

## Variation in Wheat Yield and Grain Quality – Case Study in Voiteg Area, Timiș County, during 2023–2025

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**Abstract.** Wheat is one of the most important agricultural crops in the Western Plain of Romania, with productivity and harvest quality being strongly influenced by the genotype, crop technology and climatic conditions during the growing season. The present study analyzed the variation of yield ( $Y$ , kg ha<sup>-1</sup>) and the main quality parameters of wheat grains, namely protein content (PRO, %), hectoliter weight (HW, kg hl<sup>-1</sup>), moisture (Mst, %) and foreign body content (FB, %) under the pedoclimatic conditions of the area of Voiteg, Timiș County. The study was conducted over three consecutive agricultural years, during the period 2023–2025. Experimental data were recorded for each year of study, and statistical analysis aimed to identify annual trends, relationships between production and quality parameters, and the influence of climatic conditions on wheat crop performance. The results highlighted the variation in average yield from 5500 kg ha<sup>-1</sup> in 2023 to 9000 kg ha<sup>-1</sup> in 2025. In parallel, the average protein content presented values from 10.80% to 12.00%, and the hectoliter weight from 78.00 kg hl<sup>-1</sup> to 80.00 kg hl<sup>-1</sup>. In the 2024 - 2025 agricultural year was recorded the best values for yield and for the quality indicators considered. The analysis of the relationships between parameters revealed positive associations between production, protein content and hectoliter weight, suggesting a favorable effect of climatic conditions on the accumulation of useful biomass (grain yield) and grain quality. The results confirm the importance of monitoring climatic factors in order to optimize crop technology and the stability of wheat production under current climate variability.

**Keywords:** wheat, climatic factor, comparative analysis, crop performance, quality indices, trends

### INTRODUCTION

Common wheat (*Triticum aestivum* L.) is one of the most important cultivated species worldwide, contributing approximately 20% of the caloric and protein intake of the global population (Food and Agriculture Organization – FAO, 2024). The importance of this crop is determined both by its ability to adapt to diverse pedoclimatic conditions and by its essential role in food security and the agricultural economy of numerous states (Shewry and Hey, 2015; Reynolds et al., 2021).

In Romania, wheat annually occupies areas between 2 and 2.3 million hectares, representing the main cereal cultivated for human consumption and one of the strategic crops of national agriculture (INS, 2025), and the Western Region of the country, including Timiș County, benefits from favorable conditions for wheat cultivation. Even for areas with favorable conditions for wheat cultivation, climatic variability in recent years has caused significant fluctuations in production and quality indicators (Malschi et al., 2018; Olesen et al., 2011).

Wheat production is the result of the interaction between genotype, crop technology and environmental factors, of which temperature and water availability are the most important components (Porter and Gawith, 1999; Asseng et al., 2015). Temperature influences germination, tillering, straw elongation, earing and grain filling, each stage having specific thermal requirements (Farooq et al., 2011; Hatfield and Prueger, 2015). Increasing temperatures above optimal thresholds during the reproductive period can reduce the duration of grain filling and can cause a decrease in their mass, with a direct effect on the final yield (Asseng et al., 2015; Zhao et al., 2017).

Water availability is a major limiting factor for wheat cultivation in continental areas of South-Eastern Europe (Lobell and Field, 2007; Trnka et al., 2019). Water deficit manifested during critical phases of development, especially during the period of grain formation and filling, reduces the efficiency of photosynthesis and the transport of assimilates to the fruiting organs, leading to significant decreases in production (Cattivelli et al., 2008; Farooq et al., 2014). In contrast, rainfall evenly distributed throughout the vegetation period contributes to the efficient use of the genetic potential of the varieties and to the stability of production (Lobell et al., 2011).

In the context of global climate change, the frequency of extreme phenomena, such as drought, heat waves and excessive precipitation, is continuously increasing (IPCC, 2023). Numerous studies have shown that every 1°C increase in average temperature during the growing season can reduce global wheat production by approximately 5–6% (Asseng et al., 2015; Zhao et al., 2017). These trends are particularly relevant for agricultural regions in South-Eastern Europe, where the effects of climate change are estimated to be more pronounced compared to other European regions (Olesen et al., 2011; Trnka et al., 2019).

In addition to the level of production, climatic conditions directly influence the quality of the harvest. Protein content is one of the most important indicators used in the evaluation of wheat intended for baking, being associated with the rheological properties of the dough and the technological value of the flour (Dupont and Altenbach, 2003; Triboni et al., 2006). Protein accumulation in the grain is dependent on both nitrogen availability and weather conditions during grain filling (Martre et al., 2006; Xue et al., 2016). Moderate temperatures and an adequate water supply favor the synthesis and accumulation of protein compounds, while severe thermal and water stress can negatively affect these processes (Farooq et al., 2011).

Hectoliter weight is another important indicator of the commercial and industrial quality of wheat, reflecting the degree of filling and density of the grains (Mitura et al., 2023). This parameter is influenced by the climatic conditions during the ripening period, as well as the phytosanitary status and genetic characteristics of the variety (Kaya and Akcura, 2014). High hectoliter weight values are associated with higher milling yields and better technological quality of finished products (Posner and Hibbs, 2005).

In the current conditions of European agriculture, the simultaneous monitoring of production and quality indicators, in correlation with climatic factors, represents an essential research direction for the development of resilient and sustainable agricultural systems (Senapati et al., 2019; Reynolds et al., 2021). Evaluating the relationships between production parameters and local climatic characteristics can contribute to optimizing crop technologies and adapting agricultural management strategies to new environmental conditions.

In this context, the present study aimed to analyze the variation in yield and the main quality indicators of wheat grains, cultivated in the area of Voiteg, Timiș County, during the period 2022–2025. The objectives of the research were: (i) evaluating the annual variation in production and quality parameters; (ii) identifying the relationships between production and quality indicators; (iii) analyzing the influence of climatic conditions on crop performance; and (iv) identifying the most favorable year for achieving a high level of production and harvest quality.

## MATERIAL AND METHODS

The study was conducted using data obtained from wheat (*Triticum aestivum* L.) cultivated in the area of Voiteg, Timiș County, located in the South-West of Romania, Figure 1. The study area belongs to the Banat Plain and is characterized by pedoclimatic conditions favorable to the cultivation of straw cereals, the climate being of a temperate-continental type, with sub-Mediterranean influences. The climatic particularities of the region are reflected in interannual variations in temperature and rainfall, factors that directly influence the physiological processes of plants and the productive performance of agricultural crops.



**Figure 1.** Study location, Voiteg ATU, Timiș County, Romania (Google maps)

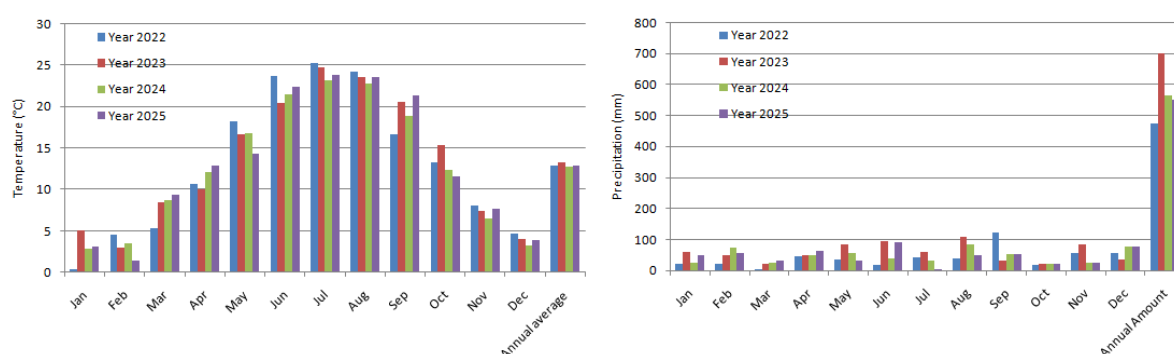
The 'Alcantara' wheat variety was cultivated. The cultivation technology ensured the proper preparation of the land, through scarification works, field scarifier, Tiger cultivator, in order to prepare the germination bed. Fertilization was done with complexes during land preparation (16:16:16; 20:20:0; 10:26:26) and urea during the vegetation period. Weed control was done by herbicides (e.g. Fundamentum), with the use of adjuvants for the effectiveness of the treatment. Disease and pest control was done by treatments during the vegetation period (e.g.

Mospilan, Prosaro, Revystar, Vantex). Foliar fertilization during vegetation was also provided. At maturity, harvesting was done mechanically, and samples were taken from the grain production to determine quality indices. Modules of 1 ha were considered as observation plots, each agricultural year.

The analysis was carried out over three consecutive agricultural years, respectively 2022 - 2023, 2023 - 2024, and 2024 - 2025. Independent determinations were performed for each year, considered as experimental repetitions in order to evaluate the variability of the analyzed parameters. In total, nine experimental observations were analyzed for each indicator considered.

The parameters considered included grain production expressed in  $\text{kg ha}^{-1}$ , protein content (PRO, %) determined on the harvested crop, hectoliter weight (HW,  $\text{kg hl}^{-1}$ ), grain moisture (Mst, %), and foreign body content (FB, %). These indicators were selected because they represent the main parameters used to assess both the production level and the commercial and technological quality of the wheat harvest. The main quality indices of wheat samples were done with the AgriCheck device.

To characterize the environmental conditions, climatic data on air temperature and precipitation during the study period were used, Figure 2. Meteorological data were analyzed both at the annual level and for critical periods of crop development, in order to highlight the relationships between climatic conditions and the productive response of plants. The climatic analysis aimed to identify favorable and unfavorable years for crop development, as well as to quantify the influence of meteorological factors on grain production and quality.



**Figure 2.** Climatic conditions during the study period

Statistical processing of the data was carried out using descriptive and inferential statistical methods. For each parameter, the arithmetic mean, standard deviation and coefficient of variation were calculated.

To verify the existence of significant differences between the study years, a single-factor analysis of variance (ANOVA) was used, with the experimental year representing the variation factor. This method allows the simultaneous comparison of the means of several variants and highlighting the contribution of the analyzed factor to the total observed variation. The statistical significance of the differences was assessed at the 5% probability threshold ( $p < 0.05$ ).

The relationships between production and grain quality parameters were evaluated using the Pearson correlation coefficient ( $r$ ). The intensity of the correlation was interpreted according to the classification proposed by Evans (1996).

In order to highlight the variation patterns of the analyzed parameters, graphical representations of the annual averages and correlation matrices were made. These representations allow the identification of the evolution trends of production and quality indicators, as well as highlighting the existing relationships between the analyzed characteristics. In addition, the interpretation of the results was carried out by referring to the specific climatic conditions of each experimental year and to the information available in the specialized literature regarding the response of the wheat crop to environmental factors.

By applying this set of statistical and comparative methods, the aim was to evaluate the variability of wheat production and harvest quality during the period 2023–2025, identify the parameters most sensitive to climatic variations and highlight the relationships between climatic factors and the agronomic performance of the crop under the specific conditions of the Voiteg area. The PAST software v.4.14 (Hammer et al., 2001) and the JASP software v.0.16.2 (2022) were used for data processing and generation of graphical representations.

## RESULTS AND DISCUSSIONS

Grain yield was the main indicator used to evaluate the response of wheat crop to the specific pedoclimatic conditions of the study period. The analysis of experimental data revealed important differences

between the analyzed years, which suggests a significant influence of climatic conditions on the level of production. The average values of yield and quality indices determined for wheat grains are presented in Table 1.

The average yield values ranged from 5500 kg ha<sup>-1</sup> in 2023 to 9000 kg ha<sup>-1</sup> in 2025, with 2024 occupying an intermediate position, with an average production of 8000 kg ha<sup>-1</sup> (Table 1). Compared to 2023, the average yield increased by 45.5% in 2024 and by 63.6% in 2025. The difference between the first and last year of study was 3500 kg ha<sup>-1</sup>, which indicated a considerable annual variation in productive performance.

**Table 1.** Yield and quality index values for wheat, under study conditions

| Year | Yield<br>(kg ha <sup>-1</sup> ) | Protein<br>(%) | Hectoliter weight<br>(kg hl <sup>-1</sup> ) | Moisture<br>(%) | Foreign bodies<br>(%) |
|------|---------------------------------|----------------|---------------------------------------------|-----------------|-----------------------|
| 2023 | 5500.00                         | 10.80          | 78.00                                       | 10.50           | 1.10                  |
| 2024 | 8000.00                         | 11.50          | 77.00                                       | 11.00           | 1.10                  |
| 2025 | 9000.00                         | 12.00          | 80.00                                       | 10.20           | 1.00                  |
| Mean | 7500.00                         | 11.43          | 78.33                                       | 10.57           | 1.07                  |

The reduction in the coefficient of variation from CV = 18.9% in 2023 to CV = 11.6% in 2025 indicated a greater stability of yield in the last year of the study. This result suggested that the plants benefited from more favorable and uniform vegetation conditions in 2025, compared to 2023.

#### **Yield variation during the study period**

In the case of yield, the comparative analysis led to the results presented in Table 2. In 2023, an average yield was recorded that was 2000 kg/ha lower than the average of the experiment (7500 kg ha<sup>-1</sup>), in conditions of statistical safety ( $p < 0.05$ ; o). In 2025, a higher yield was recorded that was 1500 kg/ha higher than the average of the study period, in conditions of statistical safety ( $p < 0.05$ ). In the case of 2024, a higher yield was recorded compared to the average of the period, with a difference of 500 kg/ha, but without statistical safety ( $p > 0.05$ ), Table 2.

**Table 2.** Significance of differences in wheat yield, period 2023 – 2025

| Statistical Parameters          | Period          |                  |                 |
|---------------------------------|-----------------|------------------|-----------------|
|                                 | 2023            | 2024             | 2025            |
| Given mean (year)               | 5500            | 8000             | 9000            |
| Sample mean (experimental mean) |                 | 7500             |                 |
| 95% conf. interval              | (6114.3 8885.7) | (6114.3 8885.7)  | (6114.3 8885.7) |
| Difference                      | -2000           | 500              | 1500            |
| 95% conf. interval              | (614.28 3385.7) | (-885.72 1885.7) | (114.28 2885.7) |
| t                               | 3.3282          | -0.8320          | -2.4962         |
| p (same mean)                   | 0.0104          | 0.4295           | 0.0371          |
| Significance                    | o               | ns               | *               |

The yield increase observed during the analyzed period can be associated with the improvement of climatic conditions during the critical stages of crop development. The specialized literature has highlighted the fact that the availability of water during the period of straw elongation, earing and grain filling is one of the main factors determining the final yield level (Lobell et al., 2011; Farooq et al., 2014). Also, moderate temperatures during the grain filling phase favor the accumulation of dry matter and the extension of the operating time of the photosynthetic apparatus (Asseng et al., 2015).

The results obtained in 2025 indicated the existence of a more favorable climatic context for crop development, reflected both by the high level of yield and by the higher values of the main quality indicators analyzed later. This behavior suggested that the increase in yield was not achieved at the expense of quality, a situation frequently encountered under conditions of a balanced supply of water and nutrients.

The differences observed between years are consistent with the results reported by other studies (Asseng et al., 2015; Zhao et al., 2017; Reynolds et al., 2021), which demonstrated that interannual variations in temperature and precipitation are the main factors responsible for wheat yield fluctuations in temperate regions.

Overall, the yield analysis highlighted an upward trend during the period 2023–2025, with 2025 being considered the most favorable year for achieving the productive potential of wheat crop under the pedoclimatic

conditions of the Voiteg area.

### Grains protein content variation during the study period

Protein content is one of the most important indicators of wheat quality, directly influencing the rheological properties of dough, baking capacity and commercial value of the crop. In general, the level of protein in the grain is determined by the interaction between the the productivity potential of the wheat genotype, nitrogen availability and climatic conditions manifested during the period of grain filling and maturation (Triboi et al., 2003; Martre et al., 2006).

Analysis of the data obtained during the period 2023–2025 highlighted the variation in the average protein content, from 10.80% in 2023, to 11.50% in 2024, and to 12.00% in 2025 (Table 1). The difference between the first, and the last year of the study was 1.20 percentage points, which represented a relative increase of approximately 1.11 percentage points during the study period.

In the case of protein content, the comparative analysis led to the results presented in Table 3. In 2023, the protein content recorded was 0.63% lower than the average of the experiment (11.43%), within statistical safety conditions ( $p < 0.05$ ; o). In 2025, the protein content recorded was 0.57% higher than the average of the study period, within statistical safety conditions ( $p < 0.05$ ). In the case of 2024, the protein content recorded was higher compared to the average of the period, with a difference of 0.07%, but without statistical safety ( $p > 0.05$ ), Table 3.

**Table 3.** Significance of differences in wheat protein content, period 2023 – 2025

| Statistical Parameters          | Period           |                    |                  |
|---------------------------------|------------------|--------------------|------------------|
|                                 | 2023             | 2024               | 2025             |
| Given mean (year)               | 10.80            | 11.50              | 12.00            |
| Sample mean (experimental mean) |                  | 11.43              |                  |
| 95% conf. interval              | (10.969 11.897)  | (10.969 11.897)    | (10.969 11.897)  |
| Difference                      | 0.63             | 0.07               | 0.57             |
| 95% conf. interval              | (0.16934 1.0973) | (-0.39732 0.53066) | (0.10268 1.0307) |
| t                               | 3.1476           | -0.3313            | -2.8163          |
| p (same mean)                   | 0.0136           | 0.7489             | 0.0226           |
| Significance                    | o                | ns                 | *                |

The values of the coefficient of variation were low in all the years analyzed, being below the 5% threshold, which indicated a high uniformity of the determinations and a good stability of the analyzed character. The low variability suggested that the differences observed between years were mainly generated by environmental conditions and not by fluctuations in the crop technology.

The variation in protein content observed during the study period is of particular interest from an agronomic point of view. In many cases, high production increases were associated with a protein dilution effect, determined by the preferential accumulation of starch in the grain (Triboi et al., 2003; Shewry and Hey, 2015). In the present case, both production and protein content recorded an upward trend during the study period, which suggested the existence of favorable conditions for both biomass accumulation and the synthesis of protein compounds.

This behavior can be explained by adequate availability of water and nutrient resources during critical periods of crop development. Martre et al. (2006) demonstrated that the processes of nitrogen accumulation and its remobilization to the grains were strongly influenced by the meteorological conditions during the grain filling phase. Also, Senapati et al. (2019) highlighted that years characterized by a balance between temperature and water availability can simultaneously favor crop production and quality.

The average value of 12.00% recorded in 2025 falls into the category of wheat with good potential for baking, according to the criteria used in the technological evaluation of cereals. This value indicates a satisfactory level of protein compound accumulation and suggests that the grain filling process took place under favorable conditions.

Compared to 2023, when the protein content was 10.80%, the 2025 results reflected a significant improvement in the technological quality of the harvest. The literature has shown that differences of 1–1.5 percentage points in protein content can significantly influence the behavior of flour in the baking process and the economic value of production (Dupont and Altenbach, 2003; Shewry and Hey, 2015).

Correlating the results regarding production and protein content, it was observed that the year 2025 was the most favorable both quantitatively and qualitatively. This situation is relatively rare in field conditions and

indicated a favorable combination of climatic and technological factors that allowed the efficient exploitation of the crop's potential.

The results obtained are consistent with observations reported by Reynolds et al. (2021), who highlighted that effective crop management and favorable climatic conditions can simultaneously lead to increased grain yield and quality. Under the experimental conditions in Voiteg, the progressive increase in protein content over the three years of study suggested a positive influence of vegetation conditions on the processes of nitrogen accumulation in the grain and on the final quality of the harvest.

#### Hectoliter weight of grains variation during the study period

Hectoliter weight is one of the main physical indicators used to evaluate the commercial and technological quality of wheat. This parameter expresses the mass of one hectoliter of grains and provides information on the degree of filling, density and maturity of the crop. In general, high hectoliter weight values are associated with well-developed grains, with a high dry matter content and with superior efficiency in the milling process (Posner and Hibbs, 2005; Kaya and Akcura, 2014).

The results obtained during the experimental period revealed obvious differences between the study years. The average values of the hectoliter weight were 78.00 kg hl<sup>-1</sup> in 2023, 77.00 kg hl<sup>-1</sup> in 2024, and 80.00 kg hl<sup>-1</sup> in 2025, respectively, Table 1. Thus, the highest value was recorded in 2025, while 2024 presented the lowest values of this indicator.

The values of the standard deviation and the coefficient of variation were very low in all the years analyzed, indicating a high uniformity of the determinations and a remarkable stability of this character. The coefficient of variation of approximately 1% demonstrated that the differences observed between years were the result of the influence of environmental conditions and not of experimental variability.

In the case of hectoliter weight, the comparative analysis led to the results presented in Table 4. In 2023, a hectoliter weight value was recorded that was 0.33 kg hl<sup>-1</sup> lower than the average of the experiment (78.33 kg hl<sup>-1</sup>), without statistical safety ( $p > 0.05$ ). In 2024, a lower hectoliter weight value was recorded compared to the average value by 1.33 kg hl<sup>-1</sup>, in conditions of statistical safety ( $p < 0.05$ ). In the case of 2025, a higher hectoliter weight value was recorded, compared to the average of the study period, with a difference of 1.67 kg hl<sup>-1</sup>, in conditions of statistical safety ( $p < 0.05$ ), Table 4.

**Table 4.** Significance of differences in hectoliter weight of wheat, period 2023 – 2025

| Statistical Parameters          | Period            |                  |                  |
|---------------------------------|-------------------|------------------|------------------|
|                                 | 2023              | 2024             | 2025             |
| Given mean (year)               | 78.00             | 77.00            | 80.00            |
| Sample mean (experimental mean) |                   | 78.33            |                  |
| 95% conf. interval              | (77.16 79.507)    | (77.16 79.07)    | (77.16 79.07)    |
| Difference                      | 0.33              | 1.33             | 1.67             |
| 95% conf. interval              | (-0.84018 1.5068) | (0.15982 2.5068) | (0.49316 2.8402) |
| t                               | 0.6550            | 2.6200           | -3.2750          |
| p (same mean)                   | 0.5308            | 0.0306           | 0.0113           |
| Significance                    | ns                | o                | *                |

From a technological point of view, the values obtained for the hectoliter weight fall within the limits considered favorable for wheat intended for breadmaking. The specialized literature mentions that values above 76–78 kg hl<sup>-1</sup> are associated with a good degree of grain maturation and with superior milling yields (Posner and Hibbs, 2005; Mitura et al., 2023).

The decrease in HW index values, observed in 2024 compared to 2023, may suggest the existence of less favorable climatic conditions during the grain filling period. Hectoliter weight is directly influenced by starch accumulation processes and the duration of the ripening period. Excessive temperatures, water stress or precipitation episodes near maturity can reduce the degree of grain filling and implicitly their density (Kaya and Akcura, 2014; Senapati et al., 2019).

The year 2025 was distinguished by the highest hectoliter weight (80.0 kg hl<sup>-1</sup>), simultaneously with the highest production and the highest protein content. This association is particularly important because it indicated that the increase in production was not achieved at the expense of the physical quality of the harvest. In many experimental situations, increased production can lead to a decrease in grain density due to dilution effects or competition for resources. In the present case, the results suggested that plants benefited from favorable conditions for complete grain filling and efficient dry matter accumulation.

Compared to 2024, the increase of 3 kg hl<sup>-1</sup> recorded in 2025 represented an important improvement from a technological point of view. This difference can have direct implications on the commercial value of the harvest and on the flour extraction yield in the milling process.

The simultaneous analysis of production, protein content and hectoliter weight highlighted that 2025 was the most favorable of the three years analyzed. The high values of all parameters suggested the existence of climatic conditions that allowed the optimal development of the processes of photosynthesis, transport of assimilates and filling of grains. Similar results have been reported in other studies (Reynolds et al., 2021; Senapati et al., 2019), which highlighted that years characterized by a balance between thermal regime and water availability simultaneously favor crop yield and quality.

Therefore, the hectoliter weight confirmed the trend observed for the other analyzed indicators, indicating a progressive improvement in harvest quality during the study period and highlighting the superiority of the 2025 agricultural year in the pedoclimatic conditions of the Voiteg area.

#### Grain moisture and foreign body content variation during the study period

In addition to yield, protein content and hectoliter weight, the assessment of wheat harvest quality also includes the analysis of indicators that reflect the physical condition of the product at the time of harvest. Among these, grain moisture (Mst, %) and foreign body content (FB, %) are important parameters for both the preservation of the harvest and its valorization in the processing chain.

Moisture influences the stability of the crop during storage, the risk of microbial growth and quality losses in the post-harvest period. High humidity values are usually associated with difficulties in grain preservation and the need for additional drying operations (Posner and Hibbs, 2005). At the same time, the content of foreign bodies reflects the degree of purity of the crop and is an important criterion in establishing the commercial quality of grain lots.

The analysis of the recorded data revealed differences between the study years for both analyzed parameters (Table 1). The grain moisture values varied between 10.20% and 11.00%, the differences between the years being relatively small. The highest value was recorded in 2024 (11.00%), while 2025 presented the lowest average grain moisture (10.20%). The year 2023 occupied an intermediate position, with an average value of 10.50%.

In the case of moisture, the comparative analysis led to the results presented in Table 5. In all cases, the moisture fell within the STAS parameters. However, the comparative analysis highlighted differences in moisture and statistical significance. In 2023, moisture value was recorded that was 0.07% lower than the average of the experiment (10.50%), without statistical safety ( $p > 0.05$ ). In 2024, a higher moisture value was recorded compared to the average value, by 0.43%, in conditions of statistical safety ( $p < 0.05$ ). In the case of 2025, a lower moisture value was recorded, compared to the average of the period, with a difference of 0.37%, in conditions of statistical safety ( $p < 0.05$ ), Table 5.

**Table 5.** Significance of differences in wheat grain moisture, period 2023 – 2025

| Statistical Parameters          | Period             |                   |                   |
|---------------------------------|--------------------|-------------------|-------------------|
|                                 | 2023               | 2024              | 2025              |
| Given mean (year)               | 10.50              | 11.00             | 10.20             |
| Sample mean (experimental mean) |                    | 10.57             |                   |
| 95% conf. interval              | (10.257 10.876)    | (10.257 10.876)   | (10.257 10.876)   |
| Difference                      | 0.07               | 0.43              | 0.37              |
| 95% conf. interval              | (-0.24288 0.37621) | (0.12379 0.74288) | (0.05712 0.67621) |
| t                               | 0.4966             | -3.2281           | 2.7315            |
| p (same mean)                   | 0.6328             | 0.0121            | 0.0258            |
| Significance                    | ns                 | *                 | o                 |

The differences recorded suggested the existence of distinct meteorological conditions during the ripening and harvesting periods. The moisture content of wheat grains is strongly influenced by rainfall and the thermal regime in the last weeks of the vegetation cycle. Under conditions of more abundant rainfall before harvest, the natural drying of the grains is slowed down, leading to higher moisture values at the time of harvest. Conversely, high temperatures and periods with low rainfall favor the loss of water from the grains and allow lower moisture levels to be reached (Farooq et al., 2011; Senapati et al., 2019).

The minimum value observed in 2025 can be considered favorable from a technological point of view, as it reduces the need for artificial drying and contributes to reducing the costs of conditioning and storing the

harvest. In addition, the low humidity level limits the risk of microbiological spoilage processes during storage.

The content of foreign bodies also showed variations between the experimental years. The average values were identical in the years 2023 and 2024 (1.10%), while the year 2025 recorded the lowest value, respectively 0.98%. Although the absolute differences are relatively small, the observed trend indicates an improvement in the purity of the harvest in the last year of the study.

In the case of foreign bodies, the comparative analysis led to the results presented in Table 6. Under the conditions of 2023 and 2024, a foreign body value was recorded that was 0.04% higher than the average of the experiment (1.06%), without statistical safety ( $p > 0.05$ ). Under the conditions of 2025, a lower humidity value was recorded compared to the average value, by 0.06%, under statistical safety ( $p < 0.05$ ), Table 6.

**Table 6.** Significance of differences in foreign bodies in wheat, period 2023 – 2025

| Statistical Parameters          | Period                |                       |                    |
|---------------------------------|-----------------------|-----------------------|--------------------|
|                                 | 2023                  | 2024                  | 2025               |
| Given mean (year)               | 1.10                  | 1.10                  | 1.00               |
| Sample mean (experimental mean) |                       | 1.06                  |                    |
| 95% conf. interval              | (1.0106 1.1094)       | (1.0106 1.1094)       | (1.0106 1.1094)    |
| Difference                      | 0.04                  | 0.04                  | 0.06               |
| 95% conf. interval              | (-0.0093681 0.089368) | (-0.0093681 0.089368) | (0.010632 0.10937) |
| t                               | -1.8684               | -1.8684               | 2.8026             |
| p (same mean)                   | 0.0987                | 0.0987                | 0.0231             |
| Significance                    | ns                    | ns                    | o                  |

The decrease in the content of foreign bodies can be associated both with favorable vegetation conditions and with a higher efficiency of harvesting and conditioning operations. The specialized literature has shown that episodes of heavy precipitation before harvest can favor the presence of plant and mineral impurities in the mass of grains, thus affecting the commercial quality of the harvested product (Posner and Hibbs, 2005). In contrast, stable weather conditions and harvesting carried out at full maturity contribute to obtaining cleaner and more uniform categories.

By simultaneously analyzing the two parameters, it was observed that the year 2025 presented both the lowest moisture content and the lowest foreign body content. This result completes the favorable picture outlined by the high values of production, protein content and hectoliter weight, confirming that the year 2025 offered the best conditions for obtaining a superior quality harvest, under the study conditions.

From an agronomic and commercial point of view, the association between low moisture, high crop purity and superior values of technological parameters is an indicator of proper crop maturation and efficient use of environmental conditions. These results suggested that the specific climatic factors of 2025 favored not only the accumulation of yield, but also the improvement of the physical and commercial characteristics of wheat grains.

Overall, the analysis of moisture and foreign body content highlighted a trend of improving harvest quality during the study period, culminating in the performances obtained in 2025, which stood out with the most favorable values for most of the analyzed indicators.

#### **Relationships between production and grain quality parameters**

In assessing the performance of an agricultural crop, the individual analysis of productive and qualitative parameters provides important information, but understanding the relationships between them allows for a deeper interpretation of the mechanisms that determine the crop's response to environmental conditions. For this reason, the analysis of correlations between grain production and the main quality indicators analyzed in the study was carried out.

To highlight the relationships between the parameters, the Pearson correlation matrix was used, Table 7, which allowed the assessment of the intensity and direction of the association between the studied variables. Positive coefficients indicated direct relationships, while negative coefficients indicated inverse relationships between the analyzed characteristics.

Data analysis revealed the existence of positive relationships between grain yield, protein content and hectoliter weight. The evolution of these parameters during the three years of study followed the same general trend, with the maximum values being recorded in 2025, while 2023 presented the lowest performances.

The positive association between production and protein content is of particular interest because the specialized literature frequently reports the existence of an antagonistic relationship between the two parameters.

**Table 7.** Correlation matrix table

| Variable |             | Y        | PRO    | HW     | Mst    | FB |
|----------|-------------|----------|--------|--------|--------|----|
| Y        | Pearson's r | —        |        |        |        |    |
|          | p-value     | —        |        |        |        |    |
| PRO      | Pearson's r | 0.992*** | —      |        |        |    |
|          | p-value     | < .001   | —      |        |        |    |
| HW       | Pearson's r | 0.590    | 0.685* | —      |        |    |
|          | p-value     | 0.094    | 0.042  | —      |        |    |
| Mst      | Pearson's r | 0.144    | 0.038  | -0.465 | —      |    |
|          | p-value     | 0.712    | 0.924  | 0.208  | —      |    |
| FB       | Pearson's r | -0.448   | -0.522 | -0.630 | 0.771* | —  |
|          | p-value     | 0.226    | 0.149  | 0.069  | 0.015  | —  |

In many cases, the increase in yield was accompanied by a decrease in protein concentration due to the dilution effect generated by the accumulation of starch in the grain (Triboi et al., 2003; Martre et al., 2006). In the present study, this relationship was not observed, the results indicating that the production increases were accompanied by a simultaneous improvement in the protein quality of the crop.

This behavior suggests that in favorable years there were adequate conditions for both biomass accumulation and nitrogen uptake and remobilization to the grains. Reynolds et al. (2021) showed that when water availability and mineral nutrition are balanced, it is possible to increase yield and protein content simultaneously, without the dilution effect observed under other crop conditions.

A positive relationship was also observed between production and hectolitre weight. This result indicated that years characterized by high production also favored the formation of better developed and denser berries. Hectolitre weight reflects the degree of filling of the berries and is directly influenced by the efficiency of photosynthesis and transport of assimilates during the ripening period (Kaya and Akcura, 2014). Thus, the conditions that favored yield accumulation simultaneously contributed to improving the physical characteristics of the crop.

The relationship between protein content and hectolitre weight was also positive, suggesting that well-filled grains also showed a higher level of protein compound accumulation. This observation is consistent with the results reported by Dupont and Altenbach (2003), who highlighted the influence of environmental conditions on the simultaneous accumulation of starch and protein during grain development.

In contrast to the positive relationships mentioned above, grain moisture showed an inverse trend to most productive and qualitative parameters. The year 2024, characterized by the highest average grain moisture, did not record the highest values of production or hectoliter weight. This result suggests that high moisture levels at harvest are not necessarily associated with superior productive performance and may reflect less favorable weather conditions near maturity.

The content of foreign bodies showed a negative relationship with most quality indicators. The year 2025, characterized by the lowest values of impurities, coincided with the best results regarding production, protein content and hectoliter weight. This association indicated that high-quality crops are generally characterized by a high degree of purity and uniformity.

From an agronomic point of view, the results obtained suggest the existence of a common set of favorable factors that simultaneously influenced most of the analyzed parameters. The fact that production, protein content and hectoliter weight showed the same evolution trend indicated an efficient capitalization of environmental conditions in favorable years and a good capacity of the crop to transform available resources into production and quality.

Overall, the correlation analysis revealed that the performance of wheat crop in the Voiteg area was the result of a complex interaction between the processes of yield formation and the accumulation of quality compounds. The observed relationships between the parameters suggested that the improvement of vegetation conditions contributed simultaneously to the increase in the quantity and quality of the harvest, the year 2025 representing the most obvious example of this favorable association.

#### **Climatic conditions influence on grain production and quality**

Climatic conditions are one of the main factors influencing the yield level and quality of the wheat harvest. Temperature and water availability act on all stages of wheat crop development, from emergence and twinning to grain formation and filling. For these reasons, the interpretation of the variations observed in the

period 2023–2025 was made in close connection with the climatic particularities of each agricultural year.

In this study, the climatic data were presented at the level of calendar years during the study period, Figure 2. The climatic analysis was performed for each year of the study, and was detailed for the period March - June, corresponding to the active vegetation cycle from spring to the maturity of the wheat crop (Meier, 2001). The climatic data highlighted important differences in both the thermal regime and the distribution of precipitation between the years analyzed.

The relationship between yield, grain quality parameters and climatic parameters was evaluated by correlation analysis, with the correlation matrix diagram in Figure 3. The analysis considered the average values of temperature and the sum of precipitation for the months of March (T Mar, P Mar), April (T Apr, P Apr), May (T May, P May) and June (T Jun, P Jun). Also, average values of temperature and the sum of precipitation for monthly periods were considered, respectively the period March - June (T Mean, P total), the period April - June (T Apr-Jun, P Apr-Jun), and the period May - June (T May-Jun, P May-Jun).

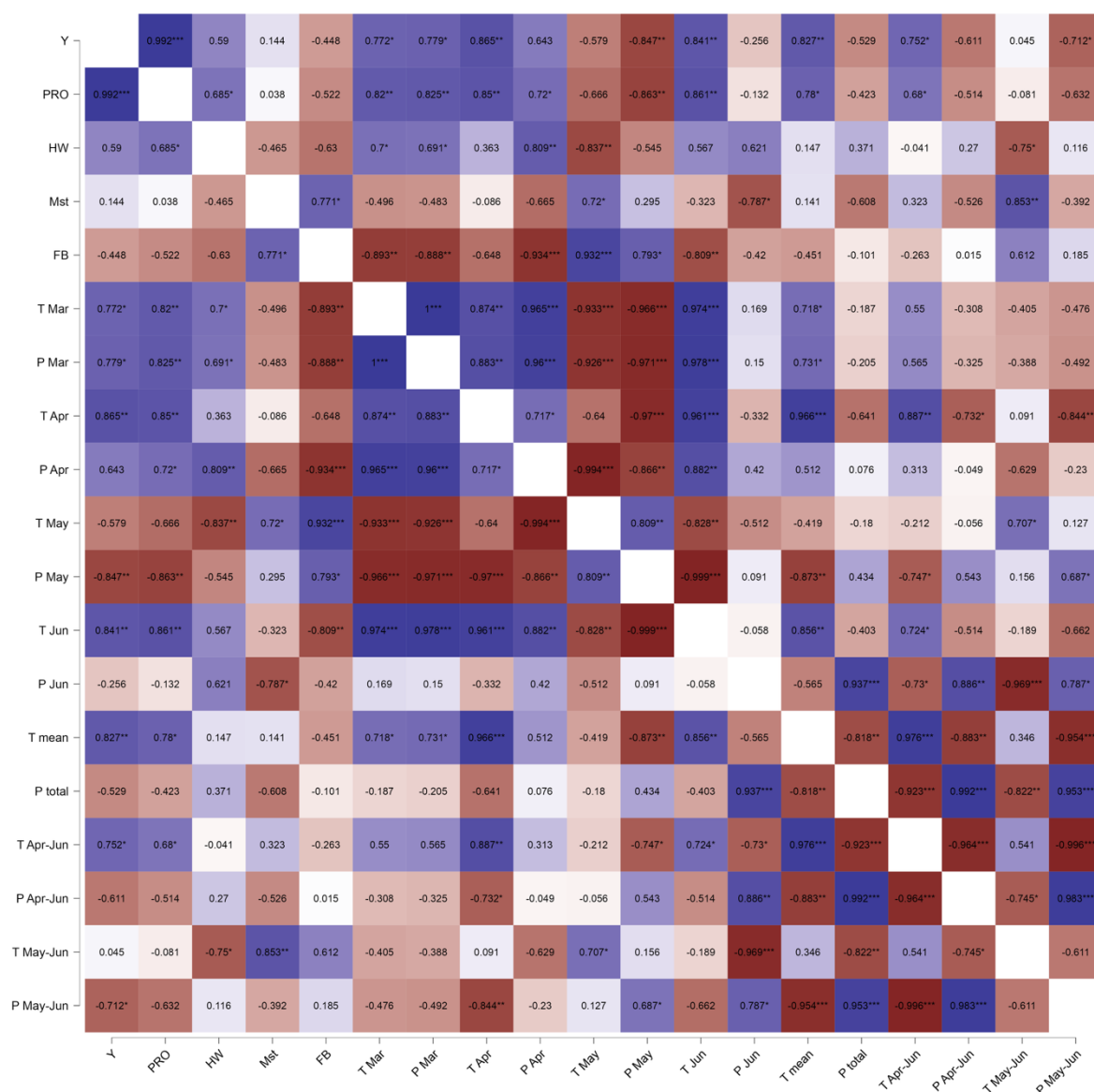


Figure 3. Correlation matrix diagram

### Thermal regime

The average annual temperature varied within a relatively narrow range, between 12.7°C and 13.3°C. The highest value was recorded in the agricultural year associated with the 2023 harvest (13.3°C), while 2024 presented the lowest average annual temperature (12.7°C). The year 2025 had an average temperature of 12.9°C, close to the values considered favorable for the development of the wheat crop.

Although the differences between the annual averages were relatively small, the distribution of temperatures during critical periods of vegetation was of major importance. In 2025, moderate temperatures were recorded in April and May, followed by favorable values during the grain filling period. These conditions allowed for the efficient development of photosynthesis processes and the accumulation of a high amount of dry matter in the grains.

Numerous studies have shown that excessive temperatures during the period of grain heading and filling reduce the duration of assimilate accumulation and lead to reduced grain production and weight (Porter & Gawith, 1999; Asseng et al., 2015; Zhao et al., 2017). In contrast, moderate temperatures favor both yield and grain quality.

#### **Rainfall regime**

More pronounced differences were observed in the case of precipitation. The agricultural year corresponding to the 2023 harvest recorded the highest annual amount of precipitation (699.0 mm), followed by 2024 (563.9 mm) and 2025 (552.2 mm). However, the yield level did not follow the same trend. Although 2023 benefited from the most precipitation, the lowest yield was recorded in that year among the years analyzed. This result highlights the fact that it is not the total amount of precipitation that is decisive for the crop performance, but its distribution in relation to the plant's development phases.

In 2023, heavy rainfall in June and July coincided with the ripening and harvesting period, which may explain higher grain moisture values and lower production performances. In contrast, in 2025, rainfall was concentrated mainly in the months favorable for vegetative development and production formation, while the ripening period was characterized by drier conditions.

This distribution of precipitation favored both the development of the leaf apparatus and the formation of productivity components, as well as the uniform ripening of the berries before harvest. The result was reflected in the maximum level of yield (9000 kg ha<sup>-1</sup>), protein content (12.0%) and hectoliter weight (80 kg hl<sup>-1</sup>).

#### **The influence of climatic conditions on yield and quality parameters**

According to the correlation matrix, Figure 3, it was found that the temperature and precipitation values in March and April showed a positive, high-intensity correlation with yield ( $r = 0.643$  to  $r = 0.865^{**}$ ), with protein ( $r = 0.72^{*}$ , to  $r = 0.85^{**}$ ) and with hectoliter weight ( $r = 0.691^{*}$ , to  $r = 0.809^{**}$ ). Also, the thermal conditions in June showed a positive correlation of high intensity with the yield ( $r = 0.841^{**}$ ), with the protein ( $r = 0.861^{**}$ ) and with the hectoliter weight ( $r = 0.567$ ).

The average temperature during the active vegetation period of wheat, in the period March - June, or in the period April - June, showed a positive influence on the yield and protein in wheat grains, compared to the pluviometric regime during the same period.

Comparative data analysis suggested that years characterized by a balance between temperature and water availability simultaneously favored the accumulation of production and improved harvest quality. The year 2025 recorded the highest values of protein content and hectoliter weight, along with the lowest values of moisture and foreign body content.

These results are consistent with observations reported by other studies (Martre et al., 2006; Senapati et al., 2019; Reynolds et al., 2021), which demonstrated that favorable rainfall distribution and moderate temperatures during the grain filling period contribute to the simultaneous increase in yield and technological quality of the grains.

#### **The most favorable year for wheat cultivation under the study conditions**

Based on the integrated analysis of yield, quality parameters and climatic conditions, the 2024–2025 agricultural year can be considered the most favorable in the study period. It ensured the optimal combination of water availability during critical vegetation phases and favorable ripening and harvesting conditions.

The year 2025 was distinguished by: the highest grain yield, the highest protein content; the highest hectoliter weight; the lowest grain moisture content; the lowest foreign body content.

The results obtained highlighted the importance of the seasonal distribution of precipitation and thermal regime on the performance of the wheat crop and confirmed that the assessment of the crop's response to climate variability represents an essential component for optimizing agricultural technologies under current climate change conditions.

#### **Variation trends of the analyzed parameters and agronomic implications**

The integrated analysis of the results obtained during the period 2023–2025 highlighted the existence of common variation trends for most of the evaluated productive and qualitative parameters. The simultaneous evolution of yield, protein content and hectoliter weight suggested that the response of the wheat crop to environmental conditions did not manifest itself in isolation on a single character, but influenced the entire complex of processes involved in the formation and maturation of grains.

The first trend identified was the positive association between yield and the main quality parameters. Over the three years of study, the increase in production was accompanied by an increase in protein content and

hectoliter weight. This trend indicated that the yield increases were the result of favorable vegetation conditions that allowed both biomass accumulation and proper grain development. In particular, the year 2025 demonstrated that achieving high yields is not incompatible with obtaining superior quality indicators when climatic and technological factors are favorable.

A second trend observed was represented by the inverse relationship between agronomic performance parameters and indicators reflecting the state of the crop at harvest. Grain moisture and foreign body content presented the lowest values in the year that recorded the highest production and the best technological characteristics. This behavior suggested that uniform ripening and favorable conditions during the harvest period simultaneously contribute to improving commercial quality and to the efficient use of the productive potential of the wheat crop.

The results of the study highlighted that the distribution of precipitation during the growing season had a more important influence than the total annual amount of precipitation. The year 2023 benefited from the highest amounts of precipitation, but this was not associated with the highest yield. In contrast, the year 2025, characterized by a more favorable distribution of precipitation during critical phases of crop development, generated the best results for all analyzed indicators. These observations confirm the conclusions formulated in the specialized literature regarding the importance of synchronizing water availability with the physiological requirements of plants (Olesen et al., 2011; Farooq et al., 2014).

From an agronomic point of view, the results obtained suggest that careful monitoring of climatic conditions and adaptation of cultivation technologies to the particularities of each season are essential elements for maintaining production stability. In conditions of increasing climatic variability, management strategies must aim at the efficient use of available water resources and reducing the impact of periods of thermal or water stress.

Also, the positive association between yield and protein content observed in the study represents a result of practical interest for farmers and processors. It demonstrates that, under favorable vegetation conditions, it is possible to simultaneously obtain quantitatively and qualitatively superior yields, without the protein dilution effect frequently described in the literature.

Overall, the identified variation trends highlighted that the performance of wheat crop in the Voiteg area was determined by the interaction between climatic conditions and the physiological processes involved in crop formation. The observed trends confirmed the importance of an integrated approach in the assessment of agricultural productivity, in which production and quality indicators are analyzed together for a complete characterization of the crop response to environmental conditions.

## CONCLUSIONS

Wheat crop yield showed significant variations between the study years, with average values ranging from 5500 kg ha<sup>-1</sup> in 2023 to 9000 kg ha<sup>-1</sup> in 2025, which highlighted the major influence of climatic conditions on crop performance.

The protein content registered a progressive variation during the analyzed period, from 10.80% in 2023 to 12.00% in 2025, indicating an improvement in the technological quality of the harvest.

The hectoliter weight varied between 77.0 kg hl<sup>-1</sup> and 80.0 kg hl<sup>-1</sup>, with the highest values being obtained in 2025, which reflected better grain filling and superior physical quality of the harvest.

Grain moisture and foreign body content showed the lowest values in 2025, confirming favorable ripening and harvesting conditions.

The analysis of the relationships between parameters revealed a positive association between production, protein content and hectoliter weight, suggesting the existence of vegetation conditions that simultaneously favored yield and harvest quality.

Climatic conditions, through the values of the thermal regime and the distribution of precipitation during the growing season, had a more important influence on crop performance than the total annual amount of precipitation.

The 2024–2025 agricultural year was the most favorable of those analyzed, recording the best values for production and all main quality indicators.

The results obtained highlighted the importance of monitoring climatic conditions and adapting crop technologies in order to maintain the stability of wheat production and quality in the context of current climatic variability.

## LIMITATIONS OF THE STUDY

For scientific rigor, potential limitations of the study were presented. The study included only three agricultural years, which limits the statistical power of the climate analyses. The data come from a single cropping location (Voiteg, Timiș County). The climate correlations should be interpreted as exploratory

relationships and not as definitive causal relationships. Extending the monitoring period to at least 5–10 years would allow the development of more robust predictive models.

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