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INFLUENCE OF SEEDING RATES ON LODGING AND YIELD OF DIFFERENT OAT CULTIVARS

A. M. S. Addaheri [1]* **E. K. Mahmood [2]** **A. Ch. Al-Fahad [1]**

[1] Department of Field Crops, College of Agriculture, University of Anbar, Ramadi 31001, Iraq.

[2] General Directorate for Education of Anbar, Ministry of Education, Ramadi 31001.

***Correspondence to:** Abdullah M.S. Addaheri, Department of Field Crops, College of Agriculture, University of Anbar, Ramadi 31001, Iraq.
Email: ag.abdullah.mahmood@uoanbar.edu.iq

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Abstract

This study investigated the potential for controlling lodging by manipulating the seeding rates for oat cultivars introduced in Iraq. A field experiment was conducted in the winter 2022-23 at one of the agricultural fields in Ramadi, in the western region of Iraq. Split-plot arrangement in a randomized complete block design (RCBD) with three replications was used. The first factor included the three Carrolup, Genzania, and Hamel oat cultivars. The other experimental factor was seeding rates of 60, 80, and 100 kg ha^{-1}. The findings showed that the Hamel cultivar had the largest average stem diameter while the Genzania produced the greatest dry matter and grain yields. The seeding rate of 60 kg ha^{-1} had the lowest plant height, lodging index and dry matter, and largest stem diameter. The 100 kg ha^{-1} seeding rate had the greatest plant height, lodging index, and grain yield, and lowest stem diameter. Lowering the seeding rate from 100 to 80 kg ha^{-1} led to a reduction in lodging by 13.9% without deteriorating dry matter and grain yield while reducing it to 60 kg ha^{-1} led to a reduction in lodging, and dry matter and grain yields. This study thus recommends adopting the seeding rate of 80 kg ha^{-1} for growing oats in the western regions of Iraq.

Keywords: Lodging index, Plant height, Stem diameter.

تأثير معدل البذار في اضطجاع وحاصل أصناف مختلفة من الشوفان

عبدالله محمود صالح الداهري [1]* احمد جياد الفهد [1] الهام خليفة محمود [2]

[1] قسم المحاصيل الحقلية، كلية الزراعة، جامعة الانبار، الرمادي، 31001، العراق.

[2] مديرية تربية الانبار، وزارة التربية، الرمادي، 31001، العراق.

*المراسلة الى: عبدالله محمود صالح الداهري، قسم المحاصيل الحقلية، كلية الزراعة، جامعة الانبار، الرمادي، 31001، العراق.

البريد الالكتروني: ag.abdullah.mahmood@uoanbar.edu.iq

الخلاصة

هدفت الدراسة الحالية إلى تحديد إمكانية السيطرة على الاضطجاع من خلال التحكم بمعدلات البذار لأصناف من الشوفان التي أدخلت إلى العراق والتي بدت أنها تعاني من الاضطجاع، لذا أجريت تجربة حقلية في الموسم الشتوي 2022–2023 في أحد الحقول الزراعية في مدينة الرمادي التي تقع في المنطقة الغربية من العراق. تم استخدام نظام القطع المنشقة في تصميم القطاعات العشوائية الكاملة (RCBD) بثلاثة قطاعات. تضمن العامل الاول ثلاثة أصناف من الشوفان هي كارلوب وجينزانيا وهامل، كان العامل التجريبي الآخر هو معدلات البذار 60 و80 و100 كغم هكتار$^{-1}$. وكانت أهم النتائج أن الصنف هامل سجل أكبر معدل لقطر الساق. سجل الصنف جينزانيا أعلى إنتاجية للمادة الجافة بالإضافة إلى أكبر إنتاجية للحبوب. كان معدل البذر البالغ 60 كجم هكتار$^{-1}$ هو أقل ارتفاع للنبات، وأكبر قطر للساق، وأقل معامل اضطجاع، وأقل مادة جافة، وأقل معدل لإنتاج. معدل البذار 100 كغم هكتار$^{-1}$ سجل اعلى ارتفاع للنبات، وأدنى قطر للساق، وأكبر معامل اضطجاع، وأعلى حاصل حبوب. أدى تخفيض معدل البذار من 100 إلى 80 كغم هكتار$^{-1}$ إلى انخفاض الاضطجاع بنسبة 13.9%، دون تدهور حاصل المادة الجافة ومحصول الحبوب، في حين ادى خفض معدل البذار إلى 60 كغم هكتار$^{-1}$ الى انخفاض معدل الاضطجاع لكنه قلل من انتاجية المادة الجافة وانتاجية الحبوب، لذا تقترح هذه الدراسة اعتماد معدل البذار 80 كغم هكتار$^{-1}$ كتوصية لزراعة الشوفان في المنطقة الغربية من العراق.

كلمات مفتاحية: ارتفاع النبات، قطر الساق، دليل الاضطجاع.

Introduction

One of the most important cereal crops is the Avena sativa L. oat which is usually cultivated for fodder and food. Furthermore, it is more suitable than many other cereal crops for cultivation in arid and poor-fertility lands (8). It is also considered a source of carbohydrates, fats, protein, vitamins, minerals, and fiber, in addition to antioxidants that have health benefits (18). Newly introduced oats need to be investigated for their adaptation and production under field practices in new environmental conditions, identifying the problems facing their cultivation, and finding better methods to address them.

Field observations show that oat cultivation is subject to the problem of lodging due to excessive elongation of the stems when planting at a seeding rate of 100 kg ha^{-1} (2). Lodging relates to the permanent displacement of plants stemming from their vertical orientation (10). The phenomenon negatively affects yield in terms of quantity and quality (25). To achieve high productivity and quality oat yield it is recommended to adopt oat cultivars having good production efficiency and reduced lodgings (9 and 15).

Plant height is one of the traits associated with plant lodging (15, 23 and 28). It has been shown that tall plants lodge better than shorter plants (3 and 21). The resistance to lodging increases as the plant height decreases and stem diameter increases (26). The seeding rate in the unit area is among the most important field practices because it corresponds to plant density and appropriate plant canopy to intercept sunlight, helping it to achieve the desired economic yield. Greater plant density leads to plants shading more over each other, resulting in stem elongation and a smaller stem diameters that affect the accumulation of dry matter (31). Increasing plant density makes the light environment worse due to the shading of neighboring plants, including poor intensity of light and a decreased "ratio of red light to far-red light." This leads to a shadow-avoidance response such as decreasing their stem diameters and increasing their elongation (17).

The processes involve gibberellin (GA) and brassinosteroids (BR) biosynthesis as these two hormones influence many parts of plant development and growth. Not having enough gas and biosynthesis of BR makes the plant half-dwarf or dwarf, which means it does not lodge as much (1, 7, 9 and 22). A previous study on wheat found that lodging resistance increased with reduced seeding rates (5). Also, previous studies noted that seeding rates suitable for growing oat differ according to the cultivar and environmental conditions (11). Cultivar and environment are the main factors affecting optimum plant density (12 and 24). Based on the information above, this study aimed to determine the optimal seeding rate to achieve the least lodging and desired yields of three important oat cultivars that may be adopted for cultivation in the western Iraq region.

Materials and Methods

This field experiment was conducted in the winter season of 2022-2023 at an agricultural area of Anbar governorate, western Iraq. A representative sample of field soil was taken from depths ranging from 0 to 30 cm and analyzed to determine its physical and chemical properties. The soil analysis results are presented in Table 1.

Table 1: Analysis of the experimental soil at a depth of 0 to 30 cm.

Analysis type	Result
Soil texture	Silty loam
Electrical conductivity (EC)	1.74 dS m^{-1}
pH	8.29
Bulk density	1.3 g cm^{-3}
Organic matter (OM)	1.28 g kg^{-1}
Total nitrogen (N)	113 mg kg^{-1}
Available phosphorus (P)	9.16 mg kg^{-1}
Available potassium (K)	120 mg kg^{-1}
Cation exchange capacity (CEC)	17 centimol kg^{-1}

A split-plot arrangement was used in this experiment based on the randomized complete block design (RCBD) with three replications. The experiment comprised two factors. The first factor involved the main plots containing the three oat cultivars, namely Carrolup, Genzania, and Hamel. The second factor involved the subplots with plantings at three seeding rates of 60, 80, and 100 kg ha^{-1}. The soil of the experimental field was plowed and then smoothed with spring harrows. The land was then divided into experimental units sized 2 m x 3 m. Planting took place in mid-November, with 25-cm row spacing. Diammonium phosphate (DAP) fertilizer was applied to the soil at 100 kg ha^{-1}. The experiment was irrigated whenever necessary, depending on soil moisture. Weed control was conducted using the 2,4-D herbicide.

The following traits were studied:

1. Plant height (cm): the average length of the main stems measured from the bottom of the plant to the top of ten random plants selected from the protected central rows of the central square meter (16 and 20).
2. Stem diameter (mm): average of the main stem diameters measured at the bottom, middle, and base of the inflorescence of ten randomly selected fully-flowered plants from the protected rows.
3. Lodging index: measured before the final harvest from the center of the experimental unit, according to the method developed by Shah et al. (2017) (21) from Berry et al. (2003) (6). An angle measuring protractor was used to measure the angle of inclination of the stems from the vertical position such that the angles were intermediate 0° to 15°, 15° to 30°, 30° to 45°, 45° to 60°, 60° to 75°, and 75° to 90°. Observations were then converted to the lodging index according to the equation described by (22):

$$Lodging\ index = \frac{1}{6}(\%\ at\ 0° \ to\ 15°) + \frac{2}{6}(\%\ at\ 15°\ to\ 30°) + \frac{3}{6}(\%\ at\ 30°\ to\ 45°) + \frac{4}{6}(\%\ at\ 45°\ to\ 60°) + \frac{5}{6}(\%\ at\ 60°\ to\ 75°) + (\%\ at\ 75°\ to\ 90°)$$

4. Dry matter (DM) (tons ha^{-1}): The total yield per square meter at the center of the experimental unit was harvested, dried, and weighed by following "DM, method ID 934.01" in kg per square meter, multiplied by the area of the hectare (10000 square meters), and converted to tons per hectare by dividing by 1000.
5. Grain yield (tons ha^{-1}): calculated from the square meter in the center of the experimental unit that was harvested and dried where the pinnacles were threshed. The grain was weighed, in kg per square meter, and converted into tons per hectare by following the method for the dry matter (13).

GenStat software was analyzed the data using the analysis of variance method, and the arithmetic means were compared using the least significant difference (LSD) at a probability level of 0.05 (14). Correlation coefficient analysis was also conducted for the traits with a degree of freedom of 25 and slope analysis for the traits under study of elements.

Results and Discussion

Plant height: As seen in Table 2, the results for plant height indicate no significant difference among the cultivars. When the seeding rate was increased from 60 to 80 kg seed ha^{-1} and then to 100 kg seed ha^{-1}, plant heights increased significantly from 91.2 to 94.4 and to 97.2 cm. There was no significant effect of the interaction of cultivars and seeding rate on plant height. Increasing seeding rates led to an increase in plant height, due perhaps to increased plant density and shading of neighboring plants, as any decrease in the "red to far-red light ratio" in plant canopies lead to an increase in stem elongation.

Table 2: Impact of seeding rates on plant height (cm) of the three oat cultivars.

Cultivars	Seeding rate (kg ha^{-1})			Mean
	60	80	100	
Carrolup	89.0	93.9	95.3	92.7
Genzania	90.3	93.3	97.3	93.6
Hamel	94.3	96.0	99.0	96.5
Mean of seeding rate	91.2 a	94.4 b	97.2 c	
LSD 5%				
Cultivars (NS)	Seeding rate (2.74)			Interaction (NS)

NS: Non-significant. Values with the same letter have no significant difference.

Stem diameter: The Hamel cultivar recorded the largest average stem diameter of 4.7 mm, significantly superior to the other two cultivars, while the Carrolup recorded the smallest at 3.7 mm. However, the Carrolup and Genzania cultivars did not differ significantly in this trait (Table 3). The variation in the stem diameters may be due to their genetic diversity, meaning the differences in the genes that control the plant's morphological form, including stem diameter.

Also, an increase in the seeding rate reduced stem diameters, with the 60 kg seed ha^{-1} rate recording the largest average stem diameter at 4.4 mm, significantly superior to the 100 kg ha^{-1} rate which had the smallest average diameter at 3.7 mm. This inverse relationship could be attributed to the higher plant density which makes the light environment worse, due to the shading of neighboring plants. The weak light intensity and decreased "red to far-red light ratio" produces a shading avoidance response, such as decreasing stem diameters and lengthening stems (17).

Table 3: Impact of seeding rates on stem diameters (mm) of the three oat cultivars.

Cultivars	Seeding rate (kg ha^{-1})			Mean
	60	80	100	
Carrolup	4.0	3.6	3.4	3.7 a
Genzania	4.3	3.8	3.5	3.9 a
Hamel	4.9	4.9	4.3	4.7 b
Mean of seeding rate	4.4 b	4.1 ab	3.7 a	
LSD 5%				
Cultivars (0.77)	Seeding rate: (0.42)			Interaction (NS)

NS: Non-significant. Values with the same letter have no significant difference.

Lodging index: Table 4 shows that decreasing the seeding rate resulted in a reduction in the lodging index from 13.6 at the highest seeding rate of 100 kg ha^{-1} to 9.4 for the lowest of 60 kg ha^{-1}. In addition, the cultivar-seeding rate interaction had a significant effect on the index, with the Carrolup cultivar recording the highest lodging rate of 15.7 at the highest seeding rate of 100 kg ha^{-1} and the Genzania having the lowest at 8.0 for the lowest rate of 60 kg ha^{-1}. The reason for the decrease in the lodging index from different seeding rates may be due to the decline in plant height and increase in stem diameter, as shown in Tables 2 and 3. This is confirmed by the positive significant correlation ($P<0.05$) between lodging index and plant height of 0.47, and the significant negative correlation ($P<0.05$) between the index and stem diameter of -0.48 (Table 7). This agrees with (27), who found that the plant resistance to lodging increases as their height decreases and stem diameter increases. Also, (5) pointed out that low seeding rates enhance resistance to lodging in wheat.

Table 4: Impact of seeding rate on lodging index of the three oat cultivars.

Cultivars	Seeding rate (kg ha^{-1})			Mean
	60	80	100	
Carrolup	9.9	10.5	15.7	12.0
Genzania	8.0	13.0	13.2	11.4
Hamel	10.1	11.5	11.8	11.1
Mean of seeding rate	9.4 a	11.7 b	13.6 c	
LSD 5%				
Cultivars (NS)	Seeding rate (1.57)			Interaction (3.50)

NS: Non-significant. Values with the same letter have no significant difference.

Dry matter: The Genzania cultivar had the highest dry matter production rate of 23.6 tons ha^{-1}, compared to Carrolup which recorded the lowest at 21.8 tons ha^{-1} (Table 5). However, the Genzania did not differ significantly from Hamel which did not outperform the Carrolup. This difference in dry matter yield among the cultivars may be due to genetic variations, which lead to differences in photosynthesis efficiency and dry matter accumulation. This is in line with (19), who found a difference among oat cultivars in dry matter yield.

Seeding rates have a significant impact on dry matter production. When planting at a rate of 80 kg ha^{-1}, the highest dry matter yield of 23.5 tons ha^{-1} was recorded, while the lowest at 21.6 tons ha^{-1} was at the minimum seeding rate of 60 kg ha^{-1}. The highest dry matter yield may have been reached at the middle seeding rate (80 kg seeds ha^{-1}). This is likely because the 80 kg ha^{-1} seeding rate creates density which produces an optimal leaf area index and plant canopy for best sunlight interception, leading to higher photosynthesis and dry matter accumulation. Increasing the seeding rate to 100 kg ha^{-1} did not increase dry matter yield because as it may have raised plant density above the critical leaf area index, and shaded neighboring plants, thus not increasing dry matter productivity. This is consistent with (31) who reported that increased plant density leads to shading of neighboring plants and reduces dry matter accumulation.

Table 5: Impact of seeding rates on dry matter (tons ha^{-1}) of the three oat cultivars.

Cultivars	Seeding rate (kg ha^{-1})			Mean
	60	80	100	
Carrolup	20.7	23.2	21.4	21.8 a
Genzania	22.5	24.2	24.2	23.6 b
Hamel	21.4	23.3	24.6	23.1 ab
Mean of seeding rate	21.6 a	23.5 c	23.4 bc	
LSD 5%				
Cultivars (1.40)	Seeding rate (1.58)			Interaction (NS)

NS: Non-significant. Values with the same letter have no significant difference.

Grain yield: Table 6 on grain yield averages shows that the Genzania cultivar recorded the highest rate of 4.79 tons ha^{-1}, significantly outperforming the Carrolup's lowest yield of 4.10 tons ha^{-1}. This may be due to the difference in their genetic composition, which impacts yield components and eventually grain yield. This is in line with (8 and 29) that genotype and environmental conditions have an impact on grain yield.

Seeding rates had a significant impact on grain yield, with the 100 kg ha^{-1} recording the highest rate of 4.57 tons ha^{-1} and significantly superior to the 60 kg ha^{-1} rate which recorded the lowest at 4.16 tons ha^{-1}. Raising the seeding rate from 60 to 80 kg ha^{-1} led to a significant increase in grain yield. This may be due to the higher plant density and number of active tillers per unit area. However, increasing the seeding rate from 80 to 100 kg ha^{-1} did not cause a significant increase in grain yield. This could be attributed to plant density that was above the appropriate limit and the increased shading and competition with neighboring plants for sources of energy and nutrition. Likewise, (4) did not find a significant difference in grain yield between the 80 and 100 kg ha^{-1} seeding rates of oat cultivars.

Table 6: Impact of seeding rates on grain yield (tons ha^{-1}) of the three oat cultivars.

Cultivars	Seeding rate (kg ha^{-1})			Mean
	60	80	100	
Carrolup	4.03	4.12	4.14	4.10 a
Genzania	4.40	4.98	4.99	4.79 b
Hamel	4.05	4.48	4.58	4.37 ab
Mean of seeding rate	4.16 a	4.53 bc	4.57 c	
LSD 5%				
Cultivars (0.490)	Seeding rate (0.330)			Interaction (NS)

NS: Non-significant. Values with the same letter have no significant difference.

Correlation coefficient and slope parameter: Statistical analysis of the correlation coefficient of the studied traits in Table 7 show a significant direct correlation for plant height and lodging index, and a significant inverse correlation between stem diameter and lodging index. This may be due to the weak resistance of the stems to collapse under the influence of external factors such as wind as well as the weight of the plant with increasing height.

Table 7: Correlation between the traits of the oat cultivars and seeding rates (Degree of freedom = 25).

	Plant height	Stem diameter	Lodging index	Dry matter
Stem diameter	-0.18			
Lodging index	0.47*	-0.48*		
Dry matter	0.44*	-0.01	0.03	
Grain yield	-0.35	0.11	-0.18	-0.01

* Significant ($P < 0.05$).

Figure 1 illustrates the direct slope parameter between plant height and lodging index ($y = 0.3323\times -19.8$) while Figure 2 displays the inverse slope parameter between stem diameter and lodging index ($y = -2.0204 + 19.792$). These results, together with that on plant height, stem diameter, and lodging index in Tables 2, 3, and 4, and the correlation coefficient in Table 7 between the three traits, indicate how seeding rates affect lodging. Reducing seeding rates results in lower plant densities, which in turn decreases plant heights and widens stem diameters, thus reducing lodging.

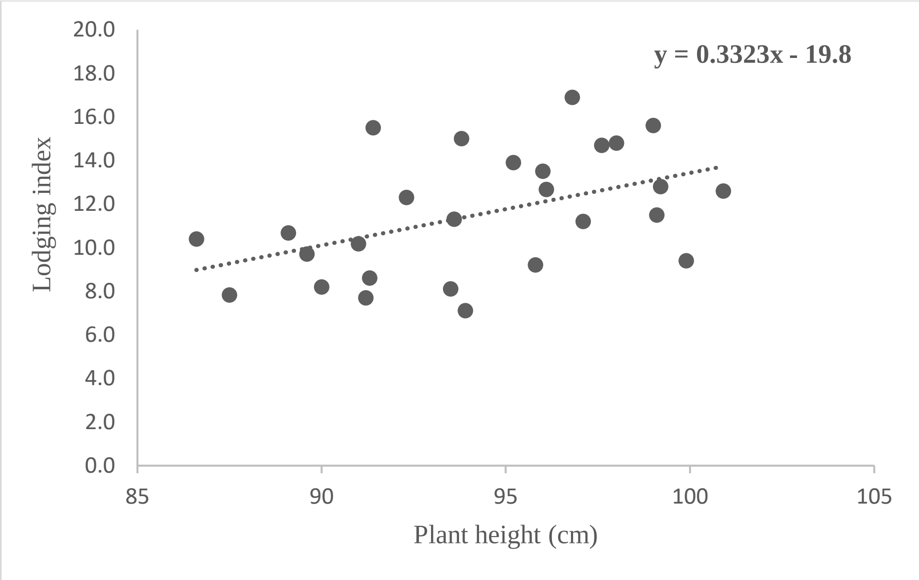

Figure 1: Slope of the lodging index with plant heights of the oat cultivars at different seeding rates.

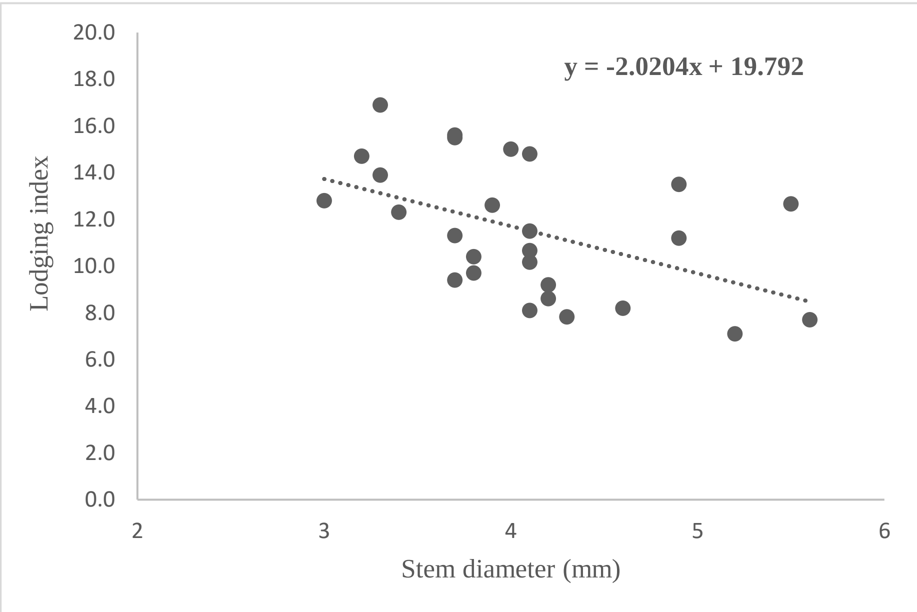

Figure 2: Slope of the lodging index with stem diameters of the oat cultivars at different seeding rates.

Conclusions

The findings of this study indicate that a seeding rate of 80 kg ha^{-1} is the most appropriate and recommended practice for oat cultivation in the western region of Iraq as it effectively mitigates lodging. Moreover, reducing seeding rates to below this threshold may result in a decline in crop yield.

Supplementary Materials:

No Supplementary Materials.

Author Contributions:

Addaheri: methodology, writing—original draft preparation; Mahmood and Al-Fahad: writing—review and editing. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

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References

1. Achard, P., and Genschik, P. (2009). Releasing the brakes of plant growth: how GAs shutdown DELLA proteins. Journal of experimental botany, 60(4): 1085-1092. https://doi.org/10.1093/jxb/ern301.
2. Addaheri, A. M. S., and Abood, N. M. (2020). Response of oat cultivars to ethephon and boron. The Iraqi Journal of Agricultural Science, 51(1): 259-268.
3. Addaheri, A. M. S., Hassan, O. M., Khalf, Q. S., Athab, M. U., and Meshal, O. S. (2021). Potential Role of Cutting Date in Lodging and Yield of Three Oat Cultivars. In IOP Conference Series: Earth and Environmental Science, 904(1): p. 012021. DOI: 10.1088/1755-1315/904/1/012021.
4. Bellamkonda, M., Ravipati, S., Madaraju, S., and Tummanepally, S. (2021). Effect of time of sowing, seed rate, and variety on seed yield of oat. The Pharma Innovation Journal, 10(11): 1263-1266.
5. Berry, P. M., Griffin, J. M., Sylvester-Bradley, R., Scott, R. K., Spink, J. H., Baker, C. J., and Clare, R. W. (2000). Controlling plant form through husbandry to minimise lodging in wheat. Field Crops Research, 67(1): 59-81. https://doi.org/10.1016/S0378-4290(00)00084-8.
6. Berry, P. M., Spink, J., Sterling, M., and Pickett, A. A. (2003). Methods for rapidly measuring the lodging resistance of wheat cultivars. Journal of Agronomy and

Crop Science, 189(6): 390-401. https://doi.org/10.1046/j.0931-2250.2003.00062.x.

7. Braumann, I., Dockter, C., Beier, S., Himmelbach, A., Lok, F., Lundqvist, U., ... and Hansson, M. (2018). Mutations in the gene of the Gα subunit of the heterotrimeric G protein are the cause for the brachytic1 semi-dwarf phenotype in barley and applicable for practical breeding. Hereditas, 155: 1-13. https://doi.org/10.1186/s41065-017-0045-1.
8. Buerstmayr, H., Krenn, N., Stephan, U., Grausgruber, H., and Zechner, E. (2007). Agronomic performance and quality of oat (Avena sativa L.) genotypes of worldwide origin produced under Central European growing conditions. Field Crops Research, 101(3): 343-351. https://doi.org/10.1016/j.fcr.2006.12.011.
9. Da Silva, J. A., Goi Neto, C. J., Fernandes, S. B., Mantai, R. D., Scremin, O. B., and Pretto, R. (2016). Nitrogen efficiency in oats on grain yield with stability. Revista Brasileira de Engenharia Agrícola e Ambiental, 20: 1095-1100. https://doi.org/10.1590/1807-1929/agriambi.v20n12p1095-1100.
10. Dahiya, S., Kumar, S., Chaudhary, C., and Chaudhary, C. (2018). Lodging: Significance and preventive measures for increasing crop production. Int. J. Chem. Stud, 6(2): 700-705.
11. Finnan, J. M., Hyland, L., and Burke, B. (2018). The effect of seeding rate on radiation interception, grain yield and grain quality of autumn sown oats. European journal of agronomy, 101: 239-247. https://doi.org/10.1016/j.eja.2018.09.008.
12. Geleta, B., Atak, M., Baenziger, P. S., Nelson, L. A., Baltenesperger, D. D., Eskridge, K. M., ... and Shelton, D. R. (2002). Seeding rate and genotype effect on agronomic performance and end-use quality of winter wheat. Crop Science, 42(3): 827-832. https://doi.org/10.2135/cropsci2002.8270.
13. Hamidi, I. H., Ajaj, H. A., and Abood, N. M. (2019). Effect of Foliar application with some amino acids Concentration in grain filling period and yield and its Quality of three wheat cultivars (Triticum aestivum L.). Anbar Journal of Agricultural Sciences, 17(1): 44-61. https://doi.org/10.32649/aagrs.2022.170533.
14. Khalid, M. M., and Al-Issawi, M. H. (2024). Phytomelatonin mitigates cadmium stress for bread wheat *Triticum aestivum* L. Anbar Journal of Agricultural Sciences, 22(1): 182-196. https://doi.org/10.32649/ajas.2024.147333.1145.
15. Marolli, A., da Silva, J. A. G., Romitti, M. V., Mantai, R. D., Scremin, O. B., Frantz, R. Z., ... and de Lima, A. R. C. (2017). Contributive effect of growth regulator Trinexapac-Ethyl to oats yield in Brazil. African Journal of Agricultural Research, 12(10): 795-804. https://doi.org/10.5897/AJAR2016.11784.
16. Mohammed, O. M., and Al-Fahad, A. C. (2024). Effect of soaking sorghum seeds with barassinolid field emergence and vegetative growth characters. Anbar Journal of Agricultural Sciences, 22(1): 560-571. https://doi.org/10.32649/ajas.2024.183756.
17. Pantazopoulou, C. K., Bongers, F. J., and Pierik, R. (2021). Reducing shade avoidance can improve Arabidopsis canopy performance against competitors. Plant, Cell and Environment, 44(4): 1130-1141. https://doi.org/10.1111/pce.13905.

18. Peterson, D. M., Wesenberg, D. M., Burrup, D. E., and Erickson, C. A. (2005). Relationships among agronomic traits and grain composition in oat genotypes grown in different environments. Crop Science, 45(4): 1249-1255. https://doi.org/10.2135/cropsci2004.0063.
19. Saleem, M., Zamir, M. S. I., Haq, I., Irshad, M. Z., Khan, M. K., Asim, M., ... and Rehman, S. (2015). Yield and quality of forage oat (Avena sativa L.) cultivars as affected by seed inoculation with nitrogenous strains. American Journal of Plant Sciences, 6(19): 3251. http://dx.doi.org/10.4236/ajps.2015.619316.
20. Schittenhelm, S., and Menge-Hartmann, U. (2006). Yield formation and plant metabolism of spring barley in response to locally injected ammonium. Journal of agronomy and Crop Science, 192(6): 434-444. https://doi.org/10.1111/j.1439-037X.2006.00226.x.
21. Shah, S. S. M., Chang, X., and Martin, P. (2017). Effect of dose and timing of application of different plant growth regulators on lodging and grain yield of a Scottish landrace of barley (Bere) in Orkney, Scotland. International Journal of Environment, Agriculture and Biotechnology, 2(4): 2010-2019. https://doi.org/10.22161/ijeab/2.4.59.
22. Swain, S. M., and Singh, D. P. (2005). Tall tales from sly dwarves: novel functions of gibberellins in plant development. Trends in plant science, 10(3): 123-129. https://doi.org/10.1016/j.tplants.2005.01.007.
23. Verma, V., Worland, A. J., Savers, E. J., Fish, L., Caligari, P. D. S., and Snape, J. W. (2005). Identification and characterization of quantitative trait loci related to lodging resistance and associated traits in bread wheat. Plant Breeding, 124(3): 234-241. https://doi.org/10.1111/j.1439-0523.2005.01070.x.
24. Weiner, J., Andersen, S. B., Wille, W. K. M., Griepentrog, H. W., and Olsen, J. M. (2010). Evolutionary Agroecology: the potential for cooperative, high density, weed-suppressing cereals. Evolutionary Applications, 3(5-6): 473-479. https://doi.org/10.1111/j.1752-4571.2010.00144.x.
25. Wu, W., and Ma, B. L. (2016). A new method for assessing plant lodging and the impact of management options on lodging in canola crop production. Scientific reports, 6(1): 31890. https://doi.org/10.1038/srep31890.
26. Xiao, Y., Liu, J., Li, H., Cao, X., Xia, X., and He, Z. (2015). Lodging resistance and yield potential of winter wheat: effect of planting density and genotype. Frontiers of Agricultural Science and Engineering, 2(2): 168-178.
27. Yan, W., Frégeau-Reid, J., Pageau, D., and Martin, R. (2016). Genotype-by-environment interaction and trait associations in two genetic populations of oat. Crop Science, 56(3): 1136-1145. https://doi.org/10.2135/cropsci2015.11.0678.
28. Yao, J., Ma, H., Zhang, P., Ren, L., Yang, X., Yao, G., ... and Zhou, M. (2011). Inheritance of stem strength and its correlations with culm morphological traits in wheat (Triticum aestivum L.). Canadian Journal of Plant Science, 91(6): 1065-1070. https://doi.org/10.4141/cjps2011-033.
29. Yu, K. M. J., McKinley, B., Rooney, W. L., and Mullet, J. E. (2021). High planting density induces the expression of GA3-oxidase in leaves and GA mediated stem elongation in bioenergy sorghum. Scientific reports, 11(1): 46. https://doi.org/10.1038/s41598-020-79975-8.