

COMPARATIVE STUDY BETWEEN WINTER WHEAT VARIETIES OF DIFFERENT ORIGINS REGARDING THE VALORIZATION OF WATER ACCUMULATED THROUGH PRECIPITATION DURING THE PERIOD 2023-2025 AT CARACAL

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Abstract

During the period 2023-2025, a wide range of winter wheat varieties of different origins were sown at SCDA Caracal. In addition to the local varieties, were sown varieties from France, Germany, Austria, Serbia, Hungary, marketed or tested in Romania by the companies: Syngenta, KWS, Donau Saat, Limagrain, Saaten Union, RAGT, Lidea, Axereal, Biocrop. In the agricultural year 2022-2023, there was a surplus of precipitation over the entire growing season for wheat (+67.3 mm), the surplus months being November, January, April and May, all against a background of low temperatures. The years 2023-2024 and 2024-2025 recorded a deficit of precipitation over the entire vegetation period but also surplus months - November and May, due to low temperatures, in both years and December only in 2024-2025, due to high temperatures. All these data were reported to the 35-year normal for the area. Distributions of the productions were made depending on the precipitations in certain phenophases and the coefficients of productions variability were calculated in order to identify the productively stable wheat varieties, regardless of climatic conditions.

Key words: wheat, precipitation, production, stability, climatic conditions.

INTRODUCTION

As one of the most important crops worldwide, wheat (*Triticum aestivum* L.) is extensively cultivated in arid and semi-arid regions, where the implementation of irrigation systems becomes indispensable for ensuring yield stability and food security (Yan et al., 2022). Since wheat is a staple cereal frequently grown under drought-prone conditions, proper irrigation management represents a critical factor sustaining both crop productivity and global food supply (Fang et al., 2018; Yuan et al., 2022).

Cultivar selection constitutes a fundamental component of wheat production technology, representing the first step toward achieving high quantitative and qualitative performance. The choice of genotype significantly influences yield potential, grain quality, and adaptability to environmental stressors.

Wheat productivity under water deficit conditions remains one of the major challenges of modern agriculture, particularly in the context

of ongoing climate change. Drought stress directly reduces yield by limiting photosynthetic activity and decreasing the number of kernels per spike, with particularly severe effects during critical phenological stages such as tillering and grain filling.

To mitigate these losses, agricultural research increasingly focuses on the development of genotypes with enhanced genetic tolerance to drought, capable of maintaining high water-use efficiency even under osmotic stress. The success of wheat cultivation in arid environments depends not only on total precipitation but, more importantly, on the cultivar's ability to extract water from deeper soil layers and to regulate evapotranspiration during periods of extreme heat.

Findings reported in the international literature emphasize that water deficit represents the primary limiting factor for global wheat production, causing average yield losses estimated between 50% and 60% in the absence of effective mitigation strategies (Nyaupane et al., 2024).

Improving the efficiency of natural resource use in agriculture is a major challenge of the current decade, with water management in wheat cultivation being a central pillar for ensuring food security. However, the added value of crop production does not stop at harvest, but extends to the livestock sector, where the quality of feed directly influences productive performance (Colă and Colă, 2021, 2024).

From the perspective of yield component dynamics, the impact of water deficit varies according to the timing of stress occurrence. Pre-anthesis stress (before flowering) significantly reduces the number of spikes per square meter and the number of kernels per spike (by approximately 16%). This stage is critical for the determination of yield components. In contrast, post-anthesis stress (during grain filling) predominantly affects thousand-kernel weight (TKW), reducing final grain weight by up to 29% (Miroslavljević et al., 2024). An increase in maximum temperatures around mid-anthesis may further lead to substantial yield reductions.

Water stress occurring during the tillering and stem elongation stages decreases the number of fertile tillers and, consequently, the number of spikes per unit area. Total grain yield may be severely compromised, as the number of kernels per square meter ($\text{spikes/m}^2 \times \text{kernels/spike}$) represents the principal determinant of yield, and this component is largely established before anthesis (Al-Ajlouni et al., 2016). Severe stress during stem elongation may reduce yield by up to 72% compared with optimal growing conditions (Kottmann et al., 2016).

Applying 60-80% of the total crop water requirement can maximize water-use efficiency without drastically penalizing yield. The adoption of drip or micro-sprinkler irrigation systems can reduce water inputs by more than 35% while maintaining harvest stability. Although overall yield may decline under water-limited conditions, drought stress tends to increase grain protein concentration by 9-18%, thereby improving certain bread-making quality parameters (Ma et al., 2025).

Drought-tolerant cultivars employ avoidance strategies (rapid stomatal closure) or escape mechanisms (shortening the period to flowering by up to 12 days) to reduce exposure to summer heat stress (Eser et al., 2024).

Ensuring optimal water supply for wheat crops is a critical challenge in the context of the new climatic realities in Romania, where extreme temperatures forecast for the near future (2021-2040) and variable precipitation regimes directly influence both the quality and quantity of the harvest (Velea et al., 2021). Water stress, not only affects production yield, but also the vulnerability of plants to pathogens, favoring epidemics such as fusarium head blight and the accumulation of mycotoxins (Prioteasa et al., 2025; Cotuna et al., 2022). In this context, understanding the relationship between water availability, the resistance of genetic lines under improvement and the efficiency of alternative organic products with fungicidal effect becomes essential for sustainable management of wheat (Paraschivu et al., 2024; Păunescu et al., 2022). Under Romanian climatic conditions, characterized by frequent pedological drought, several wheat cultivars have been developed and officially registered that combine local genetic resources (for stress resilience) with foreign germplasm (for high yield potential). For soil water conservation in wheat cropping systems, the most efficient technological approaches fall within the framework of conservation agriculture, based on minimizing soil disturbance and maintaining a protective residue layer at the soil surface.

MATERIALS AND METHODS

A collection consisting of 220 winter wheat cultivars of diverse genetic origins was sown over a three-year period (2023-2025) on a chernozem soil at Caracal.

The soil is characterized by a humus content of 3.04% in the Ap horizon and 1.78% in the Am horizon, decreasing by 1.24% in the B horizon. It is moderately supplied with total nitrogen (0.172% in Ap), very well supplied with available phosphorus in the Ap horizon (168 ppm), and well supplied with exchangeable potassium (248 ppm).

Soil reaction along the profile ranges from slightly acidic to slightly alkaline. The sum of exchangeable bases is moderate (23.2 in Ap and 24.8 in Am), while the base saturation degree reaches 92.62%, gradually increasing toward the Cca horizon.

The micronutrient content is high for zinc in the Ap horizon (176 ppm) but extremely low in the B horizon (0.40 ppm).

The soil texture is clay loam to silty clay loam within the first 70 cm and silty loam in the lower part of the profile. As a result, bulk density (BD) is moderate throughout the profile, with values of 1.46 g cm⁻³ in the Am horizon and 1.58 g cm⁻³ in the A/B horizon. Total porosity (TP) is moderate in Ap (48.8%) and high in Am (58.2%). Air-filled porosity (AFP) is moderate in Ap (15.2%), high in Am (23.8%), moderate in B (21.7%), and low in Cca (12.2%). Clay content varies between 33.4% and 40.3%.

Experimental plots were established in the research field, each covering an area of 7 m².

During the 2022-2023 growing season, a precipitation surplus was recorded over the entire wheat vegetation period (+67.3 mm), with excess rainfall occurring in November, January, April, and May, all associated with relatively low temperatures (Table 1). The 2023-2024 and 2024-2025 agricultural years showed similar patterns, characterized by an overall precipitation deficit during the wheat growing season (–32.3 mm and –39.1 mm, respectively). Nevertheless, surplus rainfall months were recorded in November and May in both years under low-temperature conditions, and in December during the 2024-2025 season under comparatively higher temperatures (Tables 2 and 3).

Table 1. Dynamics of the Main Climatic Factors during the Growing Season of Small-Grain Cereal Genotypes at S.C.D.A. Caracal, 2022-2023

Specification		X	XI	XII	I	II	III	IV	V	VI	Total for the Growing Season
Temperature (°C)	Monthly Mean	13.7	8.7	2.8	4.0	3.6	7.7	10.7	15.0	21.4	
	NORMAL	11.7	5.1	0.3	-1.3	0.8	6	12	17.7	21.6	
	(Multiannual Average)										
	Difference (±)	+2.0	+3.6	+2.5	+5.3	+2.8	+1.7	-1.3	-2.7	-0.2	
Average	Monthly Total	15.0	78.8	33.8	103.4	13.2	20.8	68.8	78.6	44.4	456.8
Precipitation (mm)	Multiannual Mean	46.0	37.0	39.1	30.8	26.3	34.2	47.8	58.6	69.7	389.5
	Difference (±)	-31.0	+31.8	-5.3	+72.6	-13.1	-13.4	+21.0	+20.0	-25.3	
Relative Air Humidity (%) Mean		75.5	93.0	97.8	96.5	86.0	79.2	84.2	80.5	80.6	

Table 2. Dynamics of the Main Climatic Factors during the Growing Season of Small-Grain Cereal Genotypes at S.C.D.A. Caracal, 2023-2024

Specification		X	XI	XII	I	II	III	IV	V	VI	Total for the Growing Season
Temperature (°C)	Monthly Mean	16.0	8.1	3.9	1.0	8.0	8.9	15.0	17.2	25.9	
	NORMAL	11.7	5.1	0.3	-1.3	0.8	6.0	12.0	17.7	21.6	
	(Multiannual Average)										
	Difference (±)	+4.3	+3.0	+3.6	+2.3	+7.2	+3.9	+3.0	-0.5	+4.3	
Average	Monthly Total	21.4	124.2	21.4	26.8	11.6	22.4	26.0	71.8	31.6	357.2
Precipitation (mm)	Multiannual Mean	46.0	37.0	39.1	30.8	26.3	34.2	47.8	58.6	69.7	389.5
	Difference (±)	-24.6	+87.2	-17.7	-4.0	-14.7	-11.8	-21.8	+13.2	-38.1	-32.3
Relative Air Humidity (%) Mean		66.9	91.1	93.8	95.4	84.7	85.3	70.8	77.8	61.3	

Table 3. Dynamics of the Main Climatic Factors during the Growing Season of Small-Grain Cereal Genotypes at S.C.D.A. Caracal, 2024-2025

Specification		X	XI	XII	I	II	III	IV	V	VI	Total for the Growing Season
Temperature (°C)	Monthly Mean	13.0	4.5	4.0	2.4	-1.3	9.3	12.5	16.0	24.0	9.37
	NORMAL	11.7	5.1	0.3	-1.3	0.8	6.0	12.0	17.7	21.6	8.21
	(Multiannual Average)										
	Difference (±)	+ 1.3	- 0.6	+3.7	+3.7	-2.1	+3.3	+0.5	-1.7	+2.4	+1.16
Average	Monthly Total	3.4	55.2	113.6	4.4	6.4	19.0	22.0	104.6	21.8	350.4
Precipitation (mm)	Multiannual Mean	46.0	37.0	39.1	30.8	26.3	34.2	47.8	58.6	69.7	389.5
	Difference (±)	-42.6	+18.2	+74.5	-26.4	-19.9	-15.2	-25.8	+46.0	-47.9	- 39.1
Relative Air Humidity (%) Mean		74.7	86.4	97.8	93.2	91.8	83.8	76.4	79.1	68.9	

The research was carried out in a randomized block design with 3 replications. Sowing was carried out at the optimal time, in the first decade of October, with a density of 550 germinable grains/m², after peas as a precursor plant. Fertilization was uniform for all variants, applying a dose of N100P40. Statistical analysis of the data was performed using statistical functions and the Data Analysis ToolPak module in Microsoft Excel.

For each tested cultivar, the following parameters were calculated: grain yield standardized to STAS moisture content, the coefficient of variation (CV, %) for yield data across the testing years, and the production index (defined as the ratio between yield under water-deficit conditions and the mean yield of all cultivars under the same conditions).

Cultivar stability was assessed based on the coefficient of variation, as follows: CV < 10% - stable cultivars; CV between 10% and 20% - moderately stable cultivars; CV > 20% - unstable cultivars.

RESULTS AND DISCUSSIONS

The obtained results are presented from multiple analytical perspectives: (i) yield distribution in relation to precipitation accumulated up to the heading stage; (ii) mean yields as influenced by total precipitation recorded throughout the entire growing season; (iii) the coefficient of variation (CV, %) of yields registered during the three experimental years; (iv) the production index, calculated as the ratio between the yield achieved under water-deficit conditions by each tested cultivar and the mean yield of all cultivars evaluated under the same conditions; and (v) graphical classification based on the relationship between the coefficient of variation and the production index.

Yield performance analyzed according to heading date under water-deficit conditions (precipitation-derived drought year) relative to a year with precipitation surplus revealed a marked reduction in yield for very early, early, medium, and late cultivars. In contrast, yield levels tended to converge in the case of very late cultivars (Figure 1).

In the 2022-2023 agricultural year, climatic conditions were characterized by an autumn with a water deficit at wheat emergence, later

compensated by an optimal water supply during the winter and early spring.

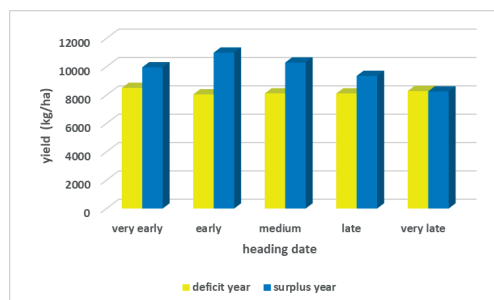


Figure 1. Mean grain yield of winter wheat cultivars in relation to total precipitation accumulated during the entire growing season, classified by earliness group – Caracal, 2023-2025

The grain filling stage took place under favorable thermal conditions, with temperatures in May and June slightly below the multiannual average, against the backdrop of excess precipitation in May (Table 1).

In 2023-2024, the dynamics of climatic factors was marked by a severe deficit at wheat emergence in October, followed by an excess of precipitation during the twinning phase and culminating in a sharp thermal stress during the grain filling period (Table 2).

In the 2024-2025 agricultural year, the wheat emergence period was critical, due to severe drought, while the twinning benefited from a reserve of soil water, accumulated in the warm windows of December. The grain filling stage was marked by a major contrast: optimal moisture conditions in May, followed by thermal and water stress in June (Table 3).

The distribution of yields recorded in relation to precipitation accumulated up to the heading stage in the deficit year (mean of the two dry years = 280 mm, derived from 283.8 mm in 2023-2024 and 276.3 mm in 2024-2025) compared with the surplus year (333.8 mm) revealed a considerably narrower yield range under water-deficit conditions (from below 6,000 up to 10,001-10,500 kg ha⁻¹). In contrast, during the year characterized by higher precipitation, the yield range was substantially broader, reaching values exceeding 13,501 kg ha⁻¹.

The peak of yield distribution in the agricultural years with lower precipitation was positioned within the 8,001-8,500 kg ha⁻¹ class, whereas in

the year with precipitation surplus it shifted toward the 8,501-9,000 kg ha⁻¹ class (Figure 2). Under water-deficit conditions (two-year mean), the highest yield was recorded for the cultivar SY Sanluca (10,299 kg ha⁻¹), while under surplus water conditions registered during the 2024-2025 agricultural year at Caracal, the most productive cultivar was Complice (13,661 kg ha⁻¹). At the opposite end of the productivity spectrum were the cultivars Bezostaia (5,759 kg ha⁻¹) and Viktoria (4,736 kg ha⁻¹), respectively.

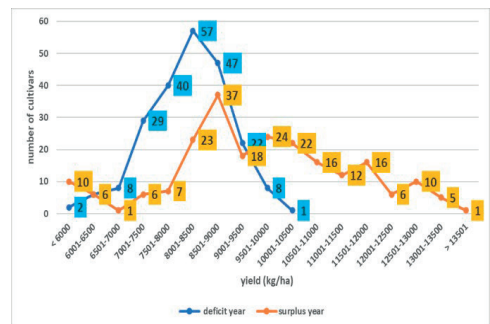


Figure 2. Distribution of winter wheat grain yields in relation to precipitation accumulated up to the heading stage

A low coefficient of variation (CV), corresponding to stable cultivars, highlighted those genotypes for which yield differences between the two contrasting conditions (deficit year versus surplus year) were minimal; however, this indicator did not necessarily emphasize cultivars with outstanding productivity under specific environmental conditions. Several illustrative examples can be provided.

The cultivar Absint, with practically similar yields under contrasting precipitation regimes (6,707 kg ha⁻¹ in the deficit year and 6,611 kg ha⁻¹ in the surplus year), exhibited a coefficient of variation of only 0.9%, thus being classified as highly stable. Likewise, the cultivar Ingenio, with a CV of 5.4% (stable), showed comparable yield performance under both conditions, similar to Absint, but at a considerably higher productivity level (8,250 kg ha⁻¹ in the deficit year versus 8,573 kg ha⁻¹ in the surplus year). In contrast, although the cultivar Irun recorded a yield in the deficit year comparable to that of Absint (6,700 kg ha⁻¹), it reached 10,270 kg ha⁻¹ under excess precipitation conditions, indicating pronounced instability (CV = 30%) (Figure 3).

Figure 3 presents the cultivars with the highest stability among those evaluated. Under the pedo-climatic conditions specific to Caracal and its surrounding area, the following cultivars were distinguished as stable while also maintaining high productivity:

- Novic, Pibrac, Python, RGT Cesario, RGT Palmeo, with yields exceeding 9,000 kg ha⁻¹ under both environmental conditions;
- Ascona, Aurelius, Avenue, Axum, Barba, Centurion, Combin, Consecvent, Dallara, Gabrio, Ingenio, KWS Lazuli, KWS Peplum, KWS Rhum, KWS Usuellum, LG Apilco, Moisson, Montecristo, Omersson, Perkussio, Rubisko, Solehio, Sonathine, SY Exaltation, SY Passion, SY Starlord, all exceeding 8,000 kg ha⁻¹ in both conditions.

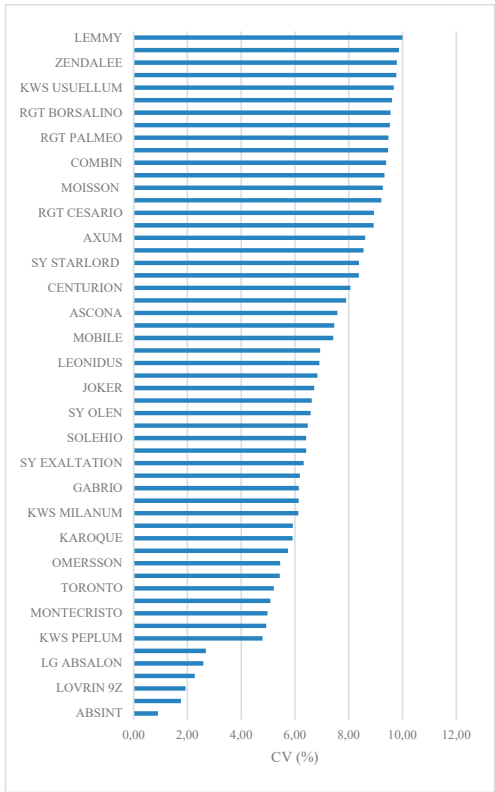


Figure 3. Highly stable winter wheat cultivars identified based on a coefficient of variation (CV) below 10% – Caracal, 2023–2025

Among the unstable cultivars, several genotypes stood out due to their wide yield fluctuations: Bezostaia (3,000-8,000 kg ha⁻¹; CV = 38.94%), Dacic (3,000-10,000 kg ha⁻¹; CV = 38.98%),

Kapitol (5,000-10,000 kg ha⁻¹; CV = 31%), Miranda (5,000-9,000 kg ha⁻¹; CV = 35%), Mv Nador (5,000-9,000 kg ha⁻¹; CV = 32%), and Promitor (6,000-10,000 kg ha⁻¹; CV = 33%). It should be noted that these cultivars were severely affected by yellow rust during the year characterized by excessive precipitation, which led to substantial yield reductions, particularly given that no fungicide treatments were applied in the experimental field (Figure 4).

Numerous studies have investigated various drought-sensitivity indices to facilitate the selection of genotypes according to their productive performance under both favorable and stress conditions (Moosavi et al., 2008; Farshadfar et al., 2013; Mursalova et al., 2015; Ali and El-Sadek, 2016).

Among these indicators, the present study employed the yield index (YI), which belongs to the category of indices most strongly dependent on genotype performance under stress conditions.

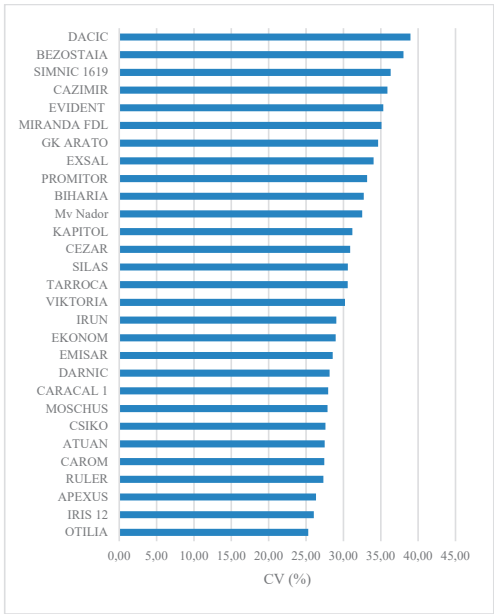


Figure 4. Winter wheat cultivars exhibiting low yield stability (coefficient of variation, CV > 25%) – Caracal, 2023–2025

The graphical representation of the relationship between the yield index (YI) and the coefficient

of variation (CV), together with the division of the scatter plot into four quadrants, allowed a clearer classification of cultivar performance under water-deficit conditions (Figure 5):

Quadrant I - low CV (stable cultivar) and subunitary index (yield below the mean of all cultivars under below-normal water supply conditions);

Quadrant II - CV > 10% (moderately stable or unstable cultivar) and subunitary index (yield below the mean under below-normal water supply conditions);

Quadrant III - CV > 10% (moderately stable or unstable cultivar) and supraunitary index (yield above the mean under below-normal water supply conditions);

Quadrant IV - low CV (stable cultivar) and supraunitary index (yield above the mean of all cultivars under below-normal water supply conditions).

This approach enabled the identification of cultivars belonging to Quadrant IV as the most well-adapted to water-deficit environments. Among these, Palmeo, Milanum, and Scrambler were distinguished as stable cultivars exhibiting the highest yield performance under drought conditions relative to the mean of the experimental assortment.

The yield index calculated for the cultivars tested at Caracal during 2023-2025 ranged from 0.72 for the cultivar Bezostaia to 1.26 for SY Sanluca.

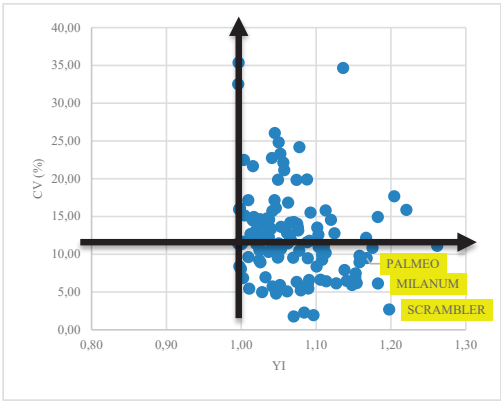


Figure 5. Relationship between yield index (YI) and coefficient of variation (CV) in winter wheat cultivars evaluated at Caracal during 2023-2025

CONCLUSIONS

Under water-deficit conditions (two-year mean), the highest yield was recorded for the cultivar SY Sanluca (10,299 kg ha⁻¹), whereas under surplus water conditions observed during the 2024-2025 agricultural year at Caracal, the most productive cultivar was Complice (13,661 kg ha⁻¹). At the lower end of the productivity spectrum were the cultivars Bezostaia (5,759 kg ha⁻¹) and Viktoria (4,736 kg ha⁻¹).

The cultivars Novic, Pibrac, Python, RGT Cesario, and RGT Palmeo, each exceeding 9,000 kg ha⁻¹ under both environmental conditions, demonstrated high yield stability under the pedo-climatic conditions specific to Caracal.

Based on the analysis of the relationship between the coefficient of variation and the yield index, the cultivars Palmeo, Milanum, and Scrambler were identified as stable genotypes exhibiting superior yield performance under water-deficit conditions relative to the mean of the experimental assortment.

The yield index calculated for the cultivars tested at Caracal during 2023-2025 ranged from 0.72 for Bezostaia to 1.26 for SY Sanluca, reflecting considerable variability in drought adaptation among the evaluated genotypes.

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