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Influence of Cultivar and Sowing Density on Grain Yield and Main Yield Components of Winter Wheat (*Triticum aestivum* L.)

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ABSTRACT

Winter wheat yield formation is influenced by cultivar, sowing density (SD) and annual climatic conditions during the growing season. This study evaluated the effects of four winter wheat cultivars (Glosa, FDL Abund, Python and Promitor) and five sowing densities [350, 450, 550, 650 and 750 germinating seeds (g.s.) m^{-2}] on grain yield, spike density, grain weight per spike and thousand-kernel weight under the pedoclimatic conditions of Moara Domnească, Ilfov County, Romania, during the 2022-2023 and 2023-2024 growing seasons. The experiment was established as a bifactorial split-plot field trial with four replications. Data were analysed separately for each growing season. The two seasons differed in rainfall distribution and total precipitation, with 445.0 mm recorded in 2022-2023 and 623.2 mm in 2023-2024, compared with the 1991-2020 long-term average of 640.6 mm. In both growing seasons, none of the tested sowing densities significantly exceeded the control SD of 550 germinating seeds m^{-2} in terms of grain yield. However, cultivar-specific yield responses were observed. Glosa reached its highest grain yield at 550 germinating seeds m^{-2}, FDL Abund at 650 germinating seeds m^{-2}, whereas Python and Promitor recorded their highest yields at 350 germinating seeds m^{-2}. Higher sowing densities generally increased spike density, but this was not accompanied by a corresponding yield advantage. In contrast, lower sowing densities favoured grain weight per spike and thousand-kernel weight in most cultivar × density combinations. The results suggest that sowing density recommendations should be tailored to cultivar-specific yield formation patterns rather than based on a single general density recommendation.

Keywords: winter wheat, sowing density, grain yield, spike density, thousand-kernel weight.

INTRODUCTION

Winter wheat (*Triticum aestivum* L.) remains one of the most important cereal crops worldwide due to its wide adaptability, high productive potential and multiple uses in human nutrition, animal feed and food processing. Bread wheat is widely used for bread-making and industrial purposes, while its grain provides an important source of carbohydrates, proteins and other nutritional compounds (Shewry, 2009; Peng et al., 2011; Levy and Feldman, 2022; Golea et al., 2023). In temperate agricultural systems, wheat is a strategic component of food security, as its productivity and grain characteristics directly influence both economic performance and technological use (Marin, 2014; Soare and Chiurciu, 2016). In Romania, wheat remains one of the main field crops, with high agronomic and economic relevance (Chiurciu et al., 2020), and its performance depends on the interaction between genetic potential, environmental conditions and crop management (Marinciu et al., 2013; Marin et al., 2015). Climate variability and climate change have made this interaction increasingly important. At global and European levels, wheat production is affected by changes in temperature regime, rainfall distribution, drought frequency and extreme weather events, which may alter crop development, phenology and yield stability (Cantelaube et al., 2004; Yue et al., 2019; Klepeckas et al., 2020). In Romania, increasing air temperatures may accelerate winter wheat phenology, while rainfall variability remains a major factor affecting grain yield and plant height (Croitoru et al., 2012; Marinciu et al., 2013). Drought and heat stress during critical stages of vegetative growth, spike formation and grain filling may restrict yield potential and reduce the stability

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of cultivar performance (Melucă et al., 2011; Voinea, 2019; Berca et al., 2021; Manole et al., 2023), as confirmed during the very dry 2019-2020 growing season in southern Romania (Berca et al., 2021). Under such variable conditions, cultivar choice becomes a key element for achieving high and stable wheat yields. Wheat cultivars differ in yield potential, ecological plasticity, response to climatic stress and stability across contrasting environments (Bunta, 2002; Mustățea et al., 2008; Voica, 2010; Voinea, 2013, 2019), and cultivar performance is strongly dependent on local environmental conditions, with significant differences among cultivars in grain yield, plant height, number of productive ears, grain number per ear, thousand-kernel weight and hectolitre mass (Dragomir, 2017; Dunăreanu and Bonea, 2020). The use of cultivars with broad adaptability may reduce the risk of yield losses in unfavourable years (Melucă et al., 2011; Marinciu et al., 2013; Voinea, 2019; Manole et al., 2023), while comparative testing remains necessary because genotype × environment interactions may change the hierarchy of cultivars from one year to another (Dragomir, 2017; Dunăreanu and Bonea, 2020). Grain yield alone cannot fully describe cultivar behaviour, as it results from several interacting components. In winter wheat, spike number per unit area, grain weight per spike and thousand-kernel weight provide essential information on how plants build productivity under specific environmental and technological conditions (Sokoto et al., 2012; Mandea et al., 2019; Paunescu et al., 2023), while compensation among these components may occur depending on cultivar, environment and management (Mandea et al., 2019; Tillett et al., 2022). Spike number is strongly influenced by stand establishment and tillering, whereas grain weight per spike and thousand-kernel weight reflect the capacity of plants to support grain formation and filling (Kiss et al., 2018; Mandea et al., 2019; Tillett et al., 2022). Among technological factors, SD plays a central role by directly influencing stand structure, tillering capacity, interplant competition and the final distribution of yield components. Higher sowing rates may increase spike number per unit area, but excessive density can intensify competition for light, water and nutrients, reducing individual plant productivity or thousand-kernel weight (Petrović et al., 2008; Kiss et al., 2018). Conversely, lower densities may be partially compensated through productive tillering, higher grain number per spike or increased kernel weight (Petrović et al., 2008; Kiss et al., 2018; Mandea et al., 2019), and the highest density is not always associated with the highest yield (Baloch et al., 2010; Mukherjee, 2012; Jat et al., 2013; Klepeckas et al., 2020; Jarecki, 2024; Lachutta and Jankowski, 2024). Similar findings were reported in southern Romania, where productivity elements varied according to cultivar, crop management and year conditions (Mandea et al., 2016; Mustăţea and Săulescu, 2011; Melucă et al., 2021; Voinea et al., 2022; Marinciu et al., 2022; Partal et al., 2023; Partal and Contescu, 2025). The effect of SD must be interpreted in relation to the local soil and climatic background. The Moara Domnească area, located in Ilfov County, is a relevant testing environment for evaluating cultivar × SD interactions under the conditions of the Romanian Plain. Previous studies carried out at Moara Domnească showed that wheat yield and crop parameters may vary depending on biological material, soil tillage, crop rotation, nitrogen fertilisation and rainfall conditions (Ciontu et al., 2012; Marin et al., 2015). More generally, soil tillage and sowing systems can also modify productive stem density, productive tillering, ear length, grain number per ear and grain weight (Gyrka et al., 2018). Although numerous studies have investigated the effects of cultivar, sowing density and crop management on winter wheat performance under different environmental conditions, cultivar-specific responses to sowing density remain insufficiently documented, particularly under increasingly variable climatic conditions. Since grain yield results from the interaction among yield components, understanding how different cultivars adjust spike density, grain weight per spike and thousand-kernel weight across a range of sowing densities is essential for optimising crop management and improving yield stability. Therefore, the objective of this study was to evaluate the influence of four winter wheat cultivars and five sowing densities on grain yield, spike density, grain weight per spike and thousand-kernel weight over two growing seasons under contrasting weather conditions.

MATERIAL AND METHODS

Experimental site and soil conditions

The experiment was conducted over two growing seasons, 2022-2023 and 2023-2024, at the Moara Domnească Agricultural Research-Development Didactic Station, Ilfov County, Romania, belonging to the University of Agronomic Sciences and Veterinary Medicine of Bucharest. The experimental field was located on a reddish preluvosol, a soil type frequently encountered in the Romanian Plain. According to previous studies, the soil has a clay-loam texture, low to moderate humus content and a moderately acidic reaction (Gheorghiță et al., 2008; Mihalache et al., 2010; Călina and Călina, 2019; Petcu and Mihalache, 2022). Under agricultural use, this soil may present limitations related to water infiltration, permeability and compaction, particularly under unfavourable moisture conditions (Mihalache et al., 2010; Călina and Călina, 2019; Petcu and Mihalache, 2022).

Climatic data

The climatic characterisation of the experimental period was based on meteorological data obtained from the Open-Meteo historical weather archive for the coordinates of the experimental site at Moara Domnească, Ilfov County, Romania. Monthly mean air temperature and total monthly precipitation were used to describe the two growing seasons, 2022-2023 and 2023-2024, in relation to the 1991-2020 long-term average (Table 1). The two experimental years showed distinct climatic patterns. The year 2023-2024 was warmer and recorded higher precipitation than 2022-2023. Both years recorded mean annual temperatures above the 1991-2020 multiannual reference, while precipitation was clearly lower in 2022-2023 and closer to the long-term average in 2023-2024.

Table 1. Climatic conditions at Moara Domnească during the 2022-2023 and 2023-2024 growing seasons, compared with the 1991-2020 long-term average

Month	Monthly mean temperature (°C)			Precipitation (mm)		
	2022-2023	2023-2024	1991-2020	2022-2023	2023-2024	1991-2020
October	14.0	15.6	12.3	10.3	21.1	50.4
November	8.9	7.9	6.3	32.9	124.7	45.2
December	2.8	3.8	0.7	25.8	32.6	45.1
January	4.4	0.6	-1.0	81.1	37.8	38.7
February	2.8	7.4	1.4	6.0	19.7	33.1
March	7.9	8.2	6.1	30.5	54.3	45.8
April	10.4	14.9	11.9	79.6	81.2	53.1
May	16.5	16.4	17.4	43.9	36.3	67.8
June	21.7	25.4	21.5	46.9	29.4	82.7
July	25.5	27.4	23.7	47.3	42.2	73.3
August	25.3	26.4	23.7	24.1	39.0	44.7
September	21.1	20.1	18.4	16.6	104.9	60.8
Mean/Total	13.4	14.5	11.9	445.0	623.2	640.6

Source: Open-Meteo historical weather archive, https://open-meteo.com/

Biological material and experimental design

The biological material consisted of four winter wheat cultivars registered in the Official Catalogue of Crop Plant Varieties in Romania for 2022 published by SITRV (State Institute for Testing and Registration of Varieties): Glosa, FDL Abund, Python and Promitor. Basic seed, category B, was used for all cultivars. The trial was organised as a bifactorial 4 × 5 (split-plot design) field experiment with four replications. Factor A was winter wheat cultivar: a_1 = Glosa, a_2 = FDL Abund, a_3 = Python and a_4 = Promitor, while Factor B consisted of sowing density (SD) levels: 350, 450, 550, 650 and 750 germinating seeds m^{-2}. The tested densities were selected to cover a broad technological range, from reduced to high stand establishment rates, as commonly used in winter wheat cultivation. The cultivar Glosa was considered the control cultivar, while 550 germinating seeds m^{-2} represented the control SD included in the experimental design.

Crop management

The crop was established under conventional field management. In the 2022-2023 growing season, winter wheat was grown after maize, whereas in 2023-2024 the preceding crop was chickpea. In both years, seedbed preparation consisted of ploughing followed by disc harrowing. Basal fertilisation was applied during seedbed preparation at rates of 60 kg active ingredient ha^{-1} nitrogen and 60 kg active ingredient ha^{-1} phosphorus. Sowing was carried out in autumn, around mid-October in the first year and in the last decade of October in the second year. At the resumption of spring vegetation, a top-dressing nitrogen fertilisation of 60 kg active ingredient ha^{-1} was applied. Weed control was performed in spring, at the post-emergence stage, using a herbicide based on florasulam and 2,4-D, applied at rates of 3.125 g a.i. ha^{-1} florasulam and 150 g a.i. ha^{-1} 2,4-D. A fungicide based on propiconazole and prochloraz was applied at rates of 72 g a.i. ha^{-1} propiconazole and 320 g a.i. ha^{-1} prochloraz in 2022-2023. In 2023-2024, a two-product fungicide programme was used, consisting of azoxystrobin at 187.5 g a.i. ha^{-1} followed by fenpropidin at 270 g a.i. ha^{-1}. Crops were harvested at full grain maturity, in early July in the first year and in the second half of June in the second year.

Traits measured and data collection

The following agronomic traits were recorded: grain yield, spike density (spikes m^{-2}), grain weight per spike, and thousand-kernel weight (TKW). At harvest, samples were collected from each plot using a 70 × 70 cm metric frame, corresponding to an area of 0.49 m^2. All spikes within the sampled area were counted to determine spike density. Grain weight per spike was determined from a representative sample of 10 spikes by threshing and weighing the grains, followed by calculation of the average grain weight per spike. Thousand-kernel weight was determined by weighing 1,000 grains and expressed in grams.

Statistical analysis

Data were analysed separately for each growing season using a two-way ANOVA model, with cultivar, sowing density (SD) and their interaction (cultivar × SD) considered as sources of variation. The field trial was established with four replications, and the final statistical processing was performed using the validated dataset available for each trait. Mean comparisons were carried out relative to the reference cultivar (Glosa) and the reference sowing density (550 germinating seeds m^{-2}), using the least significant difference (LSD) test. LSD values at $p \leq 0.10$, $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ are presented below each table.

RESULTS AND DISCUSSION

Influence of sowing density on grain yield

In the 2022-2023 growing season, which was characterised by a lower total precipitation amount compared with the long-term average, reducing the SD to 350 or 450 g.s. m^{-2}, as well as increasing it to 650 g.s. m^{-2}, did not result in statistically significant yield increases compared with the control. At 750 germinating seeds m^{-2}, a decreasing trend in grain yield was observed across most cultivars, indicating that higher SD did not confer a yield advantage under drier conditions.

In the 2023-2024 growing season, which recorded a higher total amount of precipitation and values closer to the long-term average, the general yield level tended to be higher than in the previous year. Nevertheless, changes in SD, either below or above the control, remained within the range of statistically non-significant deviations. This suggests that the more favourable water supply in 2023-2024 may have reduced the contrast among SD levels and contributed to a more uniform yield response across the tested SD range.

Across both growing seasons, no alternative SD significantly exceeded the control in terms of grain yield. The 550 germinating seeds m^{-2} level may therefore be considered a stable reference under the experimental conditions. Nevertheless, cultivar-specific yield maxima observed across SD treatments indicate that yield response patterns are genotype-dependent and cannot be generalised across cultivars.

Table 2. Grain yield (GY, kg ha^{-1}) of winter wheat as influenced by sowing density in the 2022-2023 and 2023-2024 growing seasons

Cultivar	SD (g.s. m^{-2})																		
	550			350				450				650				750			
	GY	%	Sig.	GY	%	Diff.	Sig.	GY	%	Diff.	Sig.	GY	%	Diff.	Sig.	GY	%	Diff.	Sig.
2022-2023																			
Glosa	6,239.67	100.00	C	5,832.87	93.48	-406.80	-	6,080.60	97.45	-159.07	-	5,742.27	92.03	-497.40	-	5,548.20	88.92	-691.47	o
FDL Abund	5,434.87	100.00	C	5,344.00	98.33	-90.87	-	5,367.93	98.77	-66.93	-	5,632.07	103.63	197.20	-	5,075.07	93.38	-359.80	-
Python	5,897.53	100.00	C	6,317.07	107.11	419.53	-	6,020.80	102.09	123.27	-	5,480.67	92.93	-416.87	-	5,091.67	86.34	-805.87	oo
Promitor	3,913.87	100.00	C	4,217.47	107.76	303.60	-	4,037.67	103.16	123.80	-	3,887.27	99.32	-26.60	-	3,782.67	96.65	-131.20	-
LSD 10% = 491.3333; LSD 5% = 589.6571; LSD 1% = 788.9326; LSD 0.1% = 1036.0576																			
2023-2024																			
Glosa	6,505.07	100.00	C	6,334.20	97.37	-170.87	-	6,422.80	98.74	-82.27	-	6,318.73	97.14	-186.33	-	6,127.73	94.20	-377.33	-
FDL Abund	5,810.87	100.00	C	5,585.80	96.13	-225.07	-	5,743.13	98.83	-67.73	-	5,991.07	103.10	180.20	-	5,367.53	92.37	-443.33	-
Python	5,896.27	100.00	C	6,373.87	108.10	477.60	-	6,083.73	103.18	187.47	-	5,816.33	98.64	-79.93	-	5,757.80	97.65	-138.47	-
Promitor	4,279.00	100.00	C	4,691.07	109.63	412.07	-	4,351.60	101.70	72.60	-	4,143.67	96.84	-135.33	-	4,041.07	94.44	-237.93	-
LSD 10% = 478.3024; LSD 5% = 574.0197; LSD 1% = 768.0105; LSD 0.1% = 1008.5818																			

Specifically, cultivar responses to sowing density (SD) were not uniform. In both growing seasons, Glosa achieved its maximum grain yield at 550 germinating seeds m^{-2}. FDL Abund recorded the highest yield at 650 germinating seeds m^{-2}, indicating a positive response to moderately increased plant density. In contrast, Python and Promitor showed higher yield values at the lowest tested SD (350 germinating seeds m^{-2}), suggesting different patterns of yield formation across cultivars.

Influence of cultivar on grain yield

During the 2022-2023 season, the cultivars showed different yield responses. Across the tested SD, Glosa generally recorded the highest grain yield values, followed by Python, FDL Abund and Promitor. None of the tested cultivars produced a statistically significant positive yield increase compared with the control cultivar Glosa. Conversely, Promitor registered statistically significant negative differences at all tested SD, indicating a consistently lower yield compared with Glosa.

Table 3. Grain yield (GY, kg ha^{-1}) of winter wheat as influenced by cultivar in the 2022-2023 and 2023-2024 growing seasons

Cultivar	SD (g.s. m^{-2})																			
	550				350				450				650				750			
	GY	%	Diff.	Sig.	GY	%	Diff.	Sig.	GY	%	Diff.	Sig.	GY	%	Diff.	Sig.	GY	%	Diff.	Sig.
2022-2023																				
Glosa	6,239.67	100.00	C	C	5,832.87	100.00	C	C	6,080.60	100.00	C	C	5,742.27	100.00	C	C	5,548.20	100.00	C	C
FDL Abund	5,434.87	87.10	-804.80	oo	5,344.00	91.62	-488.87	-	5,367.93	88.28	-712.67	o	5,632.07	98.07	-110.20	-	5,075.07	91.47	-473.13	-
Python	5,897.53	94.52	-342.13	-	6,317.07	108.30	484.20	-	6,020.80	99.02	-59.80	-	5,480.67	95.44	-261.60	-	5,091.67	91.77	-456.53	-
Promitor	3,913.87	62.73	-2,325.80	ooo	4,217.47	72.31	-1,615.40	ooo	4,037.67	66.40	-2,042.93	ooo	3,887.27	67.70	-1,855.00	ooo	3,782.67	68.18	-1,765.53	ooo
LSD 10% = 491.3333; LSD 5% = 589.6571; LSD 1% = 788.9326; LSD 0.1% = 1036.0576																				
2023-2024																				
Glosa	6,505.07	100.00	C	C	6,334.20	100.00	C	C	6,422.80	100.00	C	C	6,318.73	100.00	C	C	6,127.73	100.00	C	C
FDL Abund	5,810.87	89.33	-694.20	o	5,585.80	88.18	-748.40	o	5,743.13	89.42	-679.67	o	5,991.07	94.81	-327.67	-	5,367.53	87.59	-760.20	o
Python	5,896.27	90.64	-608.80	o	6,373.87	100.63	39.67	-	6,083.73	94.72	-339.07	-	5,816.33	92.05	-502.40	-	5,757.80	93.96	-369.93	-
Promitor	4,279.00	65.78	-2,226.07	ooo	4,691.07	74.06	-1,643.13	ooo	4,351.60	67.75	-2,071.20	ooo	4,143.67	65.58	-2,175.07	ooo	4,041.07	65.95	-2,086.67	ooo
LSD 10% = 478.3024; LSD 5% = 574.0197; LSD 1% = 768.0105; LSD 0.1% = 1008.5818																				

In the 2023-2024 growing season, the cultivar response followed a similar general pattern to that observed in the previous year. Glosa again showed the highest overall yield level across the tested sowing densities, followed by Python, FDL Abund and Promitor. Although the higher precipitation level in 2023-2024 resulted in increased overall yield compared with 2022-2023, no cultivar surpassed Glosa in a statistically significant manner across treatments.

Overall, cultivar had a clear role in yield expression. Glosa showed the most productive and stable behaviour across both years, while Python occupied the second position in most SD treatments. FDL Abund showed an intermediate yield performance, with its best expression at 650 g.s. m^{-2}, whereas Promitor recorded the lowest yield level among the tested cultivars. Overall, cultivar effects were evident in grain yield expression across SD levels and growing seasons, despite the lack of significant differences between some treatment combinations.

Influence of sowing density on spike density

A reduction in sowing density to 350 g.s. m^{-2} led to a decrease in spike number per square metre relative to the control SD during the 2022-2023 season. In contrast, increasing SD to 750 g.s. m^{-2} produced statistically significant increases in spike density for several cultivars. Compared with the control: FDL Abund recorded a very significant increase of +52.00 spikes m^{-2}, Python recorded a distinct significant increase of +44.00 spikes m^{-2}, and Promitor recorded a distinct significant increase of +41.33 spikes m^{-2}.

Table 4. Spike density (NS, no. spikes m^{-2}) of winter wheat as influenced by sowing density in the 2022-2023 and 2023-2024 growing seasons

Cultivar	SD (g.s. m^{-2})																	
	550			350				450				650				750			
	NS	%	Sig.	NS	%	Diff.	Sig.	NS	%	Diff.	Sig.	NS	%	Diff.	Sig.	NS	%	Diff.	Sig.
2022-2023																			
Glosa	566.67	100.00	C	478.67	84.47	-88.00	ooo	520.67	91.88	-46.00	oo	578.00	102.00	11.33	-	585.33	103.29	18.67	-
FDL Abund	470.00	100.00	C	416.00	88.51	-54.00	ooo	438.00	93.19	-32.00	o	506.00	107.66	36.00	*	522.00	111.06	52.00	***
Python	556.00	100.00	C	506.67	91.13	-49.33	oo	546.00	98.20	-10.00	-	574.00	103.24	18.00	-	600.00	107.91	44.00	**
Promitor	408.67	100.00	C	378.00	92.50	-30.67	o	384.00	93.96	-24.67	-	433.33	106.04	24.67	-	450.00	110.11	41.33	**
LSD 10% = 24.5310; LSD 5% = 29.4402; LSD 1% = 39.3895; LSD 0.1% = 51.7279																			
2023-2024																			
Glosa	586.67	100.00	C	515.33	87.84	-71.33	ooo	554.00	94.43	-32.67	o	601.33	102.50	14.67	-	635.33	108.30	48.67	**
FDL Abund	494.67	100.00	C	442.00	89.35	-52.67	oo	458.00	92.59	-36.67	o	514.00	103.91	19.33	-	527.33	106.60	32.67	*
Python	563.33	100.00	C	512.67	91.01	-50.67	oo	549.33	97.51	-14.00	-	577.33	102.49	14.00	-	614.00	108.99	50.67	**
Promitor	430.67	100.00	C	405.33	94.12	-25.33	-	419.33	97.37	-11.33	-	454.67	105.57	24.00	-	486.00	112.85	55.33	**
LSD 10% = 27.0902; LSD 5% = 32.5115; LSD 1% = 43.4988; LSD 0.1% = 57.1243																			

The 2023-2024 data followed the same general trend. The highest sowing density (750 germinating seeds m^{-2}) increased spike density (spikes m^{-2}) compared with the reference density (550 germinating seeds m^{-2}) across all cultivars. The observed increases were +48.67 spikes m^{-2} for Glosa, +32.67 spikes m^{-2} for FDL Abund, +50.67 spikes m^{-2} for Python and +55.33 spikes m^{-2} for Promitor. These results indicated a positive association between SD and final spike density. Increasing SD to 750 g.s. m^{-2} increased the number of harvestable spikes per unit area in both growing seasons. However, this structural increase did not necessarily translate into a statistically significant grain yield increase, pointing to compensation between yield components. Higher spike density may increase the productive surface of the crop, but it may also be associated with stronger interplant competition and with lower expression of individual spike productivity or grain weight.

Across sowing densities, cultivar ranking for spike density showed slight interannual variations. In 2022-2023, Python recorded the highest overall spike density, followed by Glosa, FDL Abund and Promitor. In 2023-2024, Glosa recorded the highest overall spike density, followed by Python, FDL Abund and Promitor. Overall, Glosa and Python exhibited the highest capacity to maintain elevated spike density levels across environments.

Influence of cultivar on spike density

In the 2022-2023 agricultural season, Python showed a final spike density close to that of Glosa, with no statistically significant positive difference, although it recorded a slightly higher overall spike number. FDL Abund and Promitor generally recorded lower spike density values.

In the 2023-2024 growing season, the cultivar response was generally similar. None of the tested cultivars showed a statistically significant increase in spike density compared with Glosa. Glosa maintained a high capacity to form and retain harvestable spikes, while Python remained close to it. FDL Abund and Promitor recorded lower values.

Table 5. Spike density (NS, no. spikes m^{-2}) of winter wheat as influenced by cultivar in the 2022-2023 and 2023-2024 growing seasons

Cultivar	SD (g.s. m^{-2})																			
	550				350				450				650				750			
	NS	%	Diff.	Sig.	NS	%	Diff.	Sig.	NS	%	Diff.	Sig.	NS	%	Diff.	Sig.	NS	%	Diff.	Sig.
2022-2023																				
Glosa	566.67	100.00	C	C	478.67	100.00	C	C	520.67	100.00	C	C	578.00	100.00	C	C	585.33	100.00	C	C
FDL Abund	470.00	82.94	-96.67	ooo	416.00	86.91	-62.67	ooo	438.00	84.12	-82.67	ooo	506.00	87.54	-72.00	ooo	522.00	89.18	-63.33	ooo
Python	556.00	98.12	-10.67	-	506.67	105.85	28.00	-	546.00	104.87	25.33	-	574.00	99.31	-4.00	-	600.00	102.51	14.67	-
Promitor	408.67	72.12	-158.00	ooo	378.00	78.97	-100.67	ooo	384.00	73.75	-136.67	ooo	433.33	74.97	-144.67	ooo	450.00	76.88	-135.33	ooo
LSD 10% = 24.5310; LSD 5% = 29.4402; LSD 1% = 39.3895; LSD 0.1% = 51.7279																				
2023-2024																				
Glosa	586.67	100.00	C	C	515.33	100.00	C	C	554.00	100.00	C	C	601.33	100.00	C	C	635.33	100.00	C	C
FDL Abund	494.67	84.32	-92.00	ooo	442.00	85.77	-73.33	ooo	458.00	82.67	-96.00	ooo	514.00	85.48	-87.33	ooo	527.33	83.00	-108.00	ooo
Python	563.33	96.02	-23.33	-	512.67	99.48	-2.67	-	549.33	99.16	-4.67	-	577.33	96.01	-24.00	-	614.00	96.64	-21.33	-
Promitor	430.67	73.41	-156.00	ooo	405.33	78.65	-110.00	ooo	419.33	75.69	-134.67	ooo	454.67	75.61	-146.67	ooo	486.00	76.50	-149.33	ooo
LSD 10% = 27.0902; LSD 5% = 32.5115; LSD 1% = 43.4988; LSD 0.1% = 57.1243																				

Overall, final spike density appeared to be influenced by cultivar. Glosa and Python showed the highest capacity to ensure crop stand productivity through spike number, whereas FDL Abund and Promitor relied less on spike density. This distinction is important because grain yield was not determined by spike number alone, but by the balance between spike density, grain weight per spike and thousand-kernel weight.

Influence of sowing density on grain weight per spike

During the 2022-2023 growing season, the lowest sowing density (350 germinating seeds m^{-2}) resulted in higher grain weight per spike across all cultivars compared with the reference density. The observed increases were +0.12 g for Glosa, +0.11 g for FDL Abund, +0.22 g for Python and +0.18 g for Promitor. These results indicate higher grain weight per spike at reduced plant density, particularly in Python.

In the 2023-2024 growing season, the same compensatory tendency was observed. At 350 germinating seeds m^{-2}, grain weight per spike increased across cultivars, with statistically supported differences in Glosa, Python and Promitor, while FDL Abund showed a small, non-significant increase. This response was particularly relevant because Python and Promitor also recorded their highest grain yields at 350 g.s. m^{-2} in both years. Therefore, for these cultivars, lower SD may have supported yield formation through improved individual spike productivity.

Overall, grain weight per spike showed an inverse relationship with sowing density, with higher values at lower plant density and reduced values at higher density treatments.

Table 6. Grain weight per spike (GW, g spike $^{-1}$) of winter wheat as influenced by sowing density in the 2022-2023 and 2023-2024 growing seasons

Cultivar	SD (g.s. m⁻²)																		
	550			350				450				650				750			
	GW	%	Sig.	GW	%	Diff.	Sig.	GW	%	Diff.	Sig.	GW	%	Diff.	Sig.	GW	%	Diff.	Sig.
2022-2023																			
Glosa	1.28	100.00	C	1.39	109.23	0.12	**	1.31	102.88	0.04	-	1.15	89.96	-0.13	ooo	1.11	87.27	-0.16	ooo
FDL Abund	1.33	100.00	C	1.45	108.37	0.11	**	1.39	104.15	0.06	-	1.27	95.40	-0.06	-	1.14	85.49	-0.19	ooo
Python	1.23	100.00	C	1.45	117.61	0.22	***	1.30	105.02	0.06	-	1.18	95.52	-0.06	-	1.12	90.63	-0.12	oo
Promitor	1.17	100.00	C	1.35	115.37	0.18	***	1.26	107.71	0.09	*	1.07	91.66	-0.10	oo	1.01	86.38	-0.16	ooo
LSD 10% = 0.0598; LSD 5% = 0.0717; LSD 1% = 0.0959; LSD 0.1% = 0.1260																			
2023-2024																			
Glosa	1.37	100.00	C	1.48	107.66	0.11	**	1.40	101.82	0.03	-	1.24	90.52	-0.13	ooo	1.16	84.53	-0.21	ooo
FDL Abund	1.42	100.00	C	1.49	104.58	0.06	-	1.45	102.04	0.03	-	1.40	98.62	-0.02	-	1.24	87.23	-0.18	ooo
Python	1.34	100.00	C	1.52	113.43	0.18	***	1.39	103.69	0.05	-	1.29	96.61	-0.05	-	1.20	90.05	-0.13	ooo
Promitor	1.28	100.00	C	1.41	110.61	0.14	***	1.32	103.45	0.04	-	1.19	93.28	-0.09	o	1.09	85.15	-0.19	ooo
LSD 10% = 0.0573; LSD 5% = 0.0688; LSD 1% = 0.0920; LSD 0.1% = 0.1208																			

Influence of cultivar on grain weight per spike

During the 2022-2023 growing season, FDL Abund recorded the highest grain weight per spike at 650 germinating seeds m⁻², with a significant increase of +0.13 g compared with the reference cultivar Glosa. The other cultivars did not show statistically significant positive differences compared with the control.

Table 7. Grain weight per spike (GW, g spike $^{-1}$) of winter wheat as influenced by cultivar in the 2022-2023 and 2023-2024 growing seasons

Cultivar	SD (g.s. m⁻²)																			
	550				350				450				650				750			
	GW	%	Diff.	Sig.	GW	%	Diff.	Sig.	GW	%	Diff.	Sig.	GW	%	Diff.	Sig.	GW	%	Diff.	Sig.
2022-2023																				
Glosa	1.28	100.00	C	C	1.39	100.00	C	C	1.31	100.00	C	C	1.15	100.00	C	C	1.11	100.00	C	C
FDL Abund	1.33	104.68	0.06	-	1.45	103.85	0.05	-	1.39	105.97	0.08	*	1.27	111.01	0.13	***	1.14	102.55	0.03	-
Python	1.23	96.78	-0.04	-	1.45	104.21	0.06	-	1.30	98.81	-0.02	-	1.18	102.76	0.03	-	1.12	100.51	0.01	-
Promitor	1.17	91.53	-0.11	oo	1.35	96.67	-0.05	-	1.26	95.83	-0.05	-	1.07	93.26	-0.08	o	1.01	90.59	-0.10	oo
LSD 10% = 0.0598; LSD 5% = 0.0717; LSD 1% = 0.0959; LSD 0.1% = 0.1260																				
2023-2024																				
Glosa	1.37	100.00	C	C	1.48	100.00	C	C	1.40	100.00	C	C	1.24	100.00	C	C	1.16	100.00	C	C
FDL Abund	1.42	103.60	0.05	-	1.49	100.63	0.01	-	1.45	103.82	0.05	-	1.40	112.87	0.16	***	1.24	106.90	0.08	*
Python	1.34	97.57	-0.03	-	1.52	102.80	0.04	-	1.39	99.36	-0.01	-	1.29	104.14	0.05	-	1.20	103.94	0.05	-
Promitor	1.28	93.02	-0.10	oo	1.41	95.57	-0.07	-	1.32	94.51	-0.08	o	1.19	95.86	-0.05	-	1.09	93.70	-0.07	o
LSD 10% = 0.0573; LSD 5% = 0.0688; LSD 1% = 0.0920; LSD 0.1% = 0.1208																				

In 2023-2024, a similar cultivar-specific response was observed for FDL Abund. At 650 g.s. m⁻², this cultivar recorded a very significant increase of +0.16 g compared with Glosa. This supports a stable tendency of FDL Abund to express higher grain weight per spike at the moderately increased SD of 650 g.s. m⁻².

This result is consistent with the yield pattern observed for FDL Abund, which reached its highest grain yield at 650 g.s. m⁻² in both growing seasons. Therefore, FDL Abund appears to rely more on individual spike productivity than on a high number of spikes per square metre. This suggests a cultivar-specific yield formation strategy based on heavier spikes, especially at intermediate-to-high sowing density.

Influence of sowing density on thousand-kernel weight

The 2022-2023 growing season, characterised by lower precipitation, showed higher thousand-kernel weight values at the lowest sowing density across all cultivars. Compared with the reference density of 550 g.s. m^{-2}, the differences recorded at 350 g.s. m^{-2} were +1.23 g in Glosa, +0.91 g in FDL Abund, +1.95 g in Python and +1.43 g in Promitor.

In the 2023-2024 growing season, positive responses of thousand-kernel weight were again observed at reduced SD, especially at 350 g.s. m^{-2}, where all cultivars recorded higher values compared with the control.

In both growing seasons, reduced SD tended to favour thousand-kernel weight. This response was consistent with the results observed for grain weight per spike, suggesting that lower crop density supported individual productivity components. However, higher thousand-kernel weight did not automatically lead to higher grain yield in all cultivars, because yield also depended on spike density.

Influence of cultivar on thousand-kernel weight

In 2022-2023, Glosa recorded the highest thousand-kernel weight values and none of the other cultivars produced statistically significant positive differences compared with it. This suggests that Glosa had a strong capacity for grain filling under the more restrictive precipitation conditions of the first growing season.

In the 2023-2024 growing season, a similar pattern was observed. Glosa again remained the reference cultivar with the highest thousand-kernel weight values, and none of the other cultivars exceeded it significantly.

Overall, thousand-kernel weight appeared to be one of the traits that supported the stable performance of Glosa.

Table 8. Thousand-kernel weight (TKW, grams) of winter wheat as influenced by sowing density in the 2022-2023 and 2023-2024 growing seasons

	SD (g.s. m^{-2})																		
Cultivar	550			350				450				650				750			
	TKW	%	Sig.	TKW	%	Diff.	Sig.	TKW	%	Diff.	Sig.	TKW	%	Diff.	Sig.	TKW	%	Diff.	Sig.
2022-2023																			
Glosa	38.03	100.00	C	39.27	103.24	1.23	***	38.47	101.14	0.43	-	37.22	97.85	-0.82	oo	36.90	97.02	-1.13	ooo
FDL Abund	36.82	100.00	C	37.73	102.48	0.91	**	37.10	100.77	0.28	-	35.88	97.46	-0.93	oo	33.93	92.17	-2.88	ooo
Python	37.08	100.00	C	39.04	105.27	1.95	***	37.91	102.23	0.83	**	36.42	98.20	-0.67	o	35.69	96.25	-1.39	ooo
Promitor	36.87	100.00	C	38.29	103.87	1.43	***	37.84	102.63	0.97	**	35.98	97.59	-0.89	oo	35.53	96.38	-1.33	ooo
LSD 10% = 0.4931; LSD 5% = 0.5917; LSD 1% = 0.7917; LSD 0.1% = 1.0397																			
2023-2024																			
Glosa	38.98	100.00	C	40.02	102.67	1.04	***	39.62	101.62	0.63	*	38.01	97.51	-0.97	ooo	37.25	95.55	-1.73	ooo
FDL Abund	37.17	100.00	C	38.05	102.38	0.88	**	37.62	101.21	0.45	-	36.80	99.01	-0.37	-	35.03	94.26	-2.13	ooo
Python	37.44	100.00	C	39.54	105.63	2.11	***	38.07	101.68	0.63	*	37.00	98.83	-0.44	-	36.13	96.52	-1.30	ooo
Promitor	37.18	100.00	C	38.80	104.35	1.62	***	38.13	102.55	0.95	**	36.46	98.05	-0.72	oo	36.03	96.91	-1.15	ooo
LSD 10% = 0.4405; LSD 5% = 0.5286; LSD 1% = 0.7073; LSD 0.1% = 0.9288																			

Table 9. Thousand-kernel weight (TKW, grams) of winter wheat as influenced by cultivar in the 2022-2023 and 2023-2024 growing seasons

	SD (g.s. m^{-2})																			
Cultivar	550				350				450				650				750			
	TKW	%	Diff.	Sig.	TKW	%	Diff.	Sig.	TKW	%	Diff.	Sig.	TKW	%	Diff.	Sig.	TKW	%	Diff.	Sig.
2022-2023																				
Glosa	38.03	100.00	C	C	39.27	100.00	C	C	38.47	100.00	C	C	37.22	100.00	C	C	36.90	100.00	C	C
FDL Abund	36.82	96.80	-1.22	ooo	37.73	96.09	-1.54	ooo	37.10	96.45	-1.37	ooo	35.88	96.42	-1.33	ooo	33.93	91.96	-2.97	ooo
Python	37.08	97.50	-0.95	oo	39.04	99.41	-0.23	-	37.91	98.55	-0.56	-	36.42	97.85	-0.80	oo	35.69	96.73	-1.21	ooo
Promitor	36.87	96.93	-1.17	ooo	38.29	97.52	-0.97	oo	37.84	98.36	-0.63	o	35.98	96.68	-1.24	ooo	35.53	96.30	-1.37	ooo
LSD 10% = 0.4931; LSD 5% = 0.5917; LSD 1% = 0.7917; LSD 0.1% = 1.0397																				
2023-2024																				
Glosa	38.98	100.00	C	C	40.02	100.00	C	C	39.62	100.00	C	C	38.01	100.00	C	C	37.25	100.00	C	C
FDL Abund	37.17	95.34	-1.82	ooo	38.05	95.07	-1.97	ooo	37.62	94.95	-2.00	ooo	36.80	96.81	-1.21	ooo	35.03	94.05	-2.22	ooo
Python	37.44	96.03	-1.55	ooo	39.54	98.80	-0.48	-	38.07	96.09	-1.55	ooo	37.00	97.33	-1.01	ooo	36.13	97.00	-1.12	ooo
Promitor	37.18	95.38	-1.80	ooo	38.80	96.94	-1.22	ooo	38.13	96.26	-1.48	ooo	36.46	95.91	-1.55	ooo	36.03	96.73	-1.22	ooo
LSD 10% = 0.4405; LSD 5% = 0.5286; LSD 1% = 0.7073; LSD 0.1% = 0.9288																				

CONCLUSIONS

The results of this study indicate that grain yield and yield components of winter wheat are influenced by both cultivar and sowing density under the pedoclimatic conditions of Moara Domnească, Ilfov County.

The general yield level was higher in 2023-2024, when precipitation was closer to the long-term average, while the 2022-2023 growing season was more restrictive in terms of total rainfall.

The reference sowing density of 550 germinating seeds m^{-2} remained a valid comparison level for grain yield, as none of the alternative sowing densities showed statistically significant positive yield differences compared with it in the year-specific analyses. However, cultivar-specific responses to SD were evident, indicating that optimal plant density depends on genotype and yield formation strategy.

Higher SD (750 germinating seeds m^{-2}) increased spike density, but this effect was not consistently translated into higher grain yield, suggesting compensation among yield components. Conversely, lower SD (350 germinating seeds m-^{2}) tended to enhance individual spike productivity and thousand-kernel weight in several cultivars. Among the tested genotypes, Glosa displayed the most stable and generally productive behaviour across environments, while FDL Abund showed greater dependence on moderate-to-high sowing densities for maximising individual spike productivity. Python recorded an intermediate and stable performance, whereas Promitor had lower overall productivity.

In conclusion, the study highlights that grain yield in winter wheat should be interpreted together with its yield components. Under the conditions of this experiment, sowing density recommendations should consider cultivar-specific behaviour rather than relying exclusively on a single general density.

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