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EFFECT OF SEED RATE ON GROWTH AND YIELD OF WHEAT (*TRITICUM AESTIVUM* L.) GENOTYPES UNDER RAINFED CONDITIONS

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ABSTRACT

Seed rate is a key agronomic factor that plays a vital role in determining wheat yield and grain quality. In wheat-based cropping systems, it is an adjustable management practice that can be optimized to suit specific growing conditions. However, the inappropriate or excessive use of seed rate increases production expenses and may negatively affect crop performance, ultimately reducing both yield and grain quality. The field study was conducted to assess the effect of four seed rates (75, 100, 125 and 150 kg ha⁻¹) on the growth, phenology and yield of nine wheat (NR-595, NR-613, NR-616, NR-617, NR-618, NR-619, NR-622, Wafaq-23 and NARC-Super) genotypes. Significant variations were observed among genotypes and seed rate treatments for germination percentage, coleoptile length, plant height, spike traits, tillers m⁻², days to heading, days to maturity, plant population and grain yield. Seed rate significantly influenced the growth, phenology, and yield attributes of the tested wheat genotypes. The highest coleoptile length (8.01 cm) was recorded in NR-616 under 100 kg ha⁻¹ (S₂), while spike length ranged from 10-12 cm. Genotype NR-622 showed the longest maturity duration (174 days) under 75 kg ha⁻¹, whereas NR-618 reached heading and maturity earlier under S₂. The 100 kg ha⁻¹ seed rate improved coleoptile length (14-18%) and spike length (≈20%) compared with other treatments. It also enhanced spikelets per spike, tillers m⁻², plant population and grain yield, with the highest yield recorded in NR-618 under S₂. Overall, 100 kg ha⁻¹ proved optimal seed rate for improving wheat growth and yield.

Keywords: Wheat; Seed rates; Genotypes; Yield; Food security.

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INTRODUCTION

Bread wheat is one of the major cereal crops in the world in terms of contribution to global nutrition supply for humans and livestock as well as land coverage and production (Levy & Feldman, 2022). There are many factors affecting the yield and quality of wheat majorly the climate change and environmental stresses, but incorporating improved agronomic techniques such as irrigation, seed selection, optimum seeding rate, fertilizers application, sowing and harvesting time etc. can mitigate the adverse effects of

climate change (Zahra et al., 2023).

Plant density is a paramount factor ascertaining the crop potential to utilize soil resources and generate higher yield. It can be achieved by applying efficacious agricultural practices which are suitable seeding rate and sowing time (Zawar et al., 2024). Application of different seeding rates has significant effects on yield and yield components of new wheat varieties. Improper and unplanned use of seeding rate not only increases production costs but usually decrease wheat grain yield (Shah et al., 2020). Optimum seed rates,

date of sowing, plant population and suitable cultivars plays an important role in achieving potential yield of wheat and it is under farmer's control in most of the farming systems (Zecevic et al., 2014). Higher seeding rates are responsible for the reduced tiller development, thus produce more main stem spikes which is beneficial for the varieties which tend to generate minimum tillers. Similarly, if the seed rate exceeds the optimum limit, there is reduction in yield in most of the cases (Naseri et al., 2012). Moreover, there is a close correlation exists between wheat stands and yield components. The seed rate escalated with delayed sowing due to poor plant stand, and increased seed rate results in a higher number of plants per unit area initiating high intra-crop competition thus deteriorating the overall yield and increase the production cost (Twizerimana et al., 2020). But lower seed rate produces fewer plants per unit area resulting in much vegetative growth and space wastage which ultimately affect the final grain yield (Fazily, 2021).

The seeding rate and sowing time are the two most controllable methods which can affect the entire outcome of cropping season by impacting the whole plant growth complex and developmental stages. When the optimum seeding rate is employed, it results in suitable plant density which is favourable for plants to use minerals, water, sunlight and other soil resources efficiently (Ma et al., 2018). Higher plant density increases interplant competition for extracting nitrogen and moisture from soil. The lesser seed rates decrease the interplant competition at vegetative stages, while it can escalate the intra-plant competition due to high number of tillers at grain formation stage. Similarly, higher seed rates result in much elevated plant height, non-productive stems, root biomass, and reduced leaf area in winter wheat varieties (Poltoretskyi et al., 2020). The coupling of seeding rate and sowing time with proper fertilizers application, disease control and proper irrigation can help the plants to overcome the unfavourable conditions and lead to higher grain yield (Butkovskaya & Kozulina, 2021). Thus, each variety should be tested with different seeding rate in a particular area to determine the optimum seed rate for that variety. There should be a mandatory practice employed in breeding programs before seed release that is to test a cultivar with varied seeding rate to optimize the best seeding rate (Abboye & Teto, 2020).

The seeding rate should be set based on the environmental conditions and numerous studies conducted across the world have suggested the optimum seeding rate based on the climatic conditions and seed variety. The optimum seeding rate is dependent upon the environmental conditions and suggested 191 plants per square meter in high yield

environment and 397 plants per square meter in low yield environment (Zecevic et al., 2014; Bastos et al., 2020). Moreover, it is reported that when seed rate was increased from 50 kg ha⁻¹ to 150 kg ha⁻¹ the grain yield was high as compared to seeding rate of 200 kg ha⁻¹ at which grain yield was slightly decreased. The previous literature suggested 100 kg ha⁻¹ seed rate for high grain yield in Pakistan (Akhter et al., 2017). However, there is least data about the optimization of seeding rate based on climatic conditions and variety from Pakistan. The current study is designed to determine the optimum seeding rate for obtaining the highest grain yield from advance lines/genotypes of wheat crop.

MATERIALS AND METHODS

Locality

The field experiment was laid out at the research area (33° 42' N, 73° 10' E) of Wheat Program, Crop Sciences Institute, NARC, Islamabad, Pakistan during cropping season 2024-25.

Plant material

The seed of commercial bread wheat varieties and advance lines were collected from the Wheat Program, Crop Sciences Institute, NARC Islamabad for this experiment.

Experimental Design

Randomized completed block design in split treatment structure was used to perform the experiment with three replications and a net plot size of 7.5 m² was used.

Physiochemical Traits of Experimental Site

Soil samples were randomly collected before sowing from depths of 0 to 15 cm and 15 to 30 cm with the help of augur, mixed samples of different depths distinctly, made composite, and treated to record physiochemical characteristics (ICARDA, 2013) (Table 1).

Weather Elements

Weather data regarding temperature ranges, rainfall, humidity etc. were collected and summarized (Table 2).

Treatments

Nine wheat genotypes: NR-595, NR-613, NR-616, NR-617, NR-618, NR-619, NR-622, Wafaq-23 and NARC-Super were tested. Four seed rates (75 kg ha⁻¹, 100 kg ha⁻¹, 125 kg ha⁻¹ and 150 kg ha⁻¹) were tested for each variety. The genotypes were sown in main plot while seed rates were allotted to the sub plots.

Agronomic Managements

Sowing was done through hand drill by maintaining R × R distance of 22.5 cm. Phosphorus and Nitrogen at the rate of 60 kg ha⁻¹ and 75 kg ha⁻¹, respectively were applied as band placement in soil at sowing, while 75 kg nitrogen per hectare was applied with first rain. The row length was 5

meters. The row-to-row distance was 25 cm apart. The number of rows in each plot was six. Weedicides Axil and Alymax were applied in the months of December and

January to control weeds. All other agronomic managements were maintained uniform for entire experiment and over years.

Table 1: Chemical analysis of soil before sowing of crop.

Characteristics	Unit	Value	
Depth of sample	Cm	0-15	15-30
Texture	-	Clay Loam	
pH	-	8.00	8.00
Sand	%	33.78	33.78
Silt	%	34.12	34.12
Clay	%	32.23	32.23
EC	dSm ⁻¹	1.05	0.96
Organic matter	%	0.35	0.77
Nitrogen (N)	%	0.058	0.053
Phosphorus (P)	ppm	3.2	2.9
Potassium (K)	ppm	180	180

Table 2: Monthly averages of weather elements for wheat growing season.

Weather elements	Years	October	November	December	January	February	March
Maximum temperature (°C)	2024-25	31.00	25.27	19.42	20.42	21.14	25.00
Minimum temperature (°C)		16.39	10.70	3.29	3.74	7.11	10.23
Rainfall (mm)		62.13	0.00	0.00	1.38	76.04	41.53
Pan evaporation (mm)		3.31	1.92	1.53	1.90	2.71	3.78
Average relative humidity (%)		66	63	57	60	60	59
Wind speed (km h ⁻¹)		34.70	25.12	36.77	47.39	58.57	56.59

Parameters

Data was collected for traits such as germination %age (m⁻²), coleoptile length (cm), plant height (cm), leaf area (m⁻²), spike length (cm), spikelet per spike, nodes per stem, tillers m⁻², days to 50% heading, days to maturity, plant population (m⁻²) and grain yield (kg ha⁻¹).

Statistical Methodology

Fisher Analysis of Variance was employed to determine significance of treatments at 5% probability level. Inference beyond ANOVA was comprised of comparison of means of treatments using Tukey's Honestly Significant Difference (HSD) test. The software STATISTIX 8.1 was employed in statistical analysis (Steel et al., 1997).

RESULTS

This experimental study examined key growth and yield parameters of wheat, including germination %age, coleoptile length, plant height, leaf area, spike length, spikelet per spike, nodes per stem, tillers m⁻², days to 50% heading, days to maturity, plant population and grain yield of nine different wheat genotypes. These characteristics were evaluated under four different seed rate treatments. All

under tested wheat varieties showed variations in their germination rates and coleoptile length under different seed rate treatments. Highest germination rate was observed in NR-618 with 100 kg ha⁻¹ (S₂) treatment followed by NR-616 and NR-622 on the same seed rate treatment. Lowest germination in all seed rate treatments were observed in NR-595 and NARC Super. Likewise coleoptile length was measured in NR-618 (4.08 cm) and NR-616 (8.01 cm) under S₂ treatment. However lowest coleoptile length was measured in NARC Super under all seed rate treatments (Figure 1).

Seed rate 125 kg ha⁻¹ (S₃) and 150 kg ha⁻¹ (S₄) both had also played their role in obtaining better seed germination and coleoptile length after S₂ in all wheat genotypes. Maximum plant height was measured in NR-618 under S₂ seed rate followed by NR-618. Meanwhile, wheat genotypes also showed higher plant heights under S₃ and S₄ seed rates as well. Comparing all the seed treatments and genotypes, NR-619 showed minimum plant height under all seed rate treatments. However, highest leaf area was noted in NR-618 while NR-616 and NR-622 retained highest leaf areas under S₂ seed rate treatment. Comparing the seed treatments in

plant height and leaf area, 75 kg ha⁻¹ (S₁) seed rate showed minimal values in all genotypes (Figure 2).

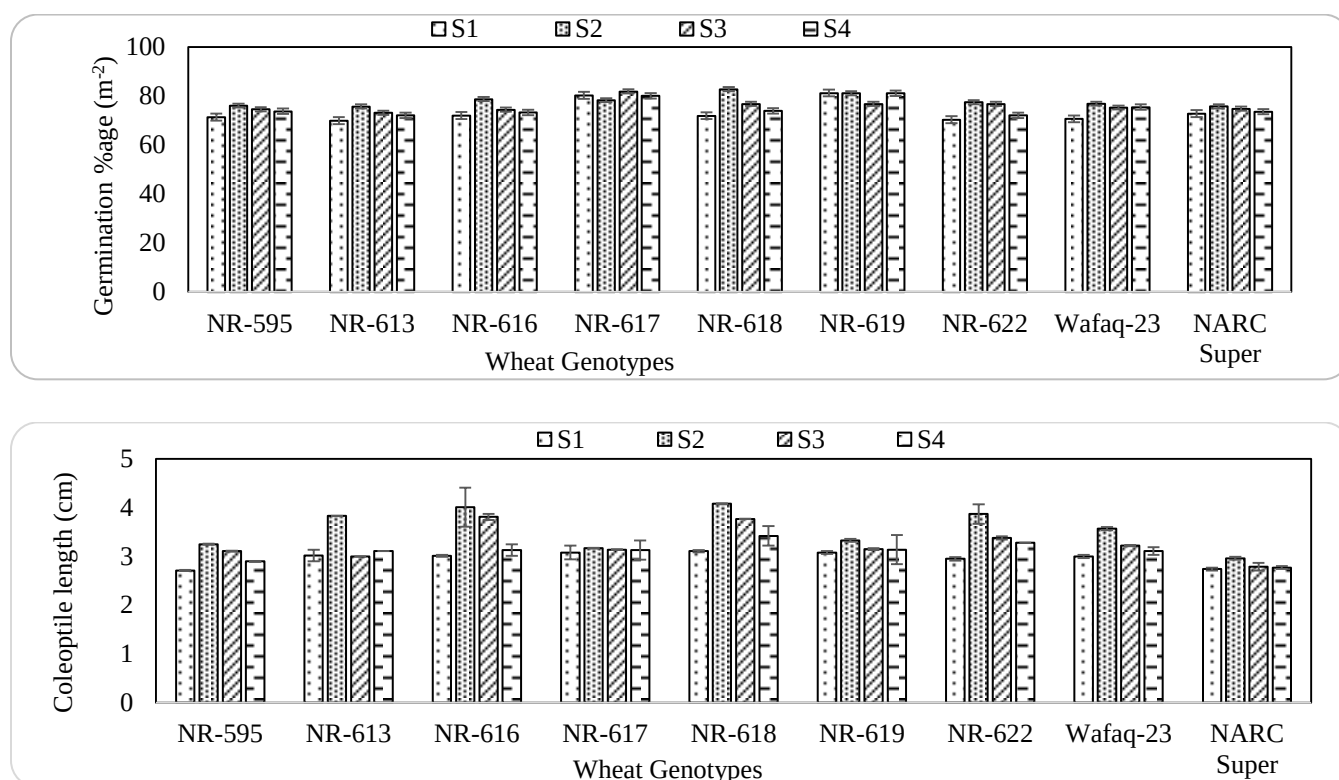


Figure 1: Performance of wheat genotypes under different seed rate treatments on germination and coleoptile length.

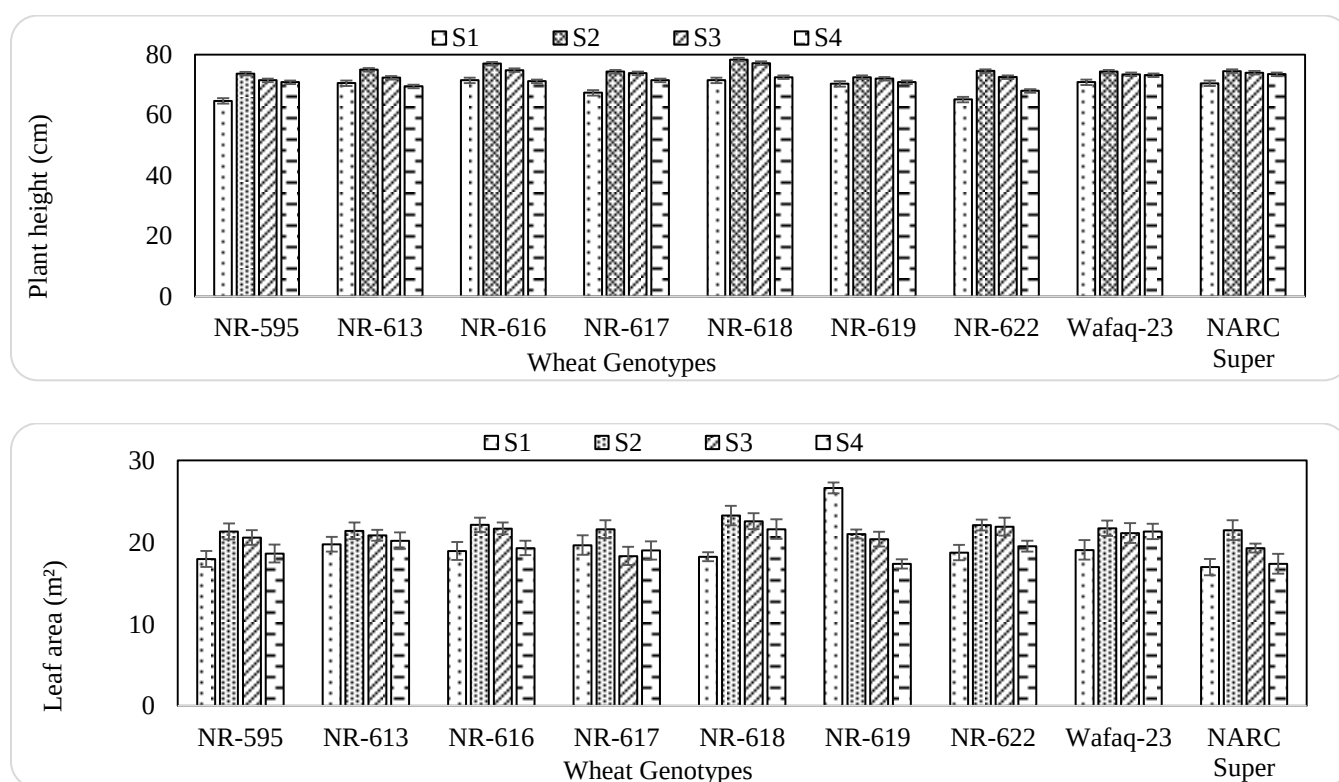


Figure 2: Performance of wheat genotypes under different seed rate treatments on plant height and leaf area.

Spike related traits also showed varied responses in different wheat genotypes as well as under different seed rates. However, NR-618 and NR-617 retained highest spike lengths under S_2 seed rate followed by NR-622. Minimum spike length was measured in NARC-Super under S_1 seed rate. Over all spike length ranged between 10-12 cm in all under studied wheat genotypes and seed rates. Likewise, spikelets per spikes were also produced by NR-618 under S_2 seed rate. However, lowest spikelets per spike were produced by NARC-Super and NR-617 under all seed rate treatments (Figure 3).

Growth traits such a nodes per stem and number of tillers also showed variations under different seed rate treatments. Maximum nodes per stem were reported in NR-618 followed by NR-616 under S_2 seed rate. However, S_3 seed rate of both these genotypes produced second highest nodes per stem. Meanwhile, S_1 seed rate produced minimum nodes per stem in all wheat genotypes. Highest number of tillers were noted in NR-613 and NR-618 under S_2 seed rate. Lowest number of tillers was counted in NARC-Super under S_1 seed rate treatment (Figure 4).

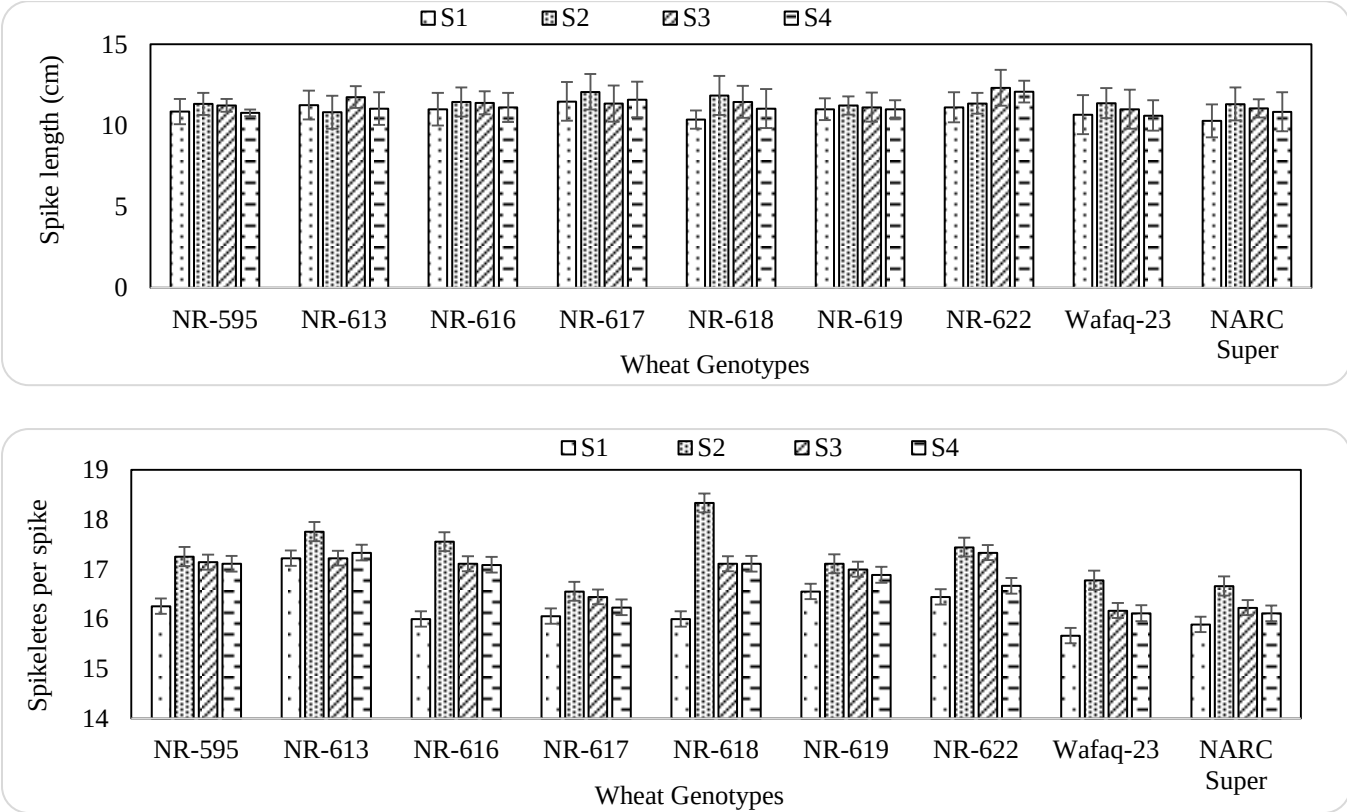
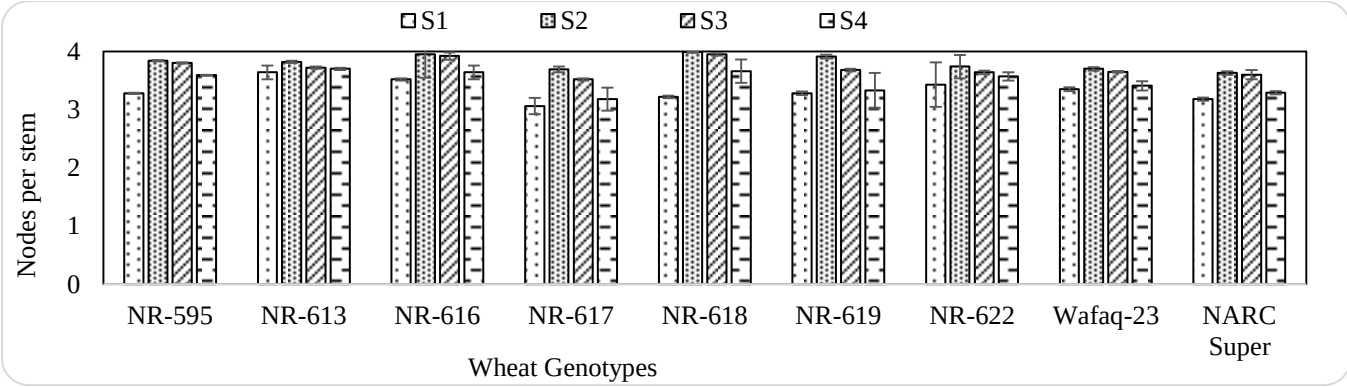


Figure 3: Performance of wheat genotypes under different seed rate treatments on spike length and spikelets per spike.



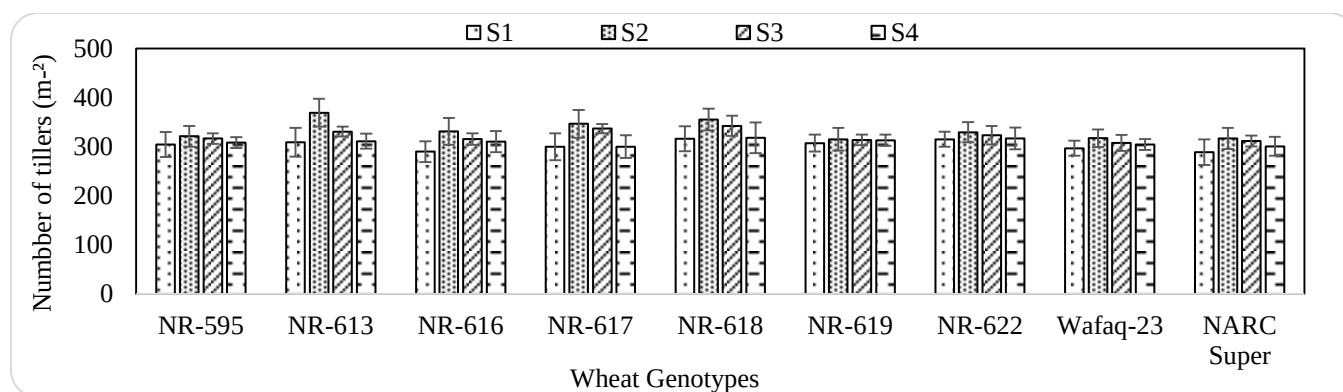


Figure 4: Performance of wheat genotypes under different seed rate treatments on nodes per stem and number of tillers.

Days to heading and days to maturity showed reverse response as compared to other growth and yield traits. The S₁ seed treatment showed delayed maturity and days to 50% flowering, NR-622 took maximum time to mature, i.e. 174 days under S₁ treatment followed by NARC-Super. Wheat varieties NR-595 and NARC-Super took maximum days to 50% heading under S₁ treatment compared to other varieties and treatments. However, NR-618 took minimum time to achieve 50% heading and maturity under S₂ (Figure 5).

Plant population also varied among different wheat genotypes and seed rate treatments. Highest plant population was determined in NR-618 followed by NR-616 and NR-622 under S₂ seed treatment. The 125 kg ha⁻¹ produced more plants and showed higher plant populations as well as grain yield in all wheat genotypes with 100 kg ha⁻¹. Highest grain yield was measured in NR-618 under S₂ treatment. NR-616 also produced better grain yield under S₂ treatment (Figure 6).

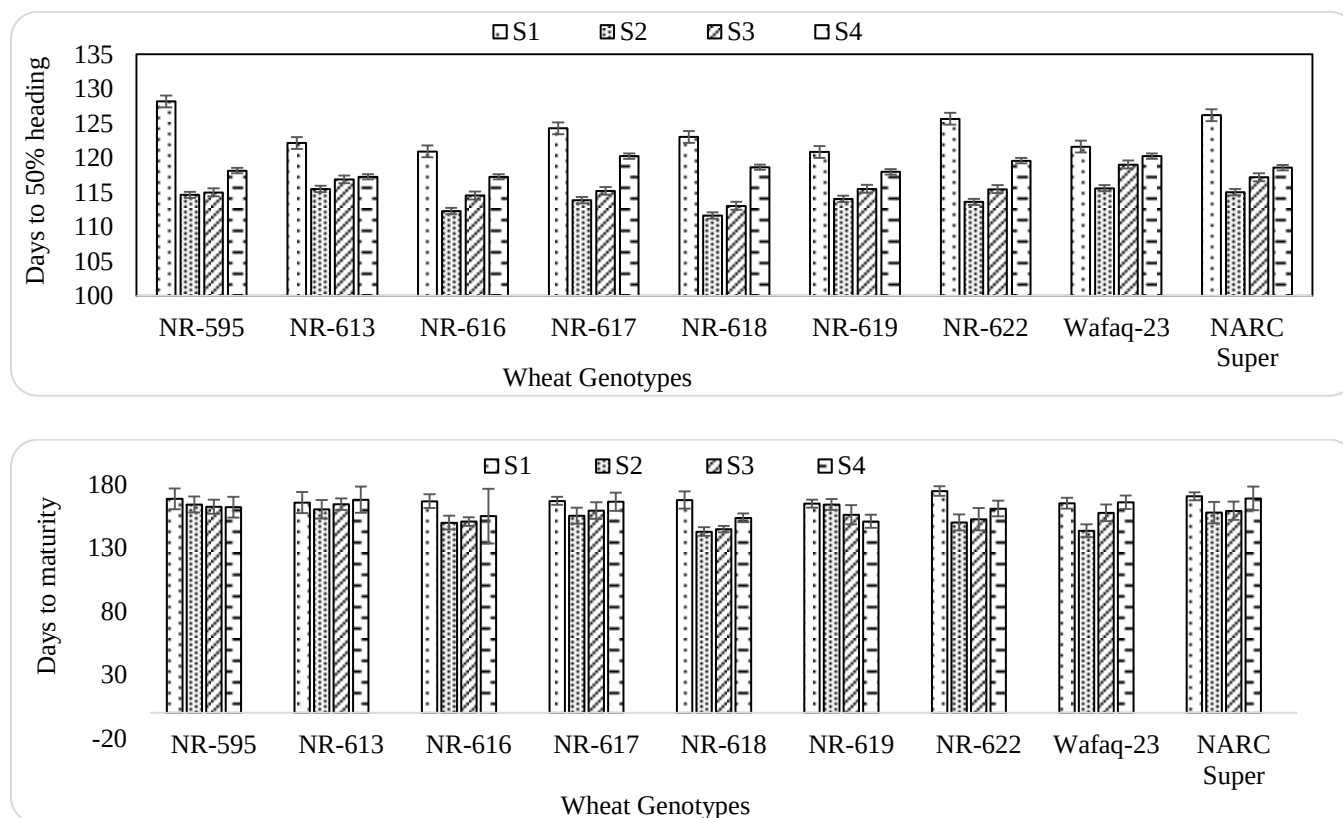


Figure 5: Performance of wheat genotypes under different seed rate treatments on days to 50% heading and days to maturity.

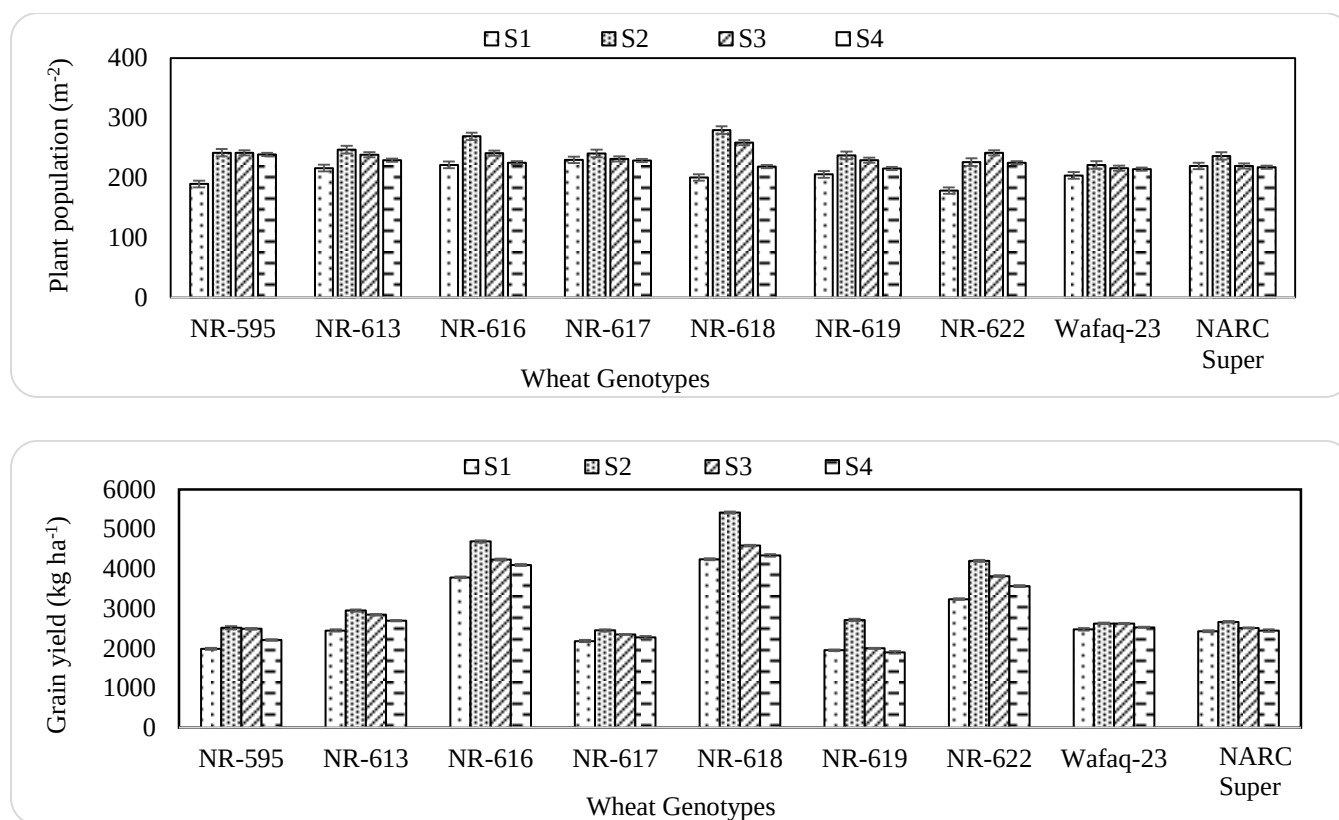


Figure 6: Performance of wheat genotypes under different seed rate treatments on plant population and grain yield.

DISCUSSION

The quadratic yield response observed in this study confirms that wheat productivity is governed by density-dependent compensatory mechanisms. Grain yield peaked at 100 kg ha⁻¹, indicating that this seed rate achieved an optimal balance between individual plant performance and stand level resource capture. This response reflects the classical yield-density relationship described in crop ecology, where yield initially increases with density due to greater light interception but declines once inter-plant competition exceeds the compensatory capacity of the crop (Sadras et al., 2019; Sala, 2019; Fischer et al., 2022). At lower density (75 kg ha⁻¹), reduced plant population limited canopy closure, resulting in suboptimal radiation interception during early vegetative growth (Reynolds et al., 2022).

Conversely, excessive densities (125-150 kg ha⁻¹) intensified asymmetric competition for light. Dense canopies reduce light penetration to lower leaves, decreasing photosynthetic efficiency and accelerating leaf senescence. Increased respiratory costs and stem elongation responses under crowding stress may divert assimilates away from spike development (Casal & Fankhauser, 2023). This mechanism explains why increasing the number of

plants beyond a threshold did not proportionally increase plant yield. Importantly, the reduction in yield at supra-optimal densities suggests that wheat compensation mechanisms (e.g. tiller abortion, spikelet adjustment) were insufficient to offset competitive stress. Compensation capacity varies among genotypes and is strongly influenced by assimilate availability during the critical period for grain number determination (Terrile et al., 2021).

The significant reduction in days to heading (9 days) and maturity (17.8 days) under higher seed rates provides evidence of density-induced phenological plasticity. High density stands alter canopy spectral quality, particularly reducing the red:far-red light ratio, which activates phytochrome-mediated shade avoidance pathways (Casal & Fankhauser, 2023).

Genotype-specific differences were notable in the wheat varieties. Wheat genotype NARC-Super exhibited a stronger phenological sensitivity to density stress, suggesting variation in photomorphogenic responsiveness among genotypes. Such variability highlights the need to integrate plant density management with genotype-specific developmental traits. The superior and stable performance of NR-595 across seed rates indicates strong phenotypic plasticity. Phenotypic plasticity allows a genotype to adjust

tillering, spike fertility and biomass allocation in response to plant density. High performing modern wheat cultivars typically possess balanced tillering capacity, efficient assimilate translocation, and strong spike fertility (Fischer et al., 2022). NR-595 combined high tiller number (335.75 m^{-2}) with superior spikelet number per spike (17.62), suggesting both high sink potential and efficient source capacity. Yield stability under density variation is often linked to maintenance of fertile tillers rather than production of excessive tillers (Khan et al., 2020). Tiller survival during the stem elongation phase is strongly dependent on carbohydrate availability and nitrogen status (Beauchamp et al., 2022).

In contrast, NR-619 exhibited density sensitivity, particularly at higher seed rates. High-yielding genotypes maintained productive tillers with high spike fertility. Recent research emphasizes that yield is more strongly associated with tiller survival rate and spike fertility index than with maximum tiller production (Reynolds et al., 2022). The genotype Wafaq-23 achieved high yield despite moderate tiller density (314.25 m^{-2}), suggesting an efficient assimilate partitioning during the critical pre-anthesis phase (Fischer et al., 2022). Modern wheat ideotypes increasingly focus on optimizing spike fertility and harvest index rather than maximizing vegetative biomass.

Optimal density maximizes sink establishment without restricting source activity. At high seed rates, sink establishment per unit area may increase initially, but source limitation during grain filling can restrict final kernel weight. Conversely, at low seed rates, source capacity per plant is high, but total sink number per area is insufficient. The moderate plant populations observed in NR-595 (223.17 m^{-2}) suggest that optimal yield does not require maximum stand density but rather balanced source sink relationship (Li et al., 2020). This aligns with recent modeling studies demonstrating that maximum radiation use efficiency occurs at intermediate plant densities (Reynolds et al., 2022). Accelerated maturity at high density raises concerns regarding grain quality. Reduced grain filling duration may decrease thousand-kernel weight and alter protein concentration. High density stands also often dilute nitrogen per grain due to increased biomass demand (Slafer et al., 2023).

The findings of the present study demonstrate that wheat yield optimization requires balancing plant population, canopy structure, and genotype-specific plasticity. Intermediate seed rates maximize radiation interception while minimizing competitive stress. Genotypes with strong tiller retention, erect leaf architecture, and stable phenology

exhibit superior adaptability to density variation. These results contribute to precision agronomy strategies and support the development of genotype specific density recommendations for sustainable wheat intensification.

CONCLUSION

In conclusion, this study shows that to achieve high wheat yield, it is important to choose the right seed rate for each wheat variety. The results showed that 100 kg ha^{-1} (S_2) consistently produced superior results in terms of germination, coleoptile length, plant height, leaf area, spike characteristics, tiller number, plant population and grain yield. Genotype NR-618 showed the best overall performance under S_2 , followed by NR-616 and NR-622. In contrast, the lowest seed rate 75 kg ha^{-1} (S_1) resulted in delayed heading and maturity along with reduced growth and yield traits. Therefore, a seed rate of 100 kg ha^{-1} is recommended for achieving optimal growth and maximum grain yield in the tested wheat genotypes.

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