Aeluropus macrostachys*. *Int. J. Adv. Biol. Biomedical Res.* **1** (2), 86–95 (2013).
22. Kanto, U., Jutamanee, K., Osotsapar, Y., Chai-arree, W. & Jattupornpong, S. Rice seed priming with swine manure extract to ameliorate vigor and nutrient status of seedlings. *Agric. Nat. Resour.* **48**(3), 333–347 (2014).
23. Iqbal, S. et al. Influence of seed priming with $CuSO_4$ and $ZnSO_4$ on germination and seedling growth of oat under NaCl stress. *Pure Appl. Biology (PAB)*. **9**(1), 84 (2020).
24. Amin. M., Khan, M. J., Jan, M. T. & Tariq, J. A. Response of wheat growth characteristics tovarious tillage practices and sowing methods under semi arid environment. *Sarhad J. Agric.* **29**(4), 529–535 (2013).
25. Asif, M., Akbar, G., Khalil, S. K., Islam, Z. & Kalwar, S. A. Effect of sowing methods on wheat production in Potohar, Pakistan. *Pakistan J. Agric. Agricultural Eng. Veterinary Sci.* **35**(2), 98–104 (2019).
26. Aslam, M. S. Effect of sowing patterns and nitrogen rates on quality traits and yield of wheat. *J. Environ. Sci. Nat. Resour.* **5**(1), 267–272 (2012).
27. Bakhsh, K. et al. Effect of sowing methods on growth and yield of wheat (*Triticum aestivum* L.) through zero and other tillage method. *J. Plant. Sci.* **8**(5), 152–157 (2020).
28. Chaudhary, G., Sharma, J. D. & Yadav, A. S. Productivity and economics of late-sown wheat under different sowing methods and weed management practices. *Indian J. Weed Sci.* **45**(4), 294–295 (2013).
29. Chouhan, B. S. et al. Effect of sowing methods, scheduling of irrigation based on IW/CPE ratio and chemical weed control on plant height, dry matter accumulation and yield of wheat. *J. Pharmacognosy Phytochemistry*. **6**(3), 169–172 (2017).
30. Dagash, Y. M. I., Ahmed, I. S. & Khalil, N. A. Effect of nitrogen fertilization, sowing methods and sowing dates on yield and yield attributes of wheat (*Triticum aestivum* L). *Univers. J. Plant. Sci.* **2**(6), 108–113 (2014).
31. Khurshid, F. F. Effect of sowing methods on the yield and yield components of wheat under two seed rates at sulaimani region. *Iraqi J. Agricultural Sci.* **53**(1), 99–110 (2022).
32. Mosalem, M. et al. Evaluation of sowing methods and nitrogen levels for grain yield and components of durum wheat under arid region of Egypt. *Rom Biotechnol. Lett.* **26**, 3031–3039 (2021).
33. Bhatta, M. et al. Seeding rate, genotype, and top-dressed nitrogen effects on yield and agronomic characteristics of winter wheat. *Crop Sci.* **57**(2), 951–963 (2017).
34. Khalil, S. K. et al. Dual purpose wheat for forage and grain yield in response to cutting, seed rate and nitrogen. *Pak J. Bot.* **43**(2), 937–947 (2011).
35. Tahir, S., Ahmad, A., Khaliq, T. & Cheema, M. J. M. Evaluating the impact of seed rate and sowing dates on wheat productivity in semi-arid environment. *Int. J. Agric. Biology*. **22**(1), 57–64 (2019).
36. Finnan, J. M., Hyland, L. & Burke, B. The effect of seeding rate on radiation interception, grain yield and grain quality of autumn sown oats. *Eur. J. Agron.* **101**, 239–247 (2018).
37. Huang, J. et al. Evaluation of regional estimates of winter wheat yield by assimilating three remotely sensed reflectance datasets into the coupled WOFOST–PROSAIL model. *Eur. J. Agron.* **102**, 1–13. https://doi.org/10.1016/j.eja.2018.10.008 (2019).
38. Akpor, O. B., Ezekudo, E. O., Sobajo, O. A., Edoh, P. A. & Mabayoje, S. O. Optimization andantimicrobial properties of biosurfactant production by four indigenous soil bacterialspecies. *Asian J. Agric. Biol.* **4**, 2022146. https://doi.org/10.35495/ajab.2022.146 (2023).
39. Bui, V. H., Nguyen, H. C. & Ngo, Q. H. Establishment of rice yield prediction model using soilcompaction. *Asian J. Agric. Biol.* **2**, 202109327. https://doi.org/10.35495/ajab.2021.09.327 (2023).
40. Fatemi, R., Yarnia, M., Mohammadi, S., Vand, E. K. & Mirashkari, B. Screening barleygenotypes in terms of some quantitative and qualitative characteristics under normaland water deficit stress conditions. *Asian J. Agric. Biol.* **2**, 2022071. https://doi.org/10.35495/ajab.2022.071 (2023).
41. Wang, X., Huang, J., Feng, Q. & Yin, D. Winter wheat yield prediction at county level and uncertainty analysis in main wheat-producing regions of China with deep learning approaches. *Remote Sens.* **12** (11), 1744. https://doi.org/10.3390/rs12111744 (2020).
42. Fatmawati, U., Sari, D. P., Santosa, S. & Wiraswati, S. M. IAA-producing and phosphatesolubilizer of rhizosphere actinobacteria consortium to promote plant growth insoybean (Glycine max L.). *Asian J. Agric. Biol.* **4**, 2021402. https://doi.org/10.35495/ajab.2021.402 (2023).
43. Ijaz, M., Afzal, A., Shabbir, G., Iqbal, J. & Rafique, M. Breeding wheat for leaf rustresistance: Past, present and future. *Asian J. Agric. Biol.* **2023**(1), 2021426. https://doi.org/10.35495/ajab.2021.426 (2023).
44. Irawan AP et al. Studies on bioflocculantexopolysaccharides (EPS) produced by Anabaena sp. and its application asbioflocculant for low cost harvesting of Chlorella sp. *Asian J. Agric. Biol.* **2023**(3), 1–9. https://doi.org/10.35495/ajab.2022.150 (2023).
45. Yang, X. et al. OsTTG1, a WD40 repeat gene, regulates anthocyanin biosynthesis in rice. *Plant. J.* **107** (1), 198–214. https://doi.org/10.1111/tpj.15285 (2021).
46. Ishaq, L. et al. Abundance of arbuscular mycorrhizal fungi in the rhizosphere of healthy anddeclining citrus in East Nusa Tenggara, Indonesia. *Asian J. Agric. Biol.* **2023**(3), 1–12. https://doi.org/10.35495/ajab.2023.011 (2023).
47. Wang, M., Wang, B., Zhang, R., Wu, Z. & Xiao, X. Flexible Vis/NIR wireless sensing system for banana monitoring. *Food Qual. Saf.* **7** https://doi.org/10.1093/fqsafe/fyad025 (2023).

48. Ismail, H. N., Noor, N. M., Ahmad, Z. & Wan Anuar, W. N. H. Algal composition inecosystem of rice field under the application of herbicides and insecticides. *Asian J.Agric. Biol.* **2023**(1), 202106254. https://doi.org/10.35495/ajab.2021.06.254 (2023).
49. Bi, Y. et al. Effects of *Bacillus subtilis* on cotton physiology and growth under water and salt stress. *Agric. Water Manag.* **303**, 109038. https://doi.org/10.1016/j.agwat.2024.109038 (2024).
50. Kupradit, C., Ranok, A., Mangkalanan, S, Khongla, C. & Musika S. β -glucan andantioxidant activities of four edible mushroom extracts from Thailand. *Asian J. Agric.Biol.* **2023**(1), 202107285. https://doi.org/10.35495/ajab.2021.07.285 (2023).
51. Zurbano, L. Y., Deocaris, C. C., Mapanao, C. P., Rendon, A. O. & Alvarez, L. V. Metabarcoding ofnematode communities associated with Ananas comosus L. (Pineapple). *Asian J. Agric. Biol.* **2023**(3). 2022114. https://doi.org/10.35495/ajab.2022.114 (2023).
52. Le Thanh, T. et al. Papathoti NKand Buensanteai K. Expression and role of defense components in Bacillus subtilis-treated riceplants against Xanthomonas oryzae pv. oryzae. *Asian J. Agric. Biol.* **2023**(3), 1–11. https://doi.org/10.35495/ajab.2022.161 (2023).
53. Zhang, L. et al. Enhancing aphid resistance in horticultural crops: a breeding prospective. *Hortic. Res.* uhae275. https://doi.org/10.1093/hr/uhae275 (2024).
54. Li, C., Ahmad, S. & Cao C. Mitigation of climate crisis from rice paddy field by tillagecombination in central China. *Asian J. Agric. Biol.* **2023**(4), 2022122. https://doi.org/10.35495/ajab.2022.122 (2023).
55. Wang, M., Zhang, R., Wu, Z. & Xiao, X. Flexible wireless in situ optical sensing system for banana ripening monitoring. *J. Food Process. Eng.* **46** (12), e14474. https://doi.org/10.1111/jfpe.14474 (2023).
56. Osei, A. F., Jin, X., Abdullah, W. Z. B. W. & Sidique, S. N. M. Silicon improves strawberryplants nutrient uptake and epicuticular wax formation in a rhizosphere cooling system. *Asian J. Agric. Biol.* **2023**(2), 2022060. https://doi.org/10.35495/ajab.2022.060 (2023).
57. Lin, N. et al. Black biodegradable mulching increases grain yield and net return while decreasing carbon footprint in rain-fed conditions of the Loess Plateau. *Field Crops Res.* **318**, 109590. https://doi.org/10.1016/j.fcr.2024.109590 (2024).
58. Victoria, O. et al. Seed treatment with 24-epibrassinolide improves wheat germinationunder salinity stress. *Asian J. Agric. Biol.* **2023**(3), 1–14. https://doi.org/10.35495/ajab.2022.076 (2023).
59. Pangaribuan, D. H., Widagdo, S., Hariri, A. M., Siregar, S. & Sardio, M. I. The effect of rice strawmulch and cow urine on growth, yield, quality on sweet corn and pest populationdensity. *Asian J. Agric. Biol.* **2023**(1), 202103123. https://doi.org/10.35495/ajab.2021.03.123 (2023).
60. Rejab, M. R. M, Manam, N. K. A., Fauzi, N. S., Mohamed, S. & Ngah, N. The effectiveness ofFurcraea plants in controlling golden apple snail and their effects on the non-targetorganism at the rice field. *Asian J. Agric. Biol.* **2023**(1), 202104164. https://doi.org/10.35495/ajab.2021.04.164 (2023).
61. Safdar, M. E. et al. Assessing critical periodof weed competition in direct seeded rice (Oryza sativa L.). *Asian J. Agric. Biol.* 2023(4), 2022190. https://doi.org/10.35495/ajab.2022.190 (2023).
62. Sennoi, R., Ruttanaprasert, R., Chinaworn, S. & Puttha, R. Effects of hormone and coldtreatments on dormancy breaking of Jerusalem artichoke (Helianthus tuberosus L.)tubers. *Asian J. Agric. Biol.* **2023**(2), 2021422. https://doi.org/10.35495/ajab.2021.422 (2023).
63. Shaukat, N. et al. Antimicrobial potential of banana peel: A natural preservative toimprove food safety. *Asian J. Agric. Biol.* **2023**(1), 202003188. https://doi.org/10.35495/ajab.2020.03.188 (2023).
64. Sindesi, O. A., Ncube, B., Lewu, M. N., Mulidzi, A. R. & Lewu, F. B. Cabbage and Swiss chardyield, irrigation requirement and soil chemical responses in zeolite-amended sandy soil. *Asian J. Agric. Biol.* **2023**(1), 202111387. https://doi.org/10.35495/ajab.2021.11.387 (2023).
65. Taratima, W., Kunpratum, N. & Maneerattanarungroj, P. Effect of salinity stress onphysiological aspects of pumpkin (Cucurbita moschata Duchesne. 'Laikaotok') underhydroponic condition. *Asian J. Agric. Biol.* **2023**(2), 202101050. https://doi.org/10.35495/ajab.2021.01.050 (2023).

Acknowledgements
The authors extend their appreciation to the Researchers Supporting Project number (RSP2024R98), King Saud University, Riyadh, Saudi Arabia, for financial support.

Author contributions
SKR: Investigation, experimentation and data Curation MS: Methodology, supervision, Writing and drafting, and research design; MSB, HQ: drafting, statistical analysis, software, resource, research design, validation; TA: drafting, statistical analysis, validation and software; AAA: writing, funding, statistical analysis, Resource, software, validation; MJA: writing, funding, statistical analysis, validation, Review, and Editing. All authors have read and approved the final manuscript and declare that they have no competitive interest.

Funding
The authors extend their appreciation to the Researchers Supporting Project number (RSP2024R98), King Saud University, Riyadh, Saudi Arabia, for financial support.

Declarations

Competing interests
The authors declare no competing interests.

Ethics approval and consent to participate
We all declare that manuscript reporting studies do not involve any human participants, human data, or human tissue. So, it is not applicable.

Study protocol must comply with relevant institutional, national, and international guidelines and legislation
Our experiment follows the relevant institutional, national, and international guidelines and legislation.

Additional information
Correspondence and requests for materials should be addressed to S.K.R., H.Q. or T.A.

Reprints and permissions information is available at www.nature.com/reprints.