Journal of Population Therapeutics & Clinical Pharmacology

RESEARCH ARTICLE
DOI: 10.53555/jptcp.v31i5.6193

EXOGENOUS APPLICATION OF PLANT GROWTH REGULATORS ON GENETIC DIVERSITY OF WHEAT TO ACCOMPLISH THE OPTIMUM PRODUCTION UNDER LATE SOWN CONDITIONS

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Abstract

Wheat yield in Pakistan is low on account of various biotic and abiotic stressors. Late sowing of wheat after harvesting of cotton, rice, and sugarcane crops is considered as the main cause of low yield in the country. The delayed physiological maturity and terminal heat stress are the main contributors to this yield decline. The appropriate use of plant growth regulators (PGRs) and selection of suitable varieties may help to alleviate these stresses. A field experiment was conducted at Pakistan Agricultural Research Council, Arid Zone Research Centre (AZRC), Dera Ismail Khan, Khyber Pakhtunkhwa (KP) Province, Pakistan on late sown wheat for two successive years (2019-2020 and 2020-2021). The experiment was comprised of different combinations of plant growth regulators-PGRs (viz. Amino Acids-AA + Gibberellic Acid-GA, GA + Potassium-K, K + AA, AA + GA + K and control), and wheat varieties i.e. AZRC Dera (long duration) and Paseena (short duration) sown on 10th December and 10th January in a randomized complete block design with factorial arrangements. The maximum plant height, chlorophyll content (i.e. Soil Plant Analysis Development-SPAD value) and crop growth rate were recorded for AZRC Dera sown on 10th December and treated with AA + GA + K combination in 2019-20 and 2020-21. Similarly, leaf area index, net assimilation rate, root length, grain yield and yield contributing parameters (tillers, grains/spike and thousand grains weight) were recorded in wheat variety AZRC Dera sown on 10th December and treated with K + AA. Recommendation from the experiment that sowing on 10th December, with exogenous application of K+AA and AA+GA+K foe shoot growth with inoculation of biozot for root development. So, the foliar application of AA+GA+K and inoculation with biozote at 10th December sowing is recommended as best under late sown conditions.

Keywords: Late sowing, PGRs, Sowing dates, Varieties and Wheat.

Introduction

Wheat (*Triticum aestivum* L.) is staple food and primary source of calories in Pakistan. According to FAO (2022), 761 million tonnes of wheat is produced on 219 million hectares globally every year. Wheat contributes about 8.9% to agricultural value addition and 1.6% to gross domestic product (GDP) in the country. In the rabi season of 2022-2023, Pakistan annually produces 27.634 million tons of wheat on 9.043 million hectares of land (Pakistan Economic Survey, 2023). Wheat is consumed worldwide due to its high calorie and protein content compared to other cereals. Wheat is a major crop in Pakistan, accounting for 60% of the daily diet and 42% of the total cropped terrestrial of the country. It is not only consumed as a human diet, but a significant portion is also used to make flour and bakery products.

Wheat crop delayed planting even by a single day may result in yield reduction up to 1% (Moshatati et al., 2017). In Pakistan, 80% of wheat is planted late due to the delay in the physical ripeness of rice and the picking of cotton, while the remaining 20% is planted at the normal time (Laghari et al., 2012). Dry conditions during the late planting period limit wheat sowings in rainfed areas. The low temperature during early growth stages and high temperature during later growth stages can decrease cytokinin levels and negatively impact the quantity and quality of late sown wheat (Feng et al., 2008; Farooq et al., 2011; Shahid et al., 2017). Late sowing is becoming a significant limiting factor for wheat output as global temperatures continue to rise (Lobell et al., 2011). Climate change has also been shown to affect protein concentration in wheat crop (Asseng et al., 2019).

Globally, there are various approaches being employed to deal with late sown wheat, including foliar nutrient applications to mitigate the effects of scarcity on plant growth (Ahmad et al., 2018). Growth regulators play a significant role in the regulation of plant growth and development under stress or normal conditions (Slama et al., 2020).

Amino acids are well-known as a bio stimulant, which has positive effects on plant growth, yield, and significantly reduces the injuries caused by abiotic stresses. When amino acid is applied under drought conditions, the total soluble sugar and total carbohydrates remain significantly higher than the untreated control (Haider et al., 2021). The foliar sprays of potassium and amino acids significantly improve the morphological as well as biochemical characteristics of wheat when grown in the presence or absence of drought stress conditions (Fabian et al., 2019). Similarly, gibberellins (GAs) are a group of plant hormones that have positive effects on seed germination, leaf expansion, stem elongation, flower and trichome initiation, and flower and fruit growth. Gibberellic acid plays a critical role in plant stress responses, as demonstrated by its ability to improve wheat growth (Iftikhar et al., 2020). Among major plant nutrients, potassium (K) plays a vital role in plant growth and physiology. It is not only a constituent of the plant structure, but also has a regulatory function in several biochemical processes related to protein synthesis, carbohydrate metabolism, and enzyme activation. In recent decades, K has been found to provide abiotic stress tolerance, helping to maintain ion homeostasis and regulate osmotic balance under salt stress (Singh et al., 2021).

Some wheat genotypes that can perform well under stressed conditions, lodging and shattering resistant varieties, which has led to the emergence of new cropping systems under late sown (Arya et al., 2013). Wheat genotypes that can perform well in any stochastic environmental condition are considered flexible (Ober et al., 2021). Mostly, it was observed that late sown wheat germplasms cannot perform to the best of their potentials in the area. The duration and stages of phenological traits are significant indicators of potential yield, with appropriate sowing date and cultivars playing a major role in optimizing crop yield. To increase the yield of the wheat crop under late sowing conditions, different PGRs and microbes will be tested to address the issue. Keeping in view the importance of wheat varieties, PGRs and microbial interaction at different sowing dates present research was designed to fulfil the objectives; (i) to study the response of late-seeded wheat to various plant growth regulators. (ii) to screen out wheat varieties suitable under late sown conditions under available sowing window.

Materials and Methods

Study site

The research was carried out at Arid Zone Research Centre, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan during two consecutive years. The site is located at the latitude of 31°-26’ N, longitude 73°-06’ E and altitude of 184.4 m. The experiment was conducted on silty clay soil with dominant clay characteristics, having organic matter content 0.5% and soil pH 8.1. The soil was low in total N (0.4 g kg^{-1}), AB-DTPA extractable phosphorus (7.5 mg P_2O_5 kg^{-1} soil), and available K (186 mg kg^{-1} soil). The rainfall during the two growing seasons was in the range of 202–266 mm. The temperature during the two growing seasons is given in Fig. 1-2.

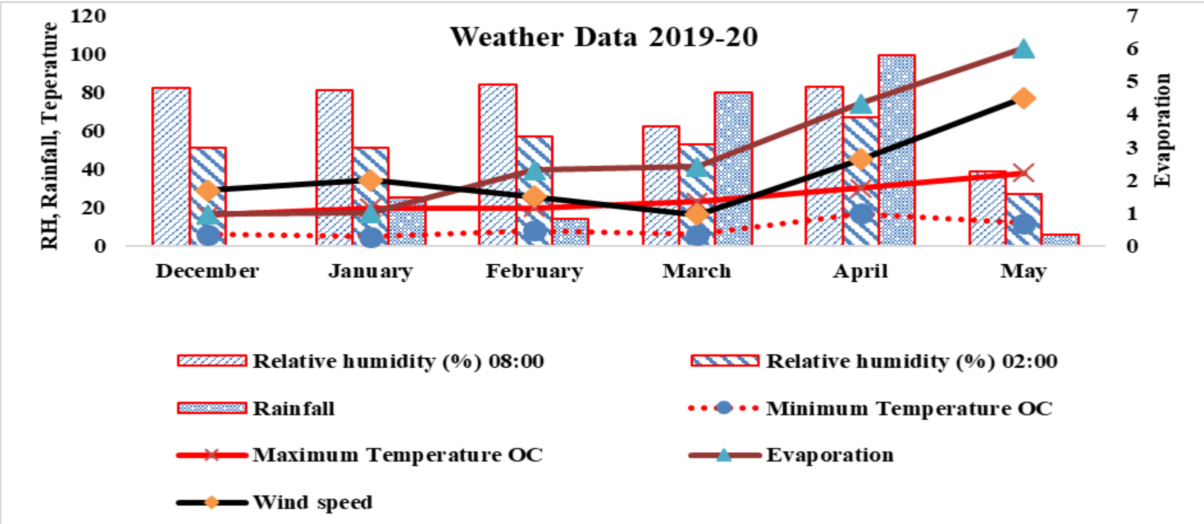

Figure 1. Weather conditions during the experimental year (2019–2020)

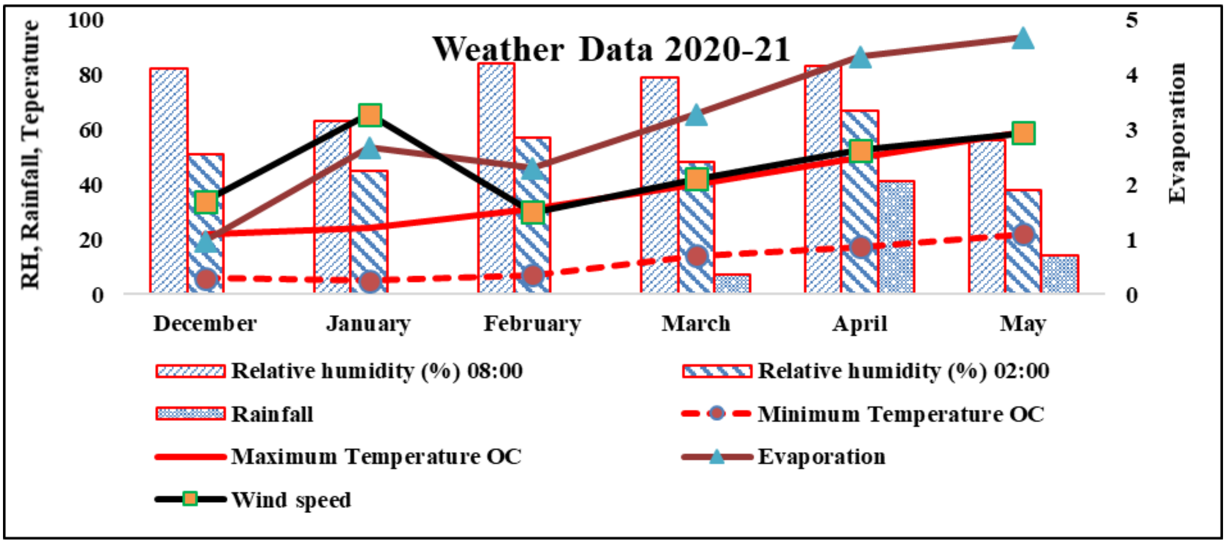

Figure 2. Weather conditions during the experimental year (2020–2021)

Experimental design and treatments detail

The experiment was comprised of different combinations of PGRs (viz. Amino Acids-AA + Gibberellic Acid-GA, GA + Potassium-K, K + AA, AA + GA + K and control), wheat varieties AZRC Dera (long duration) and Paseena (short duration), and sowing dates which was laid out in a randomized complete block design with factorial arrangements sown on 10th December and 10th January. Factor-A: Plant growth regulators i.e (i) AA + GA_3 (ii) GA_3 + K (iii) AA + K (iv) AA + GA_3 + K (v) Control, Factor-B: crop varieties (i) long duration variety (AZRC Dera) (ii) short duration variety (Paseena). Factor-C: sowing dates (i) 10th December (ii) 10th January

Crop husbandry

Wheat crop was planted on 10th December and 10th January of each year through drill method at field capacity. Seed of both varieties (AZRC Dera and Paseena) were planted at the rate of 150 kg ha^{-1}. A recommended dose of fertilizers at the rate of 150:120:90 NPK kg ha^{-1} was applied in experiment. Half of nitrogen along with full dose of phosphorous and potassium was applied at the time of sowing while remaining half dose of nitrogen was applied with first and second irrigations. Weeds were managed chemically by using weedicides viz. Clodinafop for narrow leaves (*Avena fatua*, *Phalirus minor*) and Bromoxynil for broad leaves (*Convolvulus arvensis*, *Chenopodium album*) weeds in all trials. Bromoxynil was applied after first irrigation in proper moist condition while Clodinafop was sprayed after second irrigation. Under late sown conditions, wheat crop generally requires three to four irrigations depending on rainfall, cultivar, climatic conditions, and rate of evapotranspiration. Four irrigations were applied at 1) tillering stage 2) booting stage 3) anthesis stage and 4th irrigation at milking stage. Crop was harvested at first week of May of both experimental years.

Plant sampling and data recording

Data were recorded in the central five rows of each subplot. The average root length (cm) was measured with the help of scale. Crop growth rate (g m^{-2} day^{-1}) (CGR) was determined by calculating the difference between initial and final dry weight and dividing it by time interval. Soil Plant Analysis Development (SPAD) value for chlorophyll content in five randomly selected plants was recorded forty days after foliar application of PGRs. The height of plants was measured with the help of measuring rod at physiological maturity of ten plants were selected from each experimental unit, measured their height and then averaged. LAI was calculated from leaf area divided by ground area occupied by the plants. It was measured forty days after foliar application of PGRs.

$$Leaf\ area\ index = (leaf\ area\ (m2)) \div (row\ to\ row)(plant\ to\ plant)distance$$

Net assimilation rate (g m^{-2} day^{-1}) (NAR) was calculated by using the following formula;

$$NAR = ((W2 - W1)\ (Ln\big(LA2 - Ln(LA1)\big)) \div ((T2 - T1)(LA2 - LA1))$$

Number of tillers (m^{-2}) were counted from the three successive rows up to the length of 1 meter from every experimental unit at maturity of crop. For number of grains ($spike^{-1}$) fifteen spikes taken randomly in each plot were threshed and their grains were counted and averaged. For 1000-grain weight, 1000 grains in each plot were counted and weighed by using digital balance. Grain yield (kg ha^{-1}) was recorded after harvesting. After that, grain yield (kg ha^{-1}) was calculated by using the following formula;

$$Grain\ yield\ (kg\ /\ ha) = (grain\ yield\ of\ 5\ \ rows(kg)) \div (area\ of\ 5\ rows(m2)) \times 10{,}000$$

Statistical analysis

A computer software program Statistix-8.1 was used to statistically analyse the collected data using analysis of variance-ANOVA technique (Steel et al., 1997). Subsequently, least significant difference (LSD) test was used to compare the treatment means at 5% probability level.

Results and discussion

1. Root length (cm)

Graph 3 reveals that the interaction of PGRs, varieties, and sowing dates had significant effect on root length of wheat. Overall, the combination of K + AA resulted in the longest root length (22.4 in 2019-20 and 21.7 cm in 2020-21) and AA + GA + K (22.3 and 21.8 cm) for AZRC Dera sown on 10th December each year. The shortest root length of 8.4 and 7.9 cm was noted in AA + GA treatment, which was statistically at par with untreated control (8.4 in 2019-20 and 8.0 in 2020-21) and GA + K (8.4 and 8.1 cm) in Paseena variety during both the experimental years. In these results, the use of K (potassium) and AA (amino acid) enhanced root growth of wheat. Arshad et al. (2022) also noted a similar trend in wheat crop. Additionally, the use of GA (gibberellic acid) is known to stimulate cell elongation and division in plant roots, which eventually increased the root length. These results are in line with the previous findings of Hussain et al. (2022) who reported increased root length by applying various growth regulators. The combination of these PGRs may have had a synergistic effect on root growth, leading to the increase in mean root length. Ragaey et al. (2022) reported the highest values of growth parameters by applying 20 mM arginine under normal irrigation and salt stress conditions for wheat. They were of the view that foliar application of GA_3 can improve growth and yield of wheat, while amino acid and the microbe strain had positive effects on plant growth and development.

2. Crop growth rate (g m^{-2} day^{-1})

The data presented in graph 4 indicated the interaction of plant growth regulators, crop varieties and sowing dates on CGR of wheat. The results showed that the combination of AA + GA had the highest CGR for AZRC Dera variety (20.28 in 2019-20 and 20.00 in 2020-21) and AA + GA + K treatment (20.56 in 2019-20 and 19.97 g m^{-2} day^{-1} in 2020-21) sown on 10^{th} December each year. The lowest CGR was, however, noted in control (11.85 in 2019-20 and 11.78 g m^{-2} day^{-1} in 2020-21) in Paseena variety sown on 10^{th} January during both the cropping seasons. The difference in CGR with the application of various PGRs was probably due to the variation in their active ingredients and in their concentration, which promoted the growth of wheat plants as compared to untreated control. Similarly, the difference in CGR at various sowing dates might be attributed to variation in temperature, sunlight etc. The crop sown on 10^{th} December had the longer growing period which eventually utilized all available resources more efficiently than the crop sown under late conditions at 10^{th} January each year. Earlier findings showed that the use of PGRs play a crucial role in ion homeostasis, cellular integrity, and enzymatic activities, which can help impart tolerance potential to plants under major abiotic stress conditions (Johnson et al., 2022). The difference in CGR in both the tested varieties might be due to their diverse genetic make-up as already studied by Ilyas et al. (2020). Similar variation in CGR among various wheat varieties was also noticed by Farooq et al. (2020) and Arif et al. (2021). Sowing time influenced all physiological parameters, including crop growth rate, while delayed sowing resulted in lower values (Bhayal et al., 2022).

3. Plant height at maturity (cm)

The interaction of PGR, varieties, and sowing dates exhibited significantly tallest plants of wheat (Table 2). Among various treatments, the combination of AA + GA + K resulted in highest plant height (91.6 in 2019-20 and 88.3 cm in 2020-21) which was statistically similar to AA + K treatment (89.0 in 2019-20 and 89.6 cm in 2020-21) for wheat variety AZRC Dera when sown on 10^{th} December each year. The lowest plant height of 62.0 in 2019-20 and 63.0 cm in 2020-21 was noted in untreated control when Paseena variety was planted on 10^{th} January during both the experimental years. The results of present study reveal that foliar application of AA + GA + K combination significantly increased plant height of wheat. These findings are in line with Hussein et al. (2022) who reported that application of amino acid produced significantly taller plants than the untreated control. Irshad et al. (2022) also concluded that the foliar application of K resulted in maximum plant height as compared to control. In another study, Vijay variety had the maximum height of 77.61 cm, while reverse phenomenon was observed for BL4407 variety, showing a plant height of 59.36 cm (Upadhyaya and Bhandari, 2022). Late planting was found to decrease the plant height compared to timely sowing (Singh et al., 2011). Irshad et al. (2022) corroborate the present findings revealing highest plant height in normal sowing time because late sowing alters the duration and intensity of exposure to environmental factors such as temperature and moisture.

4. Leaf area index

The interaction of PGR, crop varieties, and sowing dates was found significant in measuring LAI of wheat during the year 2019-20 and 2020-21 (Graph 5). The combined application of K + AA resulted in the highest value of LAI (2.75 in 2019-20 and 2.68 in 2020-21) for AZRC Dera variety when sown on 10th December. Whereas, in 10th January sown crop, untreated Paseena variety in 2019-20, and the same variety when treated with AA + GA in 2020-21, produced the lowest LAI (1.00 and 0.94), respectively. The relationship between leaf area index and crop yield has been extensively studied in earlier research. Several studies have reported a positive correlation between LAI and grain yield. Khan et al. (2020) found that priming and foliar of PGRs increased LAI as compared to control. Iqbal et al. (2022) noted that the LAI of a high tillering wheat variety remained higher as compared to low tillering cultivars. Tan et al. (2020) reported that LAI increased plant height and number of leaves per unit area. Liu et al. (2019) analysed the relationship between LAI and several parameters which were related to grain yield. They also found significant correlations between LAI and some other growth indices. Ahmed et al. (2022) reported the interaction between nutrient and variety which had significant effect on LAI.

5. Chlorophyll content (SPAD value)

The interaction of PGRs, crop varieties, and sowing dates was found significant during both the study years (Table 4.1.5 b). The combined application of AA + GA + K showed the highest SPAD values of 51.66 for Paseena variety in 2019-20 and of 53.33 for AZRC Dera in 2020-21, when crop was sown on 10th December. Contrarily, the lowest SPAD values of 26.00 in 2019-20 and 24.33 in 2020-21 were noted in AZRC Dera when sown on 10th January without any PGRs application. The positive effects of PGRs on chlorophyll content might be attributed to their ability to enhance plant growth and development, nutrient uptake, and inducing stress tolerance in plants. In another study by Haider et al. (2021) found that foliar applied amino acid increased the chlorophyll content and the differences found in chlorophyll content be attributed to the genetic and environmental factors. Singh et al. (2022) concluded that foliar application of PGRs can enhance photosynthetic rate, chlorophyll content, and chlorophyll fluorescence in wheat. Irshad et al. (2022) and Shah et al. (2021) both found that timely sowing resulted in higher chlorophyll content than late sowing, and priming with PGRs treatments also had a positive effect on chlorophyll-a content under late sowing of wheat.

6. Net assimilation rate (g $m^{-2}day^{-1}$)

The interaction of PGR, wheat varieties, and sowing dates significantly increased NAR during both the experimental years (Table 4.1.8 b). The K + AA treatment for the AZRC Dera variety sown on 10th December resulted in significantly higher NAR of 3.41 in 2019-20 and 3.38 g m^{-2} day^{-1} in 2020-21. Whereas, the K +AA treatment for the same AZRC Dera variety sown on January 10th resulted in lowest NAR of 2.81 in 2019-20 and 2.75 g m^{-2} day^{-1} in 2020-21. PGRs, varieties, and sowing dates all play crucial roles in regulating plant growth and development, as well as in their response to the environmental stress factors such as temperature, moisture and light. For example, Ullah et al. (2022) found that the application of K had a significant effect on NAR. Ragaey et al. (2022) reported similar results and found that the growth parameters of wheat were highest with the application of amino acid. Our findings also confirm that the combined application of AA + GA might have increased in photosynthesis rate and resulted in a higher NAR value. Regarding genotypic variations, Iqbal et al. (2022) reported that NAR of cultivars Galaxy-2013 and FSD-2008 was statistically similar and thus confirms the findings of our study during both the years.

7. Number of tillers (m^{-2})

The interaction of PGR, varieties, and sowing dates was found significant in producing number of tillers of wheat (Table 4.1.3 b). The combination of K + AA in 2019-20 and AA + GA + K in 2020-21 resulted in the highest number of tillers (341.6 and 335 m^{-2}, respectively) for wheat variety AZRC Dera when sown on 10th December. On the other hand, when the crop was sown on 10th January, it produced lowest number of tillers in untreated Paseena (246 m^{-2} in 2019-20) and in the same crop variety when treated with AA +GA (233 m^{-2} in 2020-21). This treatment (AA + GA in 2020-21) was statistically at par with untreated control in producing number of tillers (241 m^{-2}).

Several studies revealed positive effects of foliar application of potassium and amino acids on wheat growth and yield. Gu et al. (2021) also reported that the number of tillers of wheat variety "XY22" was significantly affected by the year and potassium fertilizer concentrations. Singh et al. (2022) found similar results when hormones were sprayed on the plants, which increased the number of tillers and the grain yield. Similarly, Hussein et al. (2022) reported that the application of amino acid led to significant improvements in plant height, root length, tillers and flag leaf area. Bhattarai et al. (2015) noticed that delayed sowing or edaphic factors such as salinity can have a negative impact on the wheat growth and yield.

8. Number of grains (spike^{-1})

The interaction of PGRs, wheat varieties, and sowing dates was found significant statistically in producing number of grains per spike during both the experimental years (Table 2). The crop when sown on 10th December, variety AZRC Dera responded well to the PGR treatment of K + AA, with the highest number of grains per spike (39.9 and 37.8 in 2019-20 and 2020-21, respectively). The lowest number of grains per spike (31.1 and 29.5 in 2019-20 and 2020-21, respectively) was noted in untreated Paseena variety when sown on 10th January, and it was statistically at par with the AA + GA treatment. Among the PGRs treatments, K + AA application resulted in higher number of grains per spike, might be due to the positive effect of K on the development of spikelets and grains, and amino acids on photosynthesis and grain filling stages. These results are in accordance with Kathwal et al. (2022) who reported that PGRs resulted in significantly higher effective tillers, seeds per head, and maximum 1000 grain weight. They further indicated that the improved yield attributes might be due to increased availability of K, growth hormone, phytohormones, gibberellic acid, and amino acids. Higher number of grains per spike in 10th December sown crop was supported by Koppensteiner et al. (2022) who reported that in timely sowing of wheat, the crop attains more favourable temperature conditions during the period of crop growth and development.

9. 1000 grains weight (g)

The interaction of PGRs, crop varieties and sowing dates for producing higher grain weight remained significant statistically during both the study years (Table 2). AZRC Dera variety when sown on 10th December and treated with K + AA and AA + GA + K produced heavier grains (40.6 and 38.8 g) during both the cropping years, respectively. On the other hand, when the crop was sown on 10th January, untreated Paseena variety and the same variety when treated with AA + GA showed the lowest grain weight of 33.2 and 31.3 g in 2019-20 and 2020-21, respectively. In this study, the combination of K + AA with AZRC Dera variety might have a synergistic effect which enhanced grain weight. Moreover, sowing wheat in December could have provided more favourable environmental conditions for crop growth and development. Earlier, Jeber and Khaeim (2019) also reported a significant increase in grain weight with a foliar spray of AA + OA + NA as compared to control. Gu et al. (2021) had the view that the yield contributing parameters of wheat variety "XY22" were significantly affected by potassium fertilizer. Kathwal et al. (2022) reported that spray of PGRs resulted in significantly higher effective tillers, seeds per ear, and maximum grain weight. Shah et al. (2021) found that delayed sowing of crop minimized the number and weight of grains per spike.

10. Grain yield (kg ha^{-1})

The interaction of PGRs, crop varieties, and sowing dates shows significant effect on grain yield of wheat during both the study years (Table 4.1.12 b). The results indicate that the highest grain yield (5336.7 in 2019-20 and 5140.0 kg ha^{-1} in 2020-21) was obtained in AZRC Dera variety sown on 10th December and treated with K + AA combination. Contrarily, the lowest grain yield (2812.3 in 2019-20 and 2589.0 kg ha^{-1} in 2020-21) was recorded in untreated Paseena variety when sown on 10th January. These results suggest that the exogenous application PGRs could be an effective strategy for improving the grain yield of late sown wheat. Among different PGR combinations tested, application of K + AA was found most effective in increasing grain yield due to its positive effects on cell elongation, cell division and photosynthesis, which ultimately lead to an increase in grain yield. Ragaey et al. (2022) also noted that wheat plants grown under stress showed a significant reduction in yield attributes and morphological traits compared to that treated with PGRs. The higher grain yield of AZRC Dera might be attributed to its genetic makeup, which is better adapted to the local growing conditions, as well as its higher nutrient uptake and utilization efficiency, better resistance to biotic and abiotic stresses, and better agronomic performance compared to Paseena variety. A genotype is considered flexible when it can function well under any stochastic environmental circumstance (Ober et al., 2021). Crops grown under late sowing conditions without application of PGRs are subjected to lower temperatures up to the booting stage, which can have a negative impact on grain growth (Singh et al., 2011).

Table. 1: Comparison of treatment means for plant height, number of tillers, grains spike^{-1}, Chlorophyll content and 1000 grains weight.

Sowing dates	Varieties	PGRs	Plant height (cm)		Number of tillers		Grains spike^{-1}		Chlorophyll content (Spade)		1000 grains weight (g)	
			2019-20	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**	**2019-20**	**2020-21**
10th December	**AZRC Dera**	**AA+GA**	89.0 ab	89.6 a	315 de	304 cd	37.1 d	35.3 c	44.3 bc	46.0 cd	38.8 d	36.8 a-d
		GA+K	87.0 bc	85.6 b	328 c	315 b	38.4 bc	36.2 b	40.3 c-e	36.6 hi	39.3 c	37.4 a-d
		K+AA	85.6 c	84.0 bc	341 a	327 a	39.9 a	37.8 a	48.3 ab	46.3 cd	40.6 a	38.6 ab
		AA+GA+K	91.6 a	88.3 a	335 b	335 a	39.0 b	37.8 a	51.0 a	53.3 a	40.1 b	38.9 a
		Control	82.0 d	83.6 bc	313 e	298 de	35.9 e	34.0 d	33.3 gh	28.3 kl	37.9 f	35.9 a-d
	Paseena	**AA+GA**	84.6 cd	84.0 bc	305 f	291 ef	34.7 fg	32.8 ef	41.3 c-e	39.6 f-h	37.0 h	38.1 a-c
		GA+K	79.0 e	80.6 de	299 g	285 fg	35.2 f	33.4 e	40.3 c-e	39.0 f-h	37.5 g	35.5 a-d
		K+AA	77.6 e	80.3 e	321 d	310 bc	37.8 c	35.9 b	47.3 ab	50.6 ab	39.3 c	37.3 a-d
		AA+GA+K	82.0 d	83.0 cd	312 e	301 d	36.5 d	34.6 cd	51.6 a	49.0 bc	38.4 e	36.4 a-d
		Control	78.0 e	78.3 e	286 i	274 hi	34.2 gh	32.3 fg	37.0 e-g	28.3 kl	36.5 i	34.6 a-d
10th January	**AZRC Dera**	**AA+GA**	70.0 f	70.3 fg	266 i	253 kl	32.5 kl	30.6 jk	38. d-g	41.0 e-g	35.0 l	33.1 a-d
		GA+K	72.0 f	70.6 fg	279 j	267 ij	33.5 ij	31.6 hi	30.3 hi	29.3 jk	35.9 j	33.9 a-d
		K+AA	64.6 g	64.6 h	293 h	279 gh	33.7 hi	31.8 gh	39.6 c-f	37.3 g-i	36.0 j	34.0 a-d
		AA+GA+K	72.0 f	72.6 f	280 j	266 j	33.1 jk	31.2 h-j	40.0 c-f	42.6 d-f	35.43 k	31.5 d
		Control	62.0 gh	63.67 h	259 m	246 lm	32.1 lm	30.2 kl	26.0 i	24.3 l	34.1 n	32.0 b-d
	Paseena	**AA+GA**	70.0 f	70.0 g	253 mn	233 n	31.6 mn	29.1 n	39.6 c-f	36.6 hi	33.3 op	31.3 d
		GA+K	63.3 gh	62.6 h	252 n	240 mn	31.6 mn	29.9 lm	27.3 i	25.0 l	33.6 o	31.7 cd
		K+AA	60.6 h	63.7 h	272 k	261 jk	33.0 jk	31.1 ij	42.3 cd	45.0 c-e	35.3 kl	33.4 a-d
		AA+GA+K	63.3 gh	63.3 h	265 l	265 j	32.1 lm	30.3 kl	35.3 fg	33.3 ij	34.5 m	32.6 a-d
		Control	62.0 gh	63.0 h	246 o	241 mn	31.1 n	29.5 mn	29.66 h	25.6 kl	33.2 p	31.5 cd
$LSD_{0.05}$			**2.90**	**2.40**	**6.088**	**7.823**	**0.604**	**0.656**	**4.684**	**4.028**	**0.387**	**6.686**

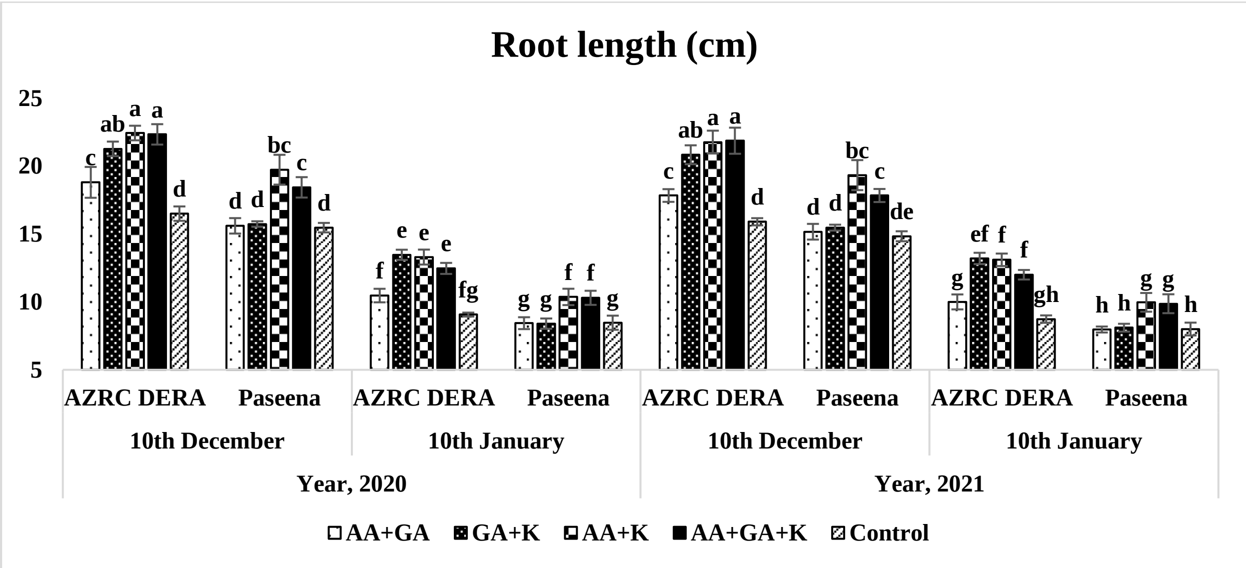

Figure. 3 Root length (cm) as affected by exogenous application of PGRs, crop varieties and sowing dates in late sown wheat.

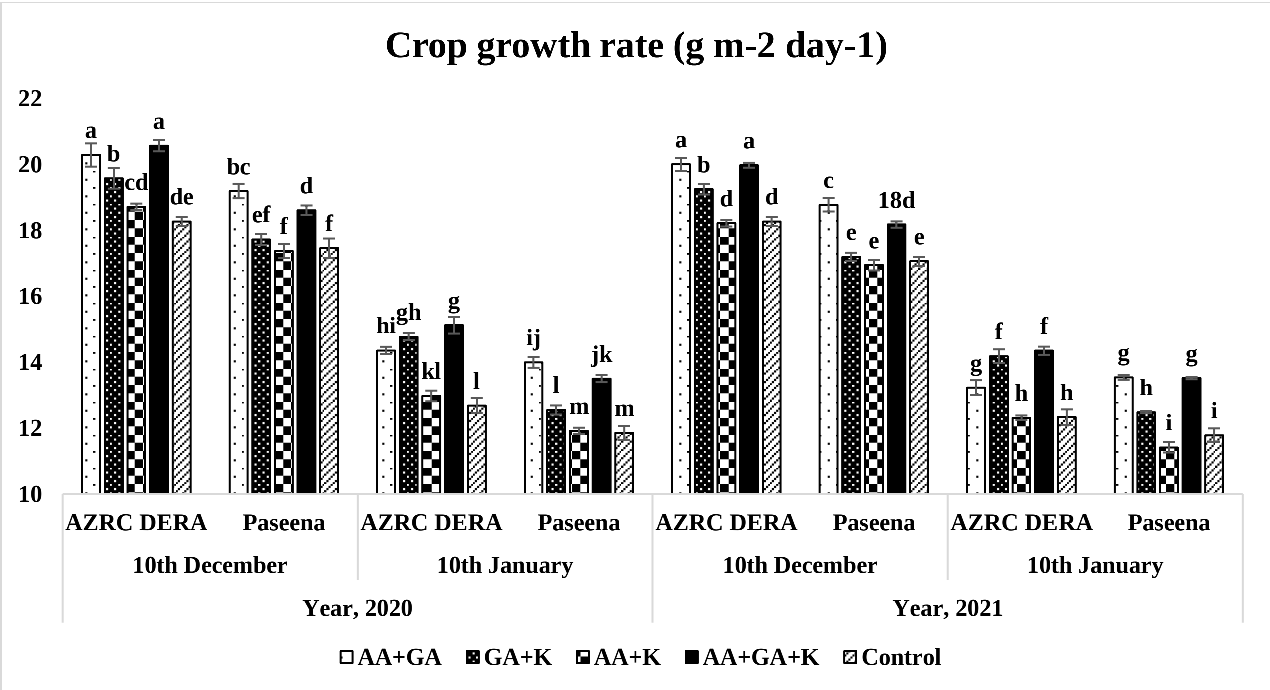

Figure. 4 Crop growth rate (g m^{-2} day^{-1}) as affected by exogenous application of PGRs, crop varieties and sowing dates in late sown wheat.

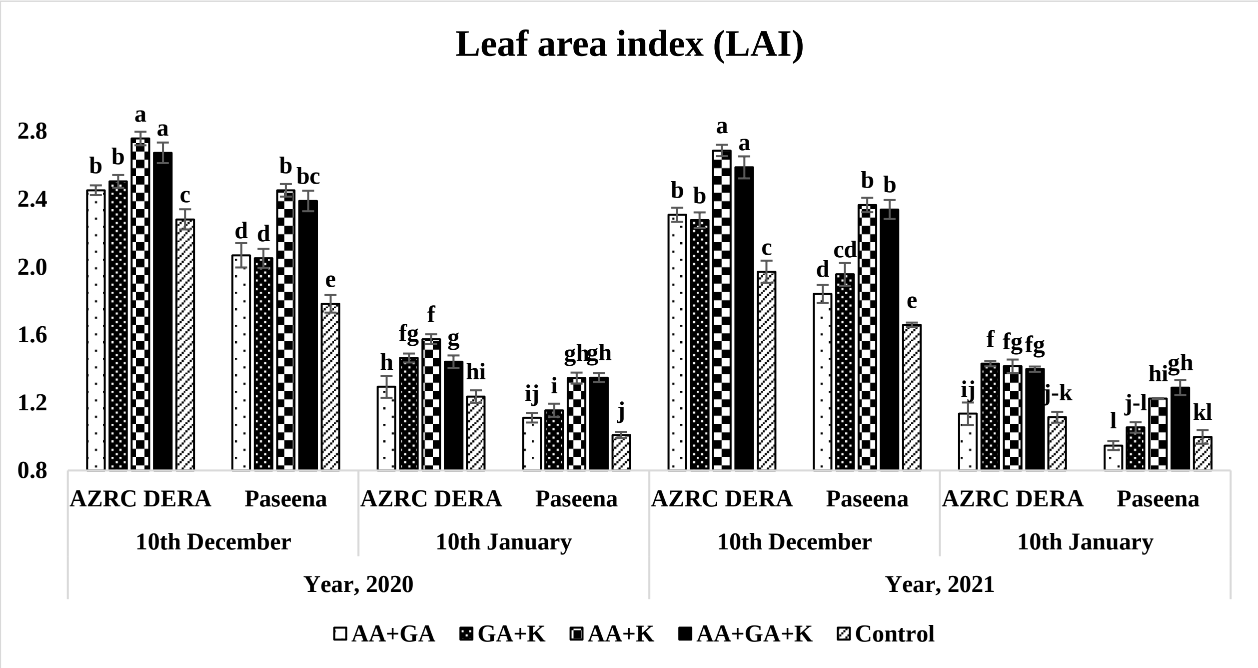

Figure. 5 Leaf area index (LAI) as affected by exogenous application of PGRs, crop varieties and sowing dates in late sown wheat.

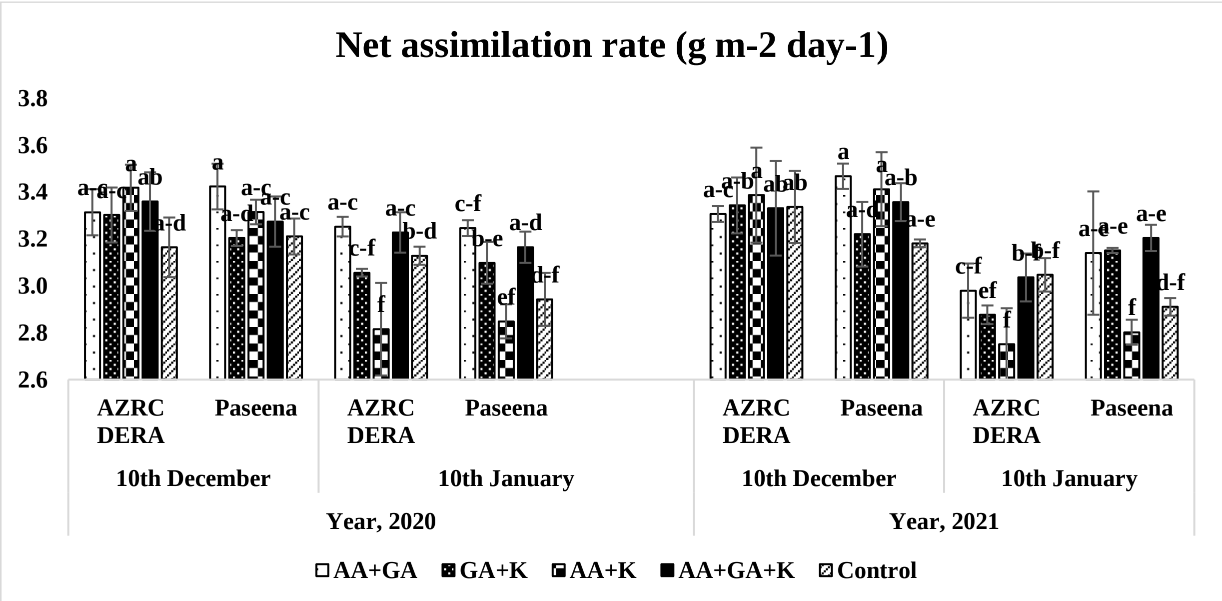

Figure. 6 Net assimilation rate (g m^{-2} day^{-1}) as affected by exogenous application of PGRs, crop varieties and sowing dates in late sown wheat.

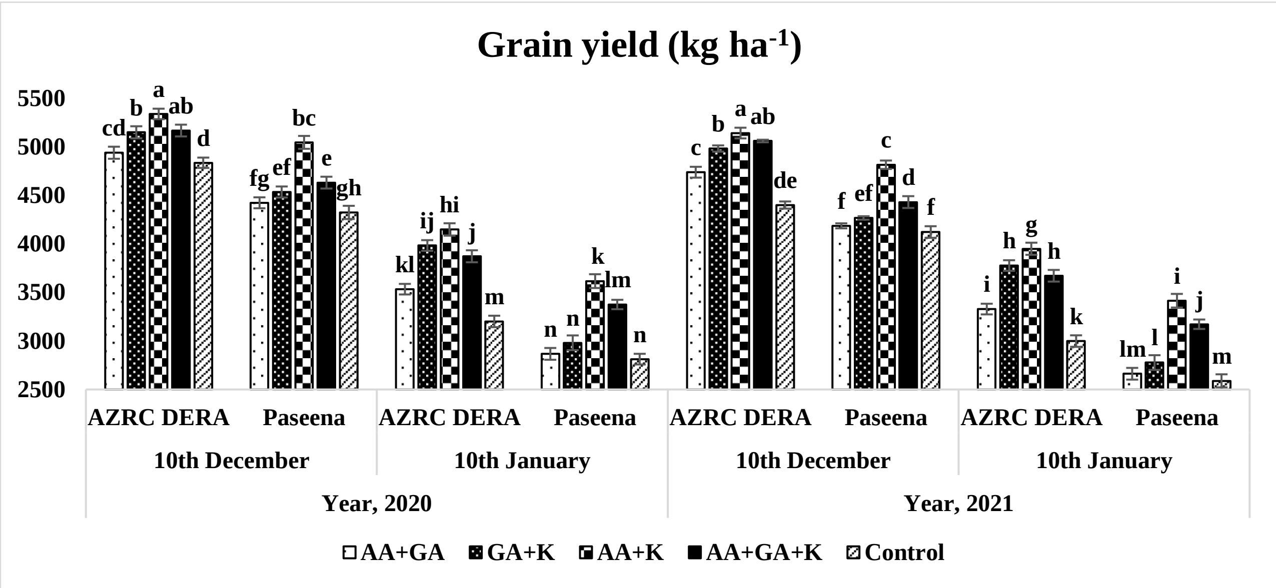

Figure. 7 Grain yield (kg ha^{-1}) as affected by exogenous application of PGRs, crop varieties and sowing dates in late sown wheat.

Conclusion and Recommendation

Based on the present research findings, it is concluded that the foliar spray of AA + GA + K, or K + AA was found best among all the PGRs combinations tested under late sown crop conditions. As far as the use of microbes is concerned, it was found that biozote excelled all other microbes used in this study for seed treatment to enhance crop productivity. Among crop varieties, AZRC Dera was found best than Paseena variety by showing best growth and yield attributes under late sown conditions. Based on two-years research trials on wheat (after the late harvest of cotton, rice, and sugarcane), the following recommendations are made: (i) A foliar spray of either AA + GA + K or AA + K combination during the tillering stage is recommended to enhance growth and improve wheat yield in order to mitigate the effects of terminal heat stress under late sown conditions, and (ii) AZRC Dera variety is recommended for cultivation in areas where wheat is sown late after the harvesting of cotton, rice, and sugarcane. This variety thrives best under late sown conditions.

Disclosure of potential conflicts of interest

No potential conflict of interest was reported by the author(s).

Acknowledgement

We acknowledge the contribution of Director General, Arid Zone Research Centre, Dera Ismail Khan and the Institute of Plant Nutrition and Soil Science, Kiel University, Germany.

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