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Physiological Response of Triticale (× *Triticosecale* Wittmack) Cultivars to Different Seeding Rates

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ABSTRACT

A field experiment was conducted during winter of 2023–2024 at the Agricultural Research Station, College of Agriculture, University of Basra. The response of four triticale (× *Triticosecale* Wittmack) cultivars, namely, Admiral, Farah, Amal 7 and Almohanad, to different seeding rates (140, 160 and 180 kg ha^{-1}) was evaluated with regard to physiological growth characteristics and yield performance. The experiment was designed as a randomised complete block design with a split-plot arrangement, which was replicated three times. Seeding rates were assigned to the main plots, whilst cultivars were allocated to the subplots. Results revealed significant differences amongst triticale cultivars for most of the studied traits. The Farah cultivar exhibited superior performance, with the highest plant height (126.25 cm), flag leaf area (51.69 cm^2), leaf area index (4.01), leaf area duration (146.70 day^{-1}), crop growth rate (23.11 g m^{-2} day^{-1}), chlorophyll content in the flag leaf (83.39 mg g^{-1} fresh weight) and grain yield (5.53 t ha^{-1}). Increasing the seeding rate from 140 to 180 kg ha^{-1} led to a higher tiller density, reaching 634.40 tillers m^{-2}. Furthermore, a seeding rate of 160 kg ha^{-1} was found to optimise grain yield across all cultivars, achieving a maximum yield of 4.53 t ha^{-1}. Based on these findings, cultivating the Farah cultivar at a seeding rate of 160 kg ha^{-1} can enhance yield performance.

الاستجابة الفسلجية لأصناف القمح الشيلمي (X *Triticosecale Wittmack*) تحت تأثير معدلات البذار

علي حسيني و لمياء محمود
قسم المحاصيل الحقلية ، كلية الزراعة ، جامعة البصرة ، العراق

الخلاصة

أُجريت تجربة حقلية خلال الموسم الزراعي الشتوي 2023 -2024 في محطة البحوث الزراعية، كلية الزراعة، جامعة البصرة. لتقييم استجابة أربعة أصناف من القمح الشيلمي (× *Triticosecale* Wittmack)، وهي: أدميرال، وفرح، وأمل 7، والمهند، لمعدلات بذار مختلفة (140، 160، 180 كغم هكتار$^{-1}$)، من حيث خصائص النمو الفسيولوجية وأداء المحصول. صممت التجربة بتصميم القطاعات العشوائية الكاملة باسلوب القطع المنشقة، وبثلاثة مكررات. وضعت معدلات البذار في القطع الرئيسية، بينما وضعت الأصناف في القطع الثانوية. أظهرت النتائج فروقاً معنوية بين أصناف القمح الشيلمي في معظم الصفات المدروسة. حيث أظهر الصنف فرح أداءً متفوقاً، مع أعلى ارتفاع للنبات (126.25 سم)، ومساحة ورقة العلم (51.69 سم^{2})، ودليل المساحة الورقية (4.01)، ومدة بقاء الورقة فعالة (146.70 يوما$^{-1}$)، ومعدل نمو المحصول (23.11 غم$^{-1}$ م$^{-2}$ يوم$^{-1}$)، ومحتوى الكلوروفيل في ورقة العلم (83.39 ملغم غم$^{-1}$ وزن طري) وحاصل الحبوب (5.53 طن هكتار$^{-1}$). أدت زيادة معدل البذار من 140 إلى 180 كغم$^{-1}$ إلى زيادة عدد الاشطاء، حيث وصلت إلى 634.40 نبات$^{-1}$ م$^{-2}$. علاوة على ذلك، وُجد أن معدل البذار البالغ 160 كغم$^{-1}$ يحسن محصول الحبوب في جميع الأصناف، محققاً أقصى محصول قدره 4.53 طن هكتار$^{-1}$. وبناءً على هذه النتائج، فإن زراعة صنف فرح بمعدل بذار يبلغ 160 كغم هكتار$^{-1}$ يمكن أن يعزز أداء المحصول.

INTRODUCTION

Cereal crops are fundamental to global food security, serving as a cornerstone of agriculture because of their nutritional contributions. In light of the increasing global population and the ongoing challenges in agricultural sustainability, triticale (× *Triticosecale* Wittmack) has emerged as a viable solution to meet the rising demand for cereal grains whilst addressing the shortage of forage crops. This synthetic hybrid exhibits a remarkable capacity for growth in low-fertility soils and under suboptimal agricultural conditions, making it a resilient alternative to traditional cereals (Ehtaiwesh, 2022).

Triticale was developed through the hybridisation of wheat (*Triticum* spp.) and rye (*Secale cereale* L.), with the objective of combining the desirable traits of both parent species. This hybridisation has resulted in a crop with enhanced adaptability to environmental fluctuations and resistance to biotic and abiotic stresses. In addition, triticale demonstrates a high potential for forage and grain production, providing superior protein content and an improved amino acid profile compared with conventional cereals (Mergoum *et al.*, 2019; Muhammed & Mohammed, 2022). Furthermore, triticale differs from wheat and barley in several morphological and agronomic traits, including plant height, spike length and grain yield potential (Del Pozo *et al.*, 2023).

The global production of triticale has been continuously increasing, with estimates indicating that the harvested area reached 3,616,655 ha in 2022, yielding a total production of 14,157,880.72 tons and an average productivity of 3.9 ton ha^{-1} (FAO, 2024). However, triticale grain and forage production are influenced by environmental conditions and agronomic practices, including cultivar selection, fertilisation, seeding rate and planting date. These factors highlight the importance of optimising production techniques, particularly in the context of climate change and crop's adaptability to diverse agricultural environments. Given its expanding role in global agriculture, triticale requires scientifically informed field management practices to maximise yield potential.

Selecting genetically diverse cultivars in combination with optimised seeding rates is an effective strategy to enhance triticale productivity. Understanding the response of different cultivars to regional growing conditions is essential, as appropriate seeding rates can not only increase yield but also improve key physiological growth parameters. Evaluating these physiological criteria is crucial for analysing the factors influencing yield and its components. By assessing growth stages and dry matter accumulation, researchers can comprehensively understand plant development and productivity dynamics (Baygi *et al.,* 2017). Previous studies have demonstrated that variations in the growth characteristics of triticale cultivars can lead to remarkable differences in yield and its components (Rashid & Alwahid, 2023; El-Absy, 2024).
Variations in seeding rates directly affect plant density per unit area, thereby influencing the growth characteristics, yield and its components. Previous studies have demonstrated that differences in seeding rates can markedly affect crop growth and productivity. For example, Abbas and Omer (2022) and Abdullah and Khalaf (2023) reported that altering seeding rates led to notable variations in growth traits and yield. Similarly, Al-Hamidawi and Noaema (2024) found that seeding rate modifications influenced the growth characteristics and yield performance of rye cultivars.

Given the importance of optimising planting density to maximise triticale productivity, this study aims to identify the optimal seeding rate to improve the physiological traits and yield performance of four triticale cultivars.

MATERIALS AND METHODS

A field experiment was conducted during the 2023–2024 agricultural season at the Agricultural Research Station, College of Agriculture, University of Basra. This experiment aimed to evaluate the response of four triticale (× *Triticosecale* Wittmack) cultivars, namely, Admiral (V1), Farah (V2), Amal 7 (V3) and Almohanad (V4), to different seeding rates of 140 kg ha^{-1} (S1), 160 kg ha^{-1} (S2) and 180 kg ha^{-1} (S3). The experiment was designed as a randomised complete block design with a split-plot arrangement, which was replicated three times. Seeding rates were assigned to the main plots, whilst triticale cultivars were allocated to the subplots.
To assess soil properties, composite soil samples were randomly collected from different locations within the experimental field at a depth of 30 cm. These samples were analysed to determine the key physical and chemical characteristics (Table 1).

Table 1: Chemical and physical properties of experimental soil before seed sowing.

Traits	Value	Unit
EC	7.12	ds m^{-1}
PH	7.62	-
O.M.	2.05	g kg^{-1}
N	38.50	mg kg^{-1}
P	12.25	mg kg^{-1}
K	139.50	mg kg^{-1}
Sand	287.30	g kg^{-1}
Silt	596.70	g kg^{-1}
Clay	116.00	g kg^{-1}
Soil texture	Loamy silt	-

The experimental field was prepared for cultivation through ploughing, smoothing and levelling before being divided into three blocks in accordance with the experimental design. Each block was further divided into three main plots, with each main plot being subdivided into four subplots. Consequently, each block contained 12 experimental units, each measuring 2 m × 1.5 m, resulting in a total of 36 experimental units.

Nitrogen fertiliser was applied in the form of urea (46% N) at a rate of 120 kg ha^{-1} in two equal doses: the first dose at the seedling emergence stage and the second dose 60 days after planting. Phosphorus was applied at a rate of 80 kg ha^{-1} using triple superphosphate (46% P_2O_5). Irrigation and weeding were performed as necessary throughout the growing season. Harvesting was performed when 50%–75% of the plants had reached full maturity.

Traits studied:

In studying the physiological traits, plant samples were taken randomly from an area of 25 cm × 25 cm during the period that started in between the elongation and flowering stages.

1. **Plant height (cm)**
   Plant height was calculated as the mean of 10 randomly selected plants from each experimental unit at full heading.
2. **Flag leaf area (cm^2)**
   Leaf area was calculated as the mean of 10 plants selected randomly in the flowering phase in accordance with the following equation:
   Flag leaf area = leaf length × maximum width × 0.95 (Robertson and Giunta, 1994).
3. **Leaf area index**
   Leaf area index (LAI) was calculated by dividing the total leaf area of the plant by the area occupied by the plant (25 cm × 25 cm) area from each experimental unit in accordance with the following equation:
   LAI = Leaf area /Harvested area.
4. **Specific leaf weight (g cm^{-2})**

The specific leaf weight (SLW) was calculated as the mean of 10 randomly selected plants from each experimental unit at full heading in accordance with the following equation:

SLW = Dry weight of the flag leaf (g) / Flag leaf area (cm^2) (Aggarwal and Sinha, 1984).

5. **Leaf area duration (day):**

Leaf area duration (LAD) was calculated as follows (Hunt *et al.*, 1982):

LAD = (LAI 1 + LAI 2) × (T2 − T1) / 2,

where LAI 1 indicates the LAI at flowering, LAI 2 indicates the LAI at physiological maturity, T1 indicates the number of days to flowering, and T2 indicates the number of days to physiological maturity.

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

Crop growth rate (CGR) was calculated as follows (Hunt *et al.*, 1982):

CGR = (1/A) × (W2 − W1) / (T2 – T1),

where A indicates the land area, W2 indicates the dry weight at flowering; W1 indicates the dry weight in the elongation stage; T2 indicates the number of days to flowering, and T1 indicates the number of days to elongation.

7. **Relative growth rate (mg g^{-1} day^{-1})**

Relative growth rate (RGR) was calculated as follows (Hunt *et al.*, 1982):

RGR = (LnW2 – LnW1) / (T2/T1),

where LnW2 indicates the inverted natural logarithm of dry weight at flowering, and LnW1 indicates the inverted logarithm of dry weight in the elongation phase.

8. **Net photosynthetic rate (gm m^{-2} day^{-1})**

Net photosynthetic rate was calculated as follows (Hunt *et al.*, 1982):

NAR = (W2 –W1) / (T2 – T1) × (log LA2 – log LA1) / (LA2 – LA1),

where W1 indicates the dry weight at elongation, W2 indicates the dry weight at flowering, T1 indicates the number of days to elongation, T2 indicates the number of days to flowering, LA1 indicates the leaf area at elongation, and LA2 indicates the leaf area at flowering.

9. **Chlorophyll content in flag leaf (mg 100 g^{-1} fresh weight [FW])**

The total chlorophyll content in the flag leaf was measured in accordance with the method of Goodwin, (1976) using a spectrophotometer.

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

The number of tillers was calculated from an area of 1 m^2 for each experimental unit at harvest.

11. **Grain yield (ton ha^{-1})**

Grain yield was calculated from the grain yield of the harvested plants from an area of 1 m^2 for each experimental unit at harvest.

Data were statistically analysed using GenStat 12.1 statistical software (Table 2), and means were compared using the least significant difference (LSD) test at $P \leq 0.05$.

Table 2: Analysis of variance representing the mean square of the studied characteristics in triticale.

S.O.V.	d.f	PH cm	FLA cm^2	LAI	SLW gm cm^{-2}	LAD Day^{-1}	CGR g m^{-2} d^{-1}	RGR mg g^{-1} d^{-1}	NAR g m^{-2} d^{-1}	Chl. mg g^{-1} FW	T. No. Tiller.m^{-2}	G.Y ta.h^{-1}
Replicate	2	4715.13	27.562	11.294	2.951E-05	3151.24	349.94	209.57	4.092	132.185	15640.0	0.3210
V	3	624.81 **	610.75 **	4.164 **	7.497E-06 **	1557.89 **	185.18 **	35.50 **	3.354 **	12.911 **	5391.0 **	14.3093 **
S	2	1856.17 *	79.64 **	0.558 **	1.179E-06 ns	1139.33 **	22.98 **	78.53 ns	0.909 **	9.528 **	22515.0 **	0.3552 **
V*S	6	115.45 **	10.58 **	0.0431 ns	2.529 ns	123.63 **	1.62 **	28.81 **	0.23 *	2.752 **	151.0 ns	0.2982 **
Error	18	5.05	0.343	0.0263	2.096E-07	3.02	0.04	0.13	0.066	0.012	118.0	0.0005

* Significant at $P \leq 0.05$; ** significant at $P \leq 0.01$; ns, non-significant

RESULTS AND DISCUSSION

The results presented in Table 3 indicate that triticale cultivars had a significant effect on plant height. The Farah cultivar recorded the highest mean plant height (126.25 cm), representing an 8.9% increase compared with the Admiral cultivar, which showed the lowest value (115.85 cm). Although Farah did not differ significantly from Almohanad, both cultivars demonstrated a clear advantage over the remaining genotypes. These differences in plant height may be attributed to genetic variability amongst the cultivars. This finding is consistent with the results reported by Al-Dulaimi (2020) and Mohammed and Mohammed (2022). The results presented in Table 4 reveal that seeding rate also had a significant effect on plant height. A seeding rate of 140 kg ha^{-1} produced the tallest plants, with a mean height of 128.61 cm, which was not significantly different from the height observed at 160 kg ha^{-1}. By contrast, a seeding rate of 180 kg ha^{-1} resulted in the shortest plants, with an average height of 114.68 cm. The observed reduction in plant height at higher seeding rates can be attributed to the increased intraspecific competition for essential resources such as light, water and nutrients (Nwry *et al.*, 2021; Batool *et al.*, 2022). Figure 1 illustrates that the Almohanad cultivar, at a seeding rate of 140 kg ha^{-1}, exhibited the greatest plant height (134.39 cm), but this cultivar did not differ significantly from the Farah cultivar at the same seeding rate, which recorded a mean height of 131.46 cm. By contrast, the Admiral cultivar at a seeding rate of 180 kg ha^{-1} produced the shortest plants, with a mean height of 103.80 cm.

The flag leaf serves as a critical determinant of grain yield and its components, as it plays an important role in grain filling from flowering to physiological maturity. In cereal crops, the translocation of assimilates from source tissues (leaves) to sink tissues (grains) is a key factor influencing yield (Aldesuquy *et al.*, 2012). The results presented in Table 3 indicate that the Farah cultivar exhibited the largest flag leaf area, with a mean of 51.69 cm^2, representing a 27.63% increase compared with the Admiral cultivar, which recorded the smallest flag leaf area (40.50

cm^2). This variation can be attributed to genetic differences amongst the cultivars, which influence photosynthetic capacity, enzyme activity and cellular expansion, particularly in the flag leaf. These physiological factors can enhance photosynthesis and increase productivity. These findings are consistent with those of Sedeeq et al. (2019), who reported significant differences in flag leaf area amongst triticale cultivars.

The results presented in Table 4 indicate that seeding rate had a significant effect on flag leaf area. A seeding rate of 140 kg ha^{-1} produced the largest mean flag leaf area (47.48 cm^2), whereas a seeding rate of 180 kg ha^{-1} resulted in the smallest flag leaf area (44.51 cm^2). This result can be attributed to the effect of plant density on resource availability, as moderate seeding rates reduce competition for essential growth factors such as light, water and nutrients, allowing for more efficient resource utilisation and improved leaf expansion. By contrast, higher plant densities increase competition, thereby limiting individual leaf development. These findings are consistent with those reported by Ahmed and Hameed (2024).

Figure 2 further illustrates a significant interaction between cultivar and seeding rate. The Farah cultivar exhibited the highest mean flag leaf area (54.01 cm^2) at a seeding rate of 140 kg ha^{-1}, whereas the Admiral cultivar recorded the lowest mean flag leaf area (39.06 cm^2) at 180 kg ha^{-1}.

The results presented in Table 3 indicate that triticale cultivars had a significant effect on the LAI. The Farah cultivar exhibited the highest LAI, averaging 4.01, whereas the Admiral cultivar recorded the lowest value (3.10). A higher LAI can enhance light use efficiency, allowing plants to optimise photosynthesis and improve overall productivity. The superior performance of the Farah cultivar can be attributed to its ability to develop an extensive leaf surface area, which maximises light interception and supports higher photosynthetic activity. This enhanced adaptability contributes to improved growth and resilience under varying environmental conditions. Conversely, the Admiral cultivar has a limited capacity to increase LAI, which may restrict its photosynthetic efficiency and negatively impact biomass accumulation. These findings are consistent with those reported by Rai et al. (2018) and Gheith et al. (2023).

The results presented in Table 4 indicate that seeding rate had a significant effect on LAI. A seeding rate of 160 kg ha^{-1} produced the highest LAI, averaging 3.69, whereas a seeding rate of 140 kg ha^{-1} resulted in the lowest average (3.44). This result can be attributed to the optimal plant density achieved at 160 kg ha^{-1}, which allows for balanced nutrient uptake and minimises excessive competition for resources. Consequently, plants exhibit uniform growth, develop a greater number of leaves and attain a larger total leaf area, ultimately enhancing LAI. These findings are consistent align with those reported by Tahir et al. (2019) and Gheith et al. (2023), who observed significant variations in LAI based on seeding rate. Moreover, the results indicate that the effects of cultivar and seeding rate on LAI were independent, which implies that genotypic differences did not interact significantly with plant density in determining LAI.

The results presented in Table 3 indicate a significant variation in SLW amongst the triticale cultivars. The Amal 7 cultivar recorded the highest average SLW (0.0064 g cm^{-2}), whereas the Admiral cultivar exhibited the lowest (0.0051 g cm^{-2}). This variation can be attributed to the differences in leaf density, which serves as an indicator of leaf thickness and resource storage efficiency. The superior SLW of Amal 7 can be attributed to its genetic composition, which favours greater leaf thickness and density, potentially enhancing its photosynthetic capacity and nutrient storage efficiency. By contrast, the lower SLW observed in Admiral implies less dense leaves, which may reduce its efficiency in resource utilisation. These findings are consistent with those reported by Burhan and Al-Hassan (2019) and Kaur (2022).

Regarding seeding rates, the results in Table 4 indicted that their effect on SLW was not statistically significant. The variation in plant density caused by different seeding rates was not sufficient to induce clear changes in leaf thickness or weight.

Moreover, the interaction between cultivars and seeding rates was not significant, indicating that the response of SLW was independent for each factor, and no synergistic or combined effect was observed when both factors were collectively considered.

The results presented in Table 3 indicate that the Farah and Amal 7 cultivars significantly outperformed the other cultivars with regard to LAD, with means of 144.37 and 143.88 days, respectively. By contrast, the Admiral cultivar exhibited the shortest LAD, averaging 130.10 days. LAD reflects the ability of a plant to sustain photosynthetic activity over an extended period, which directly influences growth and productivity. The superior LAD observed in Farah and Amal 7 may be attributed to genetic factors that enhance their ability to delay leaf senescence, thereby prolonging photosynthesis and facilitating greater carbohydrate and nutrient accumulation in the grains. By contrast, the Admiral cultivar has a reduced capacity to maintain leaf activity over time, which may contribute to low overall growth and yield potential. These findings are consistent with those reported by Al-Freeh et al. (2019) for oat cultivars and Kaur (2022) for barley cultivars in relation to LAD.

The results presented in Table 4 indicate that seeding rate had a significant effect on LAD. A seeding rate of 140 kg ha^{-1} resulted in the longest LAD, averaging 142.54 days, whereas a seeding rate of 180 kg ha^{-1} recorded the shortest duration, averaging 131.47 days. This difference can be attributed to the moderate plant density at 140 kg ha^{-1}, which reduces competition for essential resources, allowing for better individual plant growth and extended leaf functionality. In addition, a seeding rate of 140 kg ha^{-1} contributed to an increase in flag leaf area and chlorophyll content in the flag leaf, further supporting prolonged photosynthetic activity. By contrast, the high plant density at a seeding rate of 180 kg ha^{-1} intensified competition for light, water and nutrients, which may accelerate leaf senescence and reduce LAD. These findings are consistent with those reported by Rai et al. (2018), highlighting the impact of plant density on LAD.

Figure 3 illustrates a significant interaction between cultivar and seeding rate on LAD. The results indicate that the Farah cultivar exhibited the longest LAD, averaging 151.88 days, at a seeding rate of 140 kg ha^{-1}. This duration was not significantly different from that of Amal 7, which recorded 150.70 days at a seeding rate of 160 kg ha^{-1}. These findings indicate that Farah and Amal 7 respond positively to moderate plant densities, allowing for enhanced photosynthetic efficiency throughout the growth period. By contrast, the Admiral cultivar recorded the shortest LAD, averaging 124.26 days, at a seeding rate of 180 kg ha^{-1}. This result highlights the impact of high plant density on Admiral, where increased competition for light, nutrients and water may accelerate leaf senescence, thereby reducing the duration of leaf activity.

The results presented in Table 3 indicate that the Farah cultivar exhibited the highest CGR, averaging 23.11 g m^{-2} day^{-1}, whereas the Admiral cultivar recorded the lowest CGR (16.79 g m^{-2} day^{-1}). CGR reflects the ability of the cultivar to efficiently convert available resources such as light, water and nutrients into biomass, making it a key indicator of productivity. The superior CGR of Farah can be attributed to its genetic traits that enhance biomass accumulation, growth and photosynthetic efficiency. These factors contribute to a greater leaf area expansion and an extended duration of active photosynthesis, thereby improving crop productivity. By contrast, the Admiral cultivar has a limited capacity for achieving high growth rates because of genetic constraints that affect its resource utilisation efficiency. These findings are consistent with those reported by Al-Freeh et al. (2019) for oat cultivars, Kaur (2022) for barley cultivars and Gheith et al. (2023) for wheat cultivars, all of whom observed significant variations in CGR amongst different genotypes.

The results presented in Table 4 indicate that seeding rate had a significant effect on CGR. A seeding rate of 160 kg ha^{-1} produced the highest CGR, averaging 20.63 g m^{-2} day^{-1}, surpassing the values recorded at 140 and 180 kg ha^{-1}. This trend can be attributed to the balance between plant density and resource availability at a seeding rate of 160 kg ha^{-1}, which optimises light interception, nutrient uptake and water absorption. By contrast, higher seeding rates (e.g. 180 kg ha^{-1}) intensify competition for essential resources, leading to a reduction in LAI and flag leaf area, thereby limiting biomass accumulation and CGR. Conversely, a seeding rate of 140 kg ha^{-1} may provide excess space per plant, potentially reducing overall canopy coverage and limiting total biomass production. These findings are consistent with those reported by Rai et al. (2018) and Gheith et al. (2023), who observed that CGR is significantly influenced by seeding rates.

Figure 4 illustrates a significant interaction between cultivar and seeding rate with regard to CGR. The results indicate that the Farah cultivar achieved the highest CGR, averaging 23.81 g m^{-2} day^{-1}, at a seeding rate of 160 kg ha^{-1}. This result indicates that the Farah cultivar benefits most at a seeding rate of 160 kg ha^{-1}, where optimal resource distribution enhances photosynthetic efficiency and promotes maximum biomass accumulation. By contrast, the Admiral cultivar recorded the lowest CGR, averaging 15.94 g m^{-2} day^{-1}, at a seeding rate of 180 kg ha^{-1}. This reduction in growth rate may be attributed to the increased intraspecific competition at higher plant densities, which limits resource availability, restricts photosynthetic efficiency and reduces overall production potential.

The results presented in Table 3 indicate that the Amal 7 and Farah cultivars exhibited the highest RGR, accounting for 28.09 and 27.88 mg g^{-1} day^{-1}, respectively. By contrast, the Admiral cultivar recorded the lowest RGR, averaging 25.74 mg g^{-1} day^{-1}. RGR serves as a key indicator of resource use efficiency, as it reflects the ability of a plant to increase its biomass relative to its initial weight over a given period. The superior RGR observed in Amal 7 and Farah can be attributed to their genetic traits that enhance resource utilisation efficiency, particularly light interception, water absorption and nutrient uptake. In addition, these cultivars exhibit greater leaf area expansion and prolonged leaf activity, which contribute to higher photosynthetic efficiency and rapid biomass accumulation, thereby accelerating growth. By contrast, the Admiral cultivar may have a lower capacity for biomass production probably because of the limited leaf responsiveness and reduced photosynthetic efficiency. These findings are consistent with those reported by Agwa and Mohamad (2020) and Kaur (2022), who observed significant differences in RGR amongst barley cultivars because of genetic variation.

The results presented in Table 4 indicate that seeding rate did not have a significant effect on RGR. Although numerical differences were observed amongst the tested seeding rates, these variations were not sufficient to reach statistical significance, indicating that changes in plant density under the conditions of this study did not markedly influence RGR. This finding is contrary to those reported by Rai et al. (2018) and Gheith et al. (2023), who observed the significant effects of seeding rate on RGR in wheat. This discrepancy between the present results and those of earlier studies may be attributed to several factors, including differences in crop species, genetic characteristics of the cultivars used or environmental growing conditions.

Figure 5 illustrates a significant interaction between cultivar and seeding rate with regard to RGR. The Farah cultivar exhibited the highest RGR, reaching 31.37 mg g^{-1} day^{-1}, at a seeding rate of 160 kg ha^{-1}. By contrast, the Admiral cultivar recorded the lowest RGR, averaging 2.03 mg g^{-1} day^{-1}, at a seeding rate of 180 kg ha^{-1}. This disparity highlights the impact of high plant density at a seeding rate of 180 kg ha^{-1}, which intensified competition for essential resources, particularly for the Admiral cultivar. The increased competition for light, water and nutrients may restrict biomass accumulation and limit growth efficiency, thereby reducing RGR in Admiral. Conversely, a seeding rate of 160 kg ha^{-1} provided optimal plant density, allowing the Farah cultivar to efficiently utilise resources, maintain higher photosynthetic activity and achieve greater biomass production.

The results presented in Table 3 indicate a significant variation in net photosynthetic rate amongst the studied triticale cultivars. The Amal 7 cultivar exhibited the highest net photosynthetic rate, averaging 5.88 g m^{-2} day^{-1}, but this result was not significantly different from that of the Farah cultivar, which recorded 5.78 g m^{-2} day^{-1}. By contrast, the Almohanad cultivar had the lowest net photosynthetic rate, averaging 5.12 g m^{-2} day^{-1}. An increased net photosynthetic rate reflects the ability of a plant to efficiently convert light energy into biomass through carbohydrate production via photosynthesis. The superior net photosynthetic rate observed in Amal 7 and Farah can be attributed to their physiological traits that enhance light interception and nutrient utilisation efficiency, leading to higher biomass accumulation. In addition, these cultivars exhibit higher CGR and extended leaf activity duration, which further support increased photosynthetic efficiency. Conversely, the Almohanad cultivar may exhibit lower resource utilisation efficiency or higher respiration rates, leading to greater carbohydrate consumption and a reduced net photosynthetic rate. These findings are consistent with those reported by Al-Freeh et al. (2019) on oat cultivars, as well as Agwa and Mohamad (2020) and Kaur (2022) on barley cultivars, who demonstrated that variations in net photosynthetic rate across genotypes are influenced by genetic differences and environmental responses.

The results presented in Table 4 reveal significant differences in net photosynthetic rate amongst the seeding rates. A seeding rate of 140 kg ha^{-1} recorded the highest net photosynthetic rate, averaging 5.67 g m^{-2} day^{-1}, but this result was not significantly different from that at a seeding rate of 160 kg ha^{-1}, which averaged 5.60 g m^{-2} day^{-1}. By contrast, a seeding rate of 180 kg ha^{-1} resulted in the lowest net photosynthetic rate (5.30 g m^{-2} day^{-1}). The superior performance of the 140 kg ha^{-1} seeding rate can be attributed to lower plant density, which reduces competition for essential resources such as light and nutrients, thereby enhancing photosynthetic efficiency. In addition, this seeding rate promotes higher LAI, greater leaf weight and an extended duration of leaf activity, all of which contribute to more efficient carbon assimilation. Conversely, the high plant density at a seeding rate of 180 kg ha^{-1} may intensify the competition amongst plants, thereby restricting resource availability and reducing photosynthetic capacity. These findings are consistent with those reported by Rai et al. (2018) and Gheith et al. (2023), who observed a decline in net photosynthetic rate in wheat crops under high seeding rates.

Figure 6 further illustrates a significant interaction between cultivar and seeding rate with regard to net photosynthetic rate. The Amal 7 cultivar exhibited the highest mean net photosynthetic rate, reaching 6.10 g m^{-2} day^{-1}, at a seeding rate of 160 kg ha^{-1}. By contrast, the Almohanad cultivar recorded the lowest mean net photosynthetic rate, averaging 4.82 g m^{-2} day^{-1}, at a seeding rate of 180 kg ha^{-1}.

The triticale cultivars exhibited significant differences in chlorophyll content in the flag leaf, with the Farah cultivar recording the highest average (40.29 mg 100 g^{-1} FW), whereas the Admiral cultivar had the lowest (38.85 mg 100 g^{-1} FW; Table 3). Chlorophyll content is a key determinant of photosynthetic efficiency, as it enhances the ability of a plant to capture and convert light energy into chemical energy. The high chlorophyll content observed in Farah cultivar can be attributed to its genetic and physiological traits that promote chlorophyll biosynthesis, thereby improving photosynthetic capacity and overall productivity. In addition, the Farah cultivar benefited from a larger flag leaf area, higher CGR, longer LAD and an increased net photosynthetic rate, all of which contributed to its superior chlorophyll content. By contrast, the Admiral cultivar may exhibit lower efficiency in chlorophyll production, potentially limiting its ability to maintain high photosynthetic rates and reducing its overall growth and productivity. These findings are consistent with those reported by Agwa and Mohamad (2020) regarding chlorophyll variation in barley cultivars, as well as with the results of Alqasim and Al-Ghazal (2024) on bread wheat cultivars.

The results presented in Table 4 indicate the significant effect of seeding rate on chlorophyll content in the flag leaf. A seeding rate of 140 kg ha^{-1} recorded the highest average chlorophyll content (39.90 mg 100 g^{-1} FW), whereas a seeding rate of 180 kg ha^{-1} obtained the lowest chlorophyll content (38.89 mg 100 g^{-1} FW). The high chlorophyll content at a seeding rate of 140 kg ha^{-1} can be attributed to the optimal spacing between plants, allowing for better light interception and greater resource availability, which enhances chlorophyll production. By contrast, higher plant densities at a seeding rate of 180 kg ha^{-1} increase the competition for light and nutrients, thereby reducing photosynthetic efficiency. The increased shading effect at higher densities limits leaf area expansion and light absorption, thereby negatively impacting chlorophyll biosynthesis. These findings are consistent with those reported by Agwa and Mohamad (2020) and Ahmed and Hameed (2024), who observed that higher seeding rates reduce chlorophyll content because of increased plant competition.

Figure 7 illustrates a significant interaction between cultivar and seeding rate on chlorophyll content in the flag leaf. The Farah cultivar exhibited the highest chlorophyll content, reaching 41.26 mg 100 g^{-1} FW, at a seeding rate of 160 kg ha^{-1}. By contrast, the Admiral cultivar recorded the lowest chlorophyll content, averaging 38.59 mg 100 g^{-1} FW, at a seeding rate of 180 kg ha^{-1}. This positive interaction between the Farah cultivar and a seeding rate of 160 kg ha^{-1} highlights their combined ability to enhance chlorophyll production. The optimal pairing of a genetically efficient cultivar such as Farah with a moderate plant density (160 kg ha^{-1}) promotes better light interception, improved photosynthetic efficiency and increased chlorophyll biosynthesis. Conversely, a high plant density at 180 kg ha^{-1} may intensify the competition for resources, thereby limiting chlorophyll production in the Admiral cultivar.

The results presented in Table 3 indicate a significant variation in the number of tillers amongst triticale cultivars. The Amal 7 cultivar recorded the highest average tiller count, reaching 630.5 tillers m^{-2}, significantly surpassing the other cultivars. By contrast, the Admiral cultivar exhibited the lowest tiller count, averaging 596.4 tillers m^{-2}. The number of tillers is a key indicator of a plant's ability to develop lateral branches, which is a trait closely linked to crop growth vigour and the efficient utilisation of environmental resources. The superior tillering ability of the Amal 7 cultivar can be attributed to its genetic traits, which promote higher tiller formation, contributing to greater crop density and yield potential. In addition, the Amal 7 cultivar excelled in growth parameters, including higher RGR, LAD and SLW, all of which further supported increased tiller production. Conversely, the Admiral cultivar may possess genetic limitations that restrict tiller development, thereby reducing its ability to form lateral branches. These findings are consistent with those reported by Rashid and Alwahid (2023), who observed significant differences in tiller production amongst triticale cultivars.

The results presented in Table 4 indicate significant differences in the number of tillers based on seeding rate. A seeding rate of 180 kg ha^{-1} produced the highest average tiller count, reaching 634.4 tillers m^{-2}, whereas a seeding rate of 140 kg ha^{-1} recorded the lowest, with 585.5 tillers m^{-2}. The superior tiller production at a seeding rate of 180 kg ha^{-1} can be attributed to a higher plant density, which increases the number of plants per unit area and subsequently enhances tiller formation. These findings are consistent with those reported by Batool et al. (2022) and Attia (2023), who observed that higher seeding rates contribute to an increased number of tillers. Furthermore, the interaction between genotype and seeding rate was not significant, indicating that all genotypes responded similarly across different seeding rates with regard to tiller production.

The results presented in Table 3 indicate the significant effect of cultivar on grain yield. The Farah cultivar recorded the highest average yield, reaching 5.53 ton ha^{-1}, whereas the Admiral cultivar produced the lowest yield, averaging 3.97 ton ha^{-1}. This variation in grain yield can be attributed to the Farah cultivar's higher efficiency in resource utilisation, including light interception, water absorption and nutrient uptake, as well as its strong adaptation to local environmental conditions. Grain yield is influenced by multiple physiological and growth parameters, such as chlorophyll content, photosynthetic efficiency, CGR, RGR, LAD and total leaf area. The superior performance of the Farah cultivar in these factors may contribute to its higher yield potential. These findings are consistent with those reported by Attia (2023), who observed significant differences in grain yield amongst triticale cultivars based on their physiological efficiency and adaptability.

The results presented in Table 3 indicate significant differences in grain yield based on seeding rate. A seeding rate of 160 kg ha^{-1} produced the highest average grain yield, reaching 4.53 ton ha^{-1}, whereas a seeding rate of 140 kg ha^{-1} recorded the lowest yield (4.34 ton ha^{-1}). The superior performance at a seeding rate of 160 kg ha^{-1} can be attributed to optimal plant density, which enhances the efficient interaction of light, nutrients and water amongst plants, leading to improved biomass accumulation and grain production. Although increasing seeding rate per unit area can enhance yield, this effect is beneficial only up to a certain threshold. Beyond this point, higher plant densities may lead to excessive competition for resources, ultimately reducing grain yield. These findings are consistent with those reported by Yağmur (2023) and Attia (2023), who observed that higher seeding rates can enhance grain yield up to an optimal level, after which competition effects may become detrimental.

Figure 8 illustrates a significant interaction between cultivar and seeding rate in determining grain yield. The Farah cultivar achieved the highest grain yield, recording 5.71 ton ha^{-1}, at a seeding rate of 160 kg ha^{-1}. By contrast, the Admiral cultivar produced the lowest yield, averaging 3.85 ton ha^{-1}, at a seeding rate of 140 kg ha^{-1}. This interaction highlights the importance of combining a high yielding cultivar such as Farah with an optimal seeding rate 160 kg ha^{-1} to enhance resource use efficiency and maximise grain production. The results indicate that the careful selection of cultivar and seeding rate plays a critical role in optimising growing conditions and improving overall yield potential.

Table 3: Effect of triticale cultivars on physiological growth traits and yield

Cultivars	PH cm	FLA cm^2	LAI	SLW gm. cm^{-2}	LAD day^{-1}	CGR g m^{-2} d^{-1}	RGR mg $g^{-1}d^{-1}$	NAR g m^{-2} d^{-1}	Chl. mg g^{-1} fw	T. No. Tiller.m^{-2}	G.Y ta.h^{-1}
Admiral	115.85	40.50	3.10	0.0051	130.10	16.79	25.74	5.39	38.85	596.40	3.95
Farah	126.25	51.69	4.01	0.0055	144.37	23.11	27.88	5.78	40.29	615.30	5.53
Amal 7	122.68	44.19	3.41	0.0064	143.88	20.04	28.09	5.88	39.75	630.50	4.24
Almohanad	125.84	47.42	3.73	0.0057	131.99	19.07	26.39	5.12	38.92	609.70	4.09
$LSD_{0.05}$	1.29	0.36	0.09	0.0003	0.993	0.112	0.203	0.147	0.064	6.22	0.013

PH, plant height; FLA, flag leaf area; LAI, leaf area index; SLW, specific leaf weight; LAD, leaf area duration; CGR, crop growth rate; RGR, relative growth rate; NAR, net photosynthetic rate; Chl., chlorophyll; T. no., tiller number; G. Y, grain yield.

Table 4: Effect of seeding rates on physiological growth traits and yield

Seeding rates	PH cm	FLA cm^2	LAI	SLW gm. cm^{-2}	LAD day^{-1}	CGR g m^{-2} d^{-1}	RGR mg $g^{-1}d^{-1}$	NAR g m^{-2} d^{-1}	Chl. mg g^{-1} fw	T. No. Tiller.m^{-2}	G.Y ta.h^{-1}
140 kg h^{-1}	128.61	47.48	3.44	0.0059	142.54	19.56	27.99	5.67	39.90	585.50	4.34
160 kg h^{-1}	124.67	45.85	3.69	0.0056	138.74	20.63	27.75	5.60	39.57	619.00	4.53
180 kg h^{-1}	114.68	44.51	3.55	0.0055	131.47	19.07	25.32	5.37	38.89	634.40	4.47
$LSD_{0.05}$	10.23	0.11	0.01	N.S	0.504	0.098	N.S	0.043	0.063	7.84	0.02

PH, plant height; FLA, flag leaf area; LAI, leaf area index; SLW, specific leaf weight; LAD, leaf area duration; CGR, crop growth rate; RGR, relative growth rate; NAR, net photosynthetic rate; Chl., chlorophyll; T. no., tiller number; G. Y, grain yield.

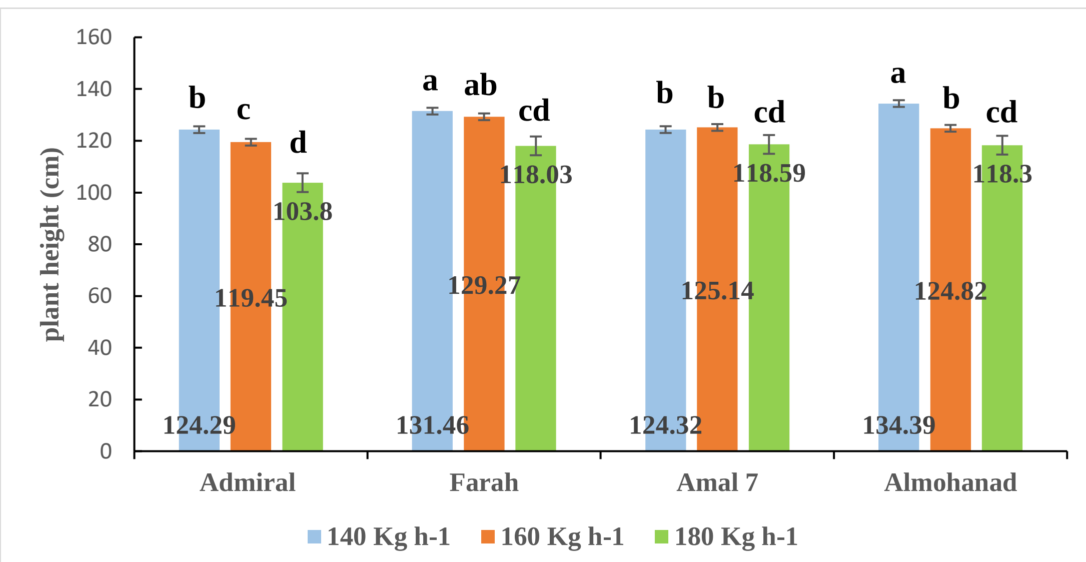

Figure (1) Effect of interaction between triticale cultivars and seeding rates on plant height (cm) (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

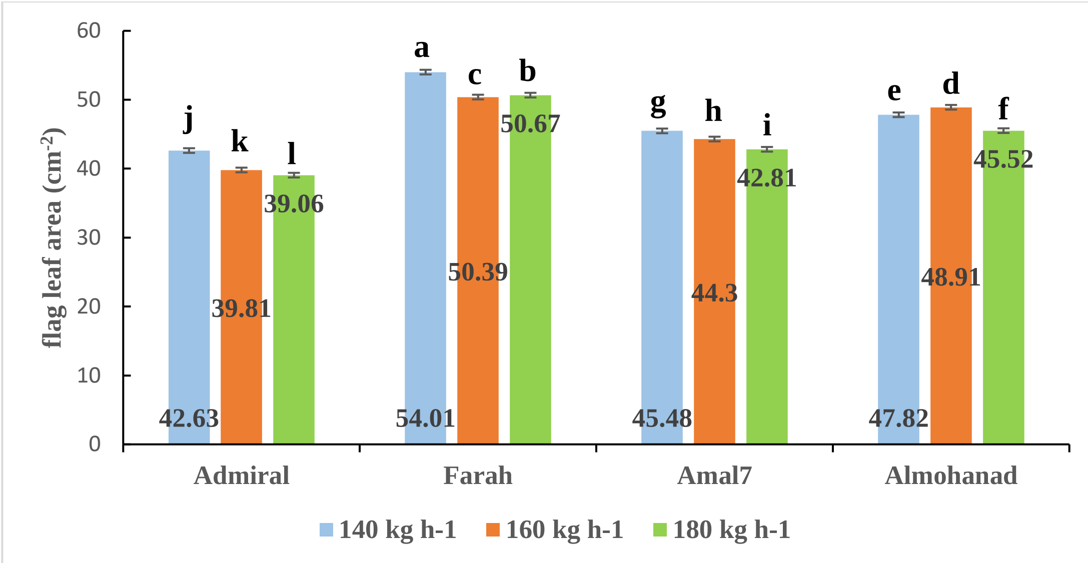

Figure (2) Effect of interaction between triticale cultivars and seeding rates on flag leaf area (cm^2) (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

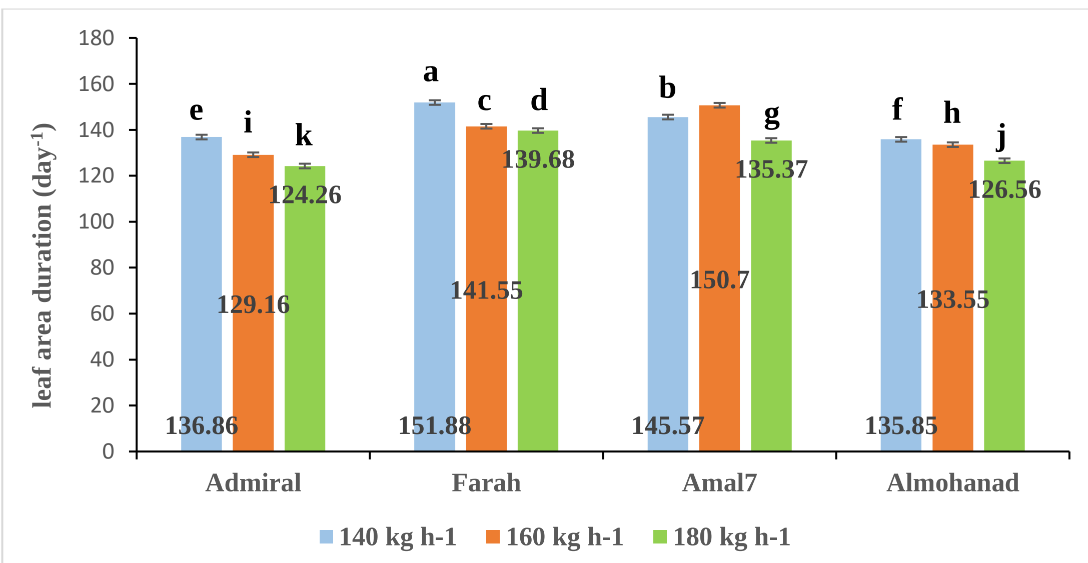

Figure (3) Effect of interaction between triticale cultivars and seeding rates on leaf area duration (day^{-1}) (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

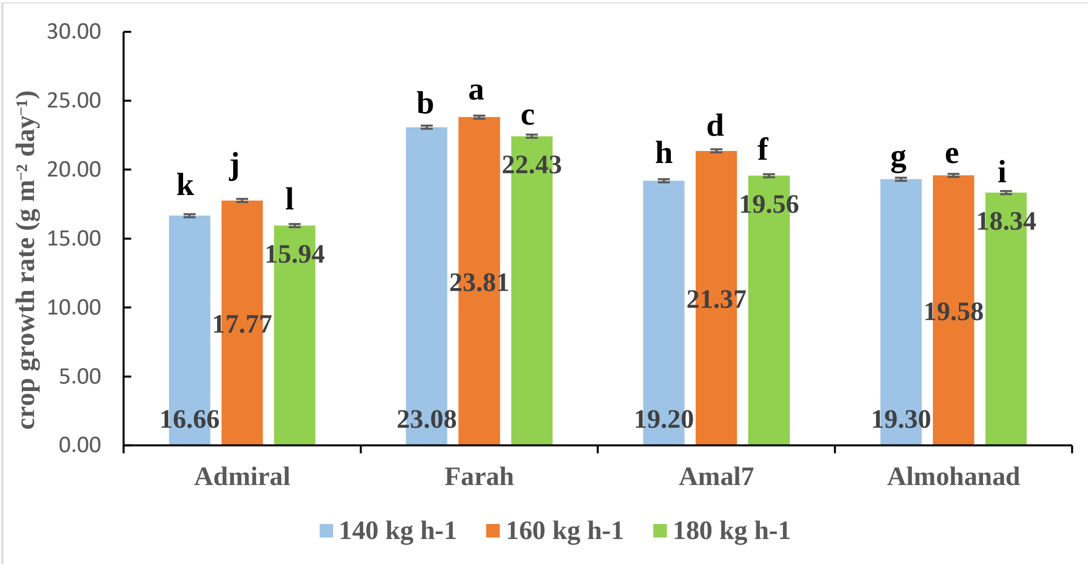

Figure (4) Effect of interaction between triticale cultivars and seeding rates on crop growth rate (g m^{-2} day^{-1}) (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

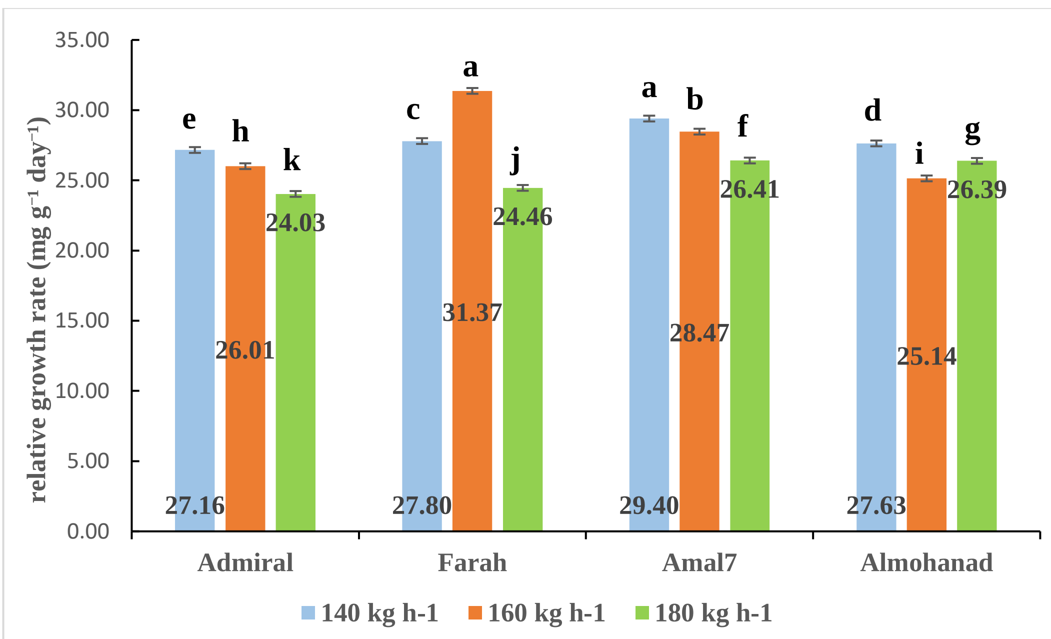

Figure (5) Effect of interaction between triticale cultivars and seeding rates on relative growth rate (mg g^{-1} day^{-1}) (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

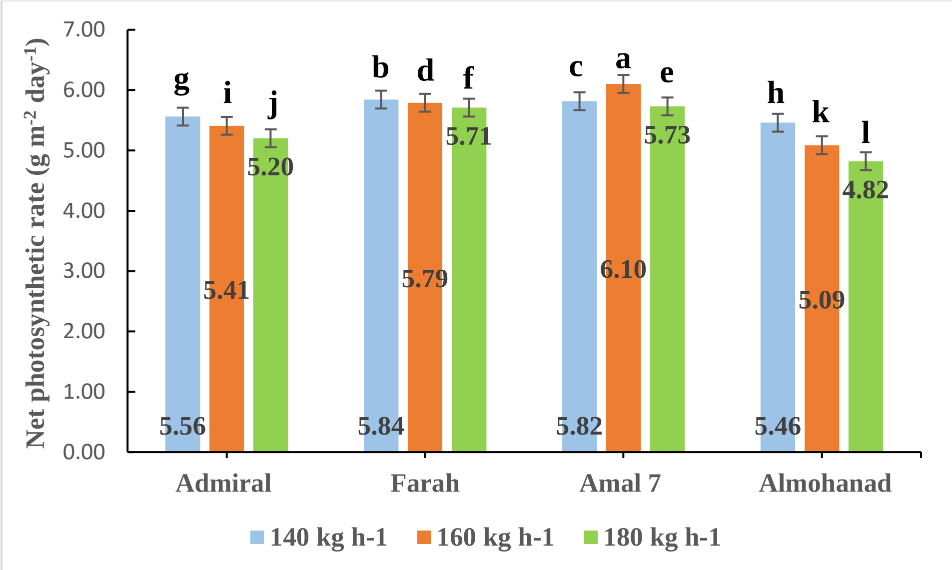

Figure (6) Effect of interaction between triticale cultivars and seeding rates on Net photosynthetic rate (g m^{-2} day^{-1}). (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

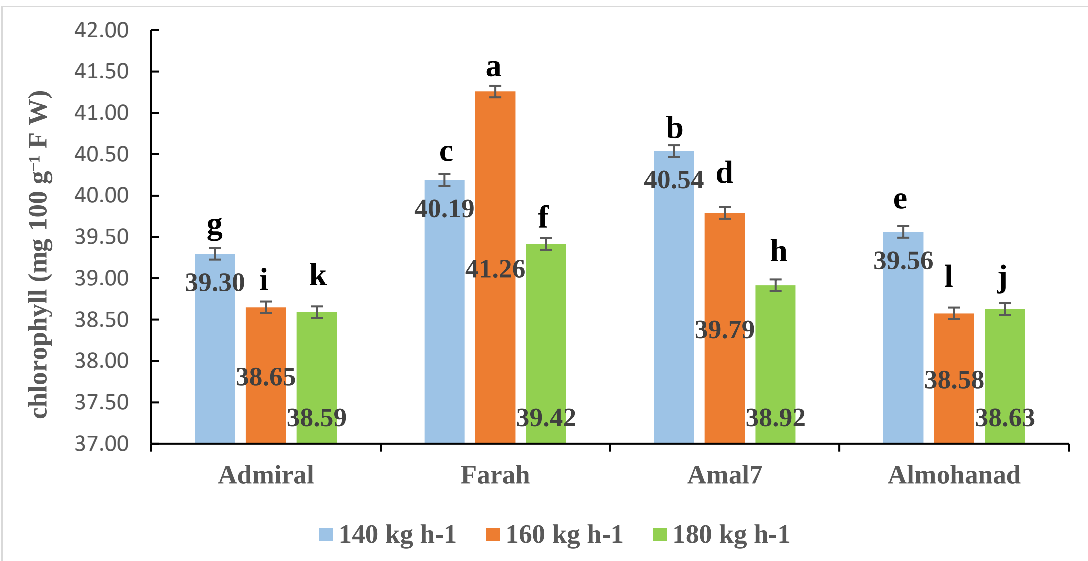

Figure (7) Effect of interaction between triticale cultivars and seeding rates on chlorophyll (mg 100 g^{-1} fresh weight) (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

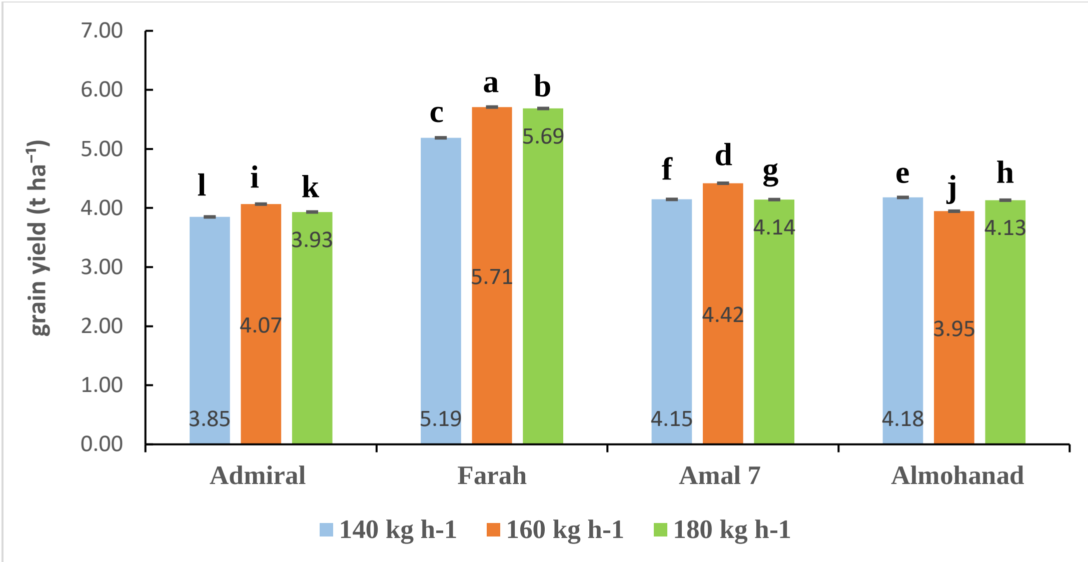

Figure (8) Effect of interaction between triticale cultivars and seeding rates on grain yield (ton ha^{-1}) (mean ± SE) Different letters indicate significant differences ($p < 0.05$) in the means between cultivars and seeding rates according to the LSD.

CONCLUSION

This study demonstrates that triticale cultivars exhibit differential responses in physiological growth traits under varying seeding rates primarily because of genetic variation. The Farah cultivar outperformed the others in LAD, CGR, flag leaf area and chlorophyll content, which contribute to its high grain yield of 5.53 ton ha^{-1}. Meanwhile, the Amal 7 cultivar excelled in flag leaf specific weight, RGR and tiller production, accounting for 20.31%, 8.37% and 5.41%, respectively. Therefore, optimising the seeding rate is crucial for maximising grain yield, as higher densities may lead to increased competition for resources. A seeding rate of 160 kg ha^{-1} produced the highest average grain yield, reaching 4.53 ton ha^{-1}, which represented a 4.19% increase compared with 140 kg ha^{-1} and a 1.32% increase compared with 180 kg ha^{-1}. These findings highlight the importance of selecting an optimal cultivar and seeding rate to enhance yield potential and resource use efficiency.

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