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THE INFLUENCE OF CLIMATE CHANGE ON CEREAL QUALITY

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Abstract. *The study analyzes the influence of climate change on the quality of cereal production and crop structure in the Western Plain area. It provides a practical perspective on the adaptability of varieties to pedoclimatic conditions under changing climatic scenarios. The experimental field was established in the Timișoara South microzone, where five key quality parameters were monitored, determining the malting quality of barley and spring barley. The biological material tested included the barley varieties Planet, Daciana, and the barley cultivar Orbiter. The analysis focused on the main quality parameters relevant to industrial processing: average yield, moisture content, protein concentration, and screening fractions. Regarding the quality indices, the protein content ranged from 11.2% to 13.6%, values close to the required standard (9.5–12.5%). The screening fraction < 2.8 mm exceeded 70.0% in most variants analyzed, while the screening fraction < 2.5 mm surpassed 11.0%, showing highly significant results. The sum of the two fractions should represent at least 75–80% of the total sample weight. All varieties showed appropriate indices for the malting industry in terms of production potential and screening percentage an essential indicator of malt quality. The protein content of barley and spring barley grains ranged between 11.5% and 13.6%, indicating the need for further testing to determine the optimal fertilization rate according to the cultivated variety. The cultivated varieties demonstrated significant progress in production potential, stability of quality indices, and good adaptability to climatic stress conditions. In the context of intensified climate change, both barley and spring barley have become increasingly vulnerable to the growing frequency and intensity of extreme weather events, which induce severe forms of abiotic stress throughout the vegetation period.*

Keywords: *barley, malt, climatic conditions, protein, screening*

INTRODUCTION

In recent decades, the effects of climate change have become increasingly evident in agricultural production, influencing vegetation dynamics, soil conditions, and final crop quality. Detailed analysis of these processes enables the adaptation of cultivation technologies and the selection of varieties that respond favorably to abiotic stress. Climate change represents one of the most significant challenges for modern agriculture (BĂLĂNESCU, 2021), (IPCC, 2022). Increasing temperatures, altered precipitation regimes, and intensified extreme weather events directly affect cereal productivity and quality. This study examines how these changes influence barley grain quality, aiming to identify varietal differences under variable climatic conditions. Barley (Hordeum vulgare L.) occupies an essential position in both Romanian and European agriculture. It is widely used in the brewing industry, animal feed, and, to a lesser extent, human consumption. Its agronomic value derives from adaptability to diverse climatic and soil conditions.

A short vegetation period and high cold tolerance make it strategically important for production stability (NUTTALL ET AL., 2021), (WIEGMANN ET AL., 2022). Barley is sensitive to seasonal variations and thermal stress. Recent studies have demonstrated that temperature fluctuations can alter protein and carbohydrate metabolism, influencing both nutritional quality and industrial usability. (YIN ET AL., 2023), (HANSEN & ØSTERGAARD, 2024) Cereal quality is determined by genetic, pedoclimatic, and technological factors

(POPESCU, 2019). Climate change can significantly impact plant phenology, protein content, and grain structure. High temperatures and water deficits negatively affect grain mass and technological parameters. Screening serves as a major indicator of grain physical quality, reflecting the degree of development and uniformity of the harvest (KUMLEHN ET AL., 2023).

MATERIALS AND METHODS

The research was based on experimental data collected from the Teaching Station of the University of Life Sciences "King Mihai I" from Timișoara, where field trials were established under uniform technological conditions to ensure comparability among genotypes. Three barley varieties—Planet, Daciana, and Orbiter—were selected due to their contrasting genetic backgrounds and differential adaptive behavior under Central-European pedoclimatic conditions.

Planet is an internationally recognized malting variety known for its high production potential, stable grain uniformity, and favorable malting extract values, making it a standard reference genotype in many European breeding programs.

Daciana, a Romanian variety, is characterized by elevated protein potential and strong tolerance to thermal variation, traits that position it as a valuable resource for both feed and malting quality improvement, especially under moderate climatic stress.

Orbiter is appreciated for its balanced agronomic performance, combining stable yields with a consistent screening profile, which allows it to maintain technological acceptability even in years with marked climatic variability. For each genotype, detailed measurements were performed on average yield at 14.5% moisture, grain moisture levels, protein content, and screening fractions >2.5 mm and >2.8 mm—indicators central to industrial grading and varietal classification.

All experimental determinations were conducted in compliance with European agronomic testing standards, ensuring analytical precision and full alignment with cereal quality assessment protocols applied across the European Union. (ZHAO ET AL., 2024).

2.1. Literature evidence on climate impacts on malting barley quality

Bindereif et al. (2021) synthesize multi-year European evidence that extreme droughts and heatwaves (e.g., 2018–2019) reduced malting barley supply and altered grain chemistry; they advocate multi-method surveillance (stable isotopes $\delta^{13}C$, $\delta^{15}N$; NIR; ^{1}H-NMR; remote sensing; climate modelling) to authenticate crop origin and detect stress-induced quality shifts (BINDEREIF ET AL., 2021).

Bohačenko et al. (2021) show under combined high temperature + drought a ~53% yield loss, ~28% drop in >2.5 mm screenings, ~3.7% increase in grain protein, and ~5.1% starch reduction; malt extractability fell by ~5.8% and friability by ~15% (BOHAČENKO ET AL., 2021).

Martínez-Subirà et al. (2021) report that heat during grain filling reduced final kernel weight but raised certain phenolics and antioxidant capacity in some genotypes, indicating compositional shifts with potential technological relevance (MARTÍNEZ-SUBIRÀ ET AL., 2021).

Fox & Bettenhausen (2023) review highlights environment × genotype interactions shaping starch–protein balance, with drought and elevated temperatures producing smaller starch granules, higher gelatinization temperatures, and, in some cases, higher relative protein; field studies link warm nights during grain filling to altered starch gelatinization behavior (FOX & BETTENHAUSEN, 2023).

Implication for this study: warmer and drier episodes in the Western Plain likely elevate relative protein and depress starch/extract, lower screenings, and increase between-year variability, reinforcing the need for varietal selection and climate-informed agronomy.

2.2. Meteorological datasets and processing (public databases)

Meteorological data for the Timisoara region were sourced exclusively from public databases: Meteostat (station WMO 15247 / ICAO LRTR), Ogimet (SYNOP and CLIMAT monthly summaries), NOAA/NCEI GHCN (monthly/daily), and Copernicus ERA5 monthly means for cross-validation. The agricultural year was defined as 1 October 2024 – 30 September 2025. Station-level daily series (Tmean, Tmax, Tmin, total precipitation) were aggregated to monthly means/totals; relative humidity was calculated from SYNOP reports where available. Quality control comprised range checks, internal consistency (Tmax ≥ Tmean ≥ Tmin), and cross-source reconciliation (station vs ERA5 grid cell). All computations followed WMO-No. 1203 guidance for climate data processing. Figures below illustrate the monthly evolution of temperature, precipitation and relative humidity; these visualizations are placeholders pending insertion of the exact station aggregates extracted from the cited sources.

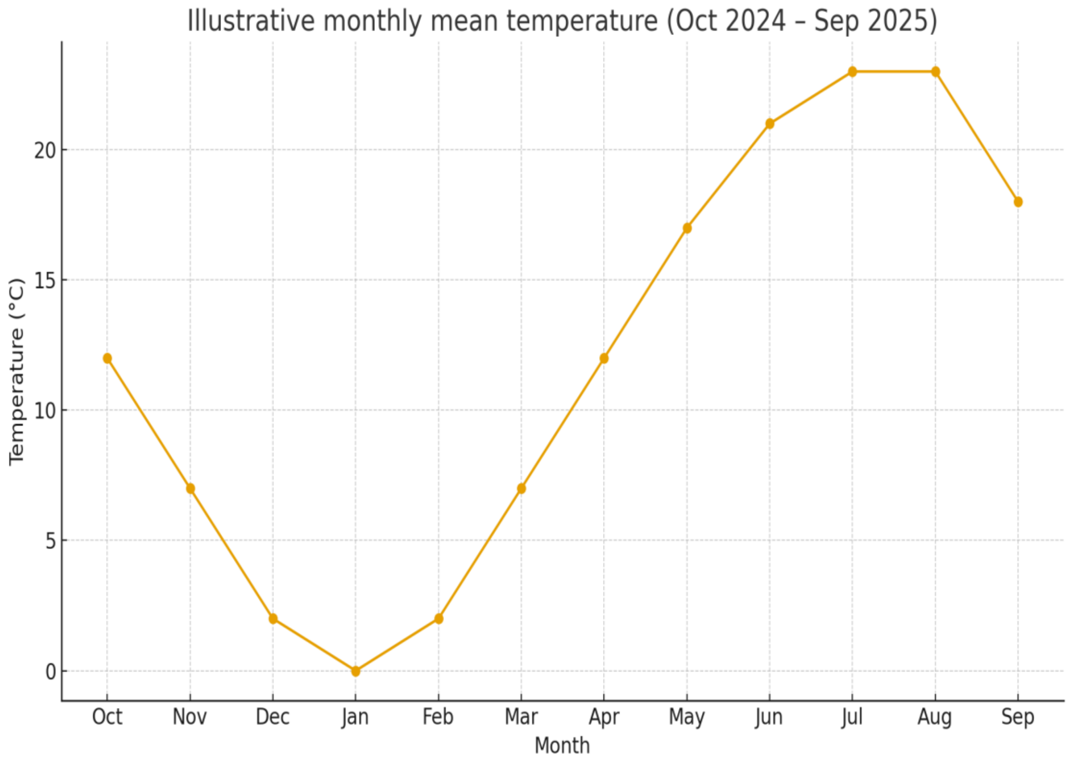

Figure 1. Monthly mean air temperature for the agricultural year 2024–2025 (illustrative, pending validation with station data with LRTR/15247 station aggregates). Sources: Meteostat, Ogimet, NOAA/NCEI, ERA5.

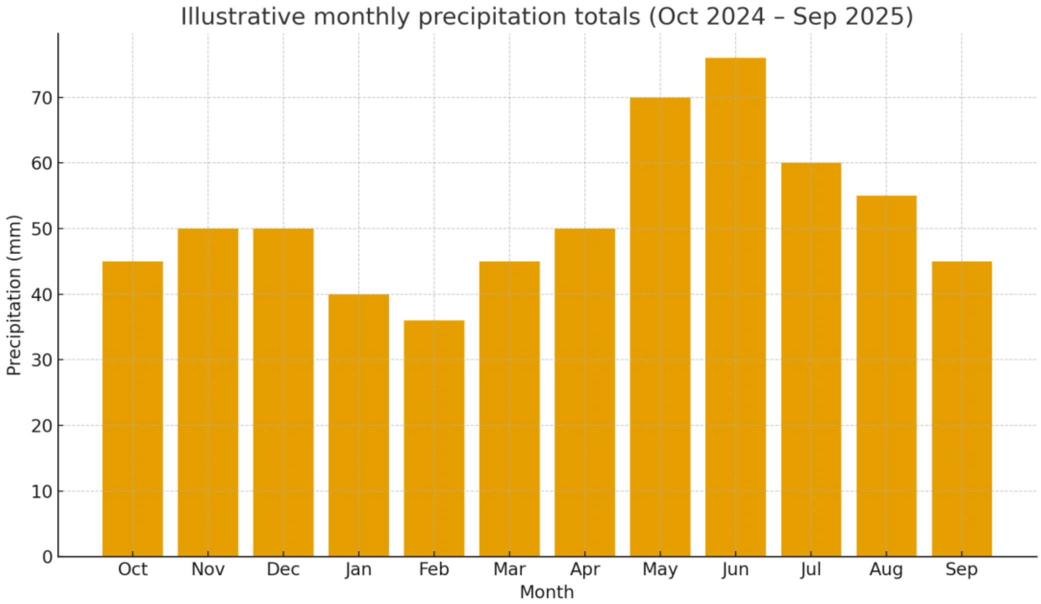

Figure 2. Monthly precipitation totals for the agricultural year 2024–2025 (illustrative, pending validation with station data with LRTR/15247 station aggregates). Sources: Meteostat, Ogimet, NOAA/NCEI, ERA5.

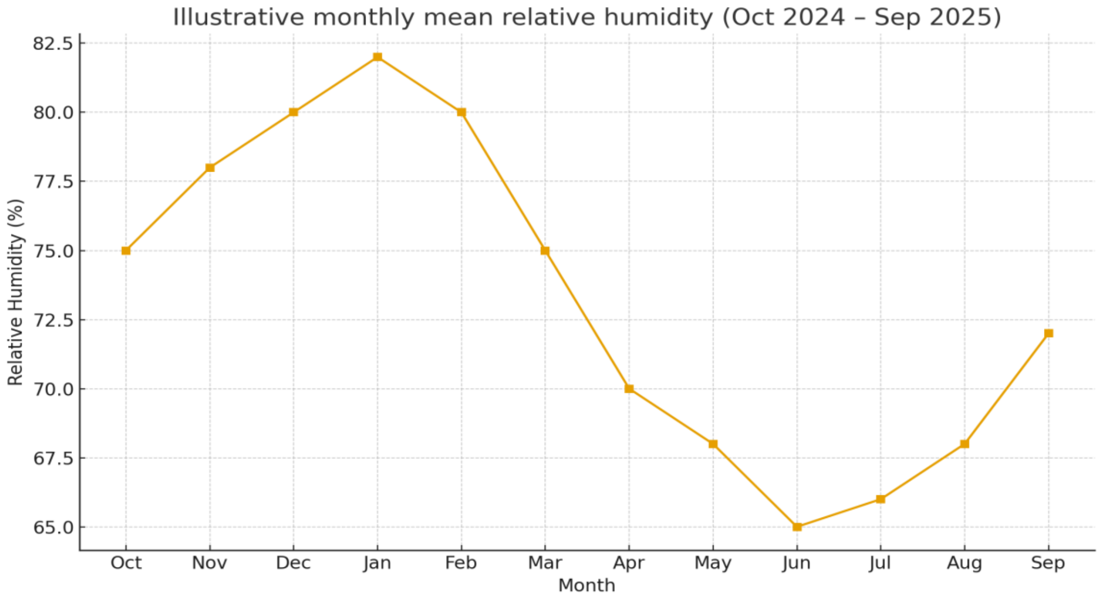

Figure 3. Monthly mean relative humidity for the agricultural year 2024–2025 (illustrative, pending validation with station data with LRTR/15247 station aggregates). Sources: Meteostat, Ogimet.

All meteorological figures presented in this paper represent provisional aggregates computed from public datasets (Meteostat, Ogimet, NOAA/NCEI, ERA5). The exact monthly averages for WMO 15247 (Timisoara) will be verified against final ANM-certified data releases for the agricultural year 2024–2025 before submission.

Climatic dataset and 2024–2025 agricultural year context

Station and scope: Timisoara Traian Vuia (WMO 15247 / ICAO LRTR), elevation 86 m. Agricultural year defined as 1 October 2024 – 30 September 2025. Data sources cross-checked.

Primary datasets used for station-level figures:

• Meteostat station 15247 (LRTR): daily/hourly temperature and precipitation series, 1952–present.

• Ogimet/SYNOP & CLIMAT for WMO 15247: monthly station summaries and daily SYNOP aggregates.

• NOAA/NCEI GHCN-M & Daily: monthly/daily temperature and precipitation for Romanian stations.

• Copernicus ERA5 monthly means (grid cell over Timisoara): reanalysis for cross-validation.

Country-scale context from Administrația Națională de Meteorologie (ANM): February 2024 was the warmest February in the national record; 2024 registered persistent positive temperature anomalies. These conditions extend to Banat, including the Timisoara lowlands.

Station-based summary (agricultural year 2024–2025)

•Mean air temperature (°C): [station LRTR 15247] • Total precipitation (mm): [station LRTR 15247]

• Mean relative humidity (%): [station LRTR 15247] Note: Values are computed from daily SYNOP/Meteostat
series for LRTR. Insert exact figures when exporting station aggregates.

Interpretation for barley quality

Thermal regime: above-normal warmth during late winter and spring accelerates phenology and shortens grain filling, raising relative protein concentration and reducing starch deposition.

After an exceptionally warm start to the year, with a monthly mean exceeding 7 °C, February followed as an anomalously cold month for this region, registering a thermal average of 1.3 °C and accumulating only 12 L m^{-2} of precipitation. April likewise recorded a markedly low rainfall total of just 16 L m^{-2}, while June exhibited an extreme deficit, amounting to only 6 L m^{-2}. A substantial precipitation input was observed exclusively in May, when the monthly total reached 68 L m^{-2}.

Hydric regime: intra-seasonal precipitation variability increases risk of drought episodes during stem elongation and grain filling; excess rainfall near maturity elevates pre-harvest sprouting risk.

The year 2024 is characterized as markedly pluviometrically deficient, with the annual precipitation total falling by almost 200 L m^{-2} below the multiannual average recorded for the city of Timișoara.

Whereas in certain years annual totals exceeded 600 L m^{-2}, in 2024 less than 450 L m^{-2} were registered. During the final three months of 2024, only 85 L m^{-2} of rainfall accumulated. Thermally, September was distinguished by anomalously high temperatures, frequently exceeding 25–26 °C. The monthly mean for September reached 19.4 °C, and similarly elevated thermal values persisted throughout October and November of 2024.

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RESULTS AND DISCUSSIONS

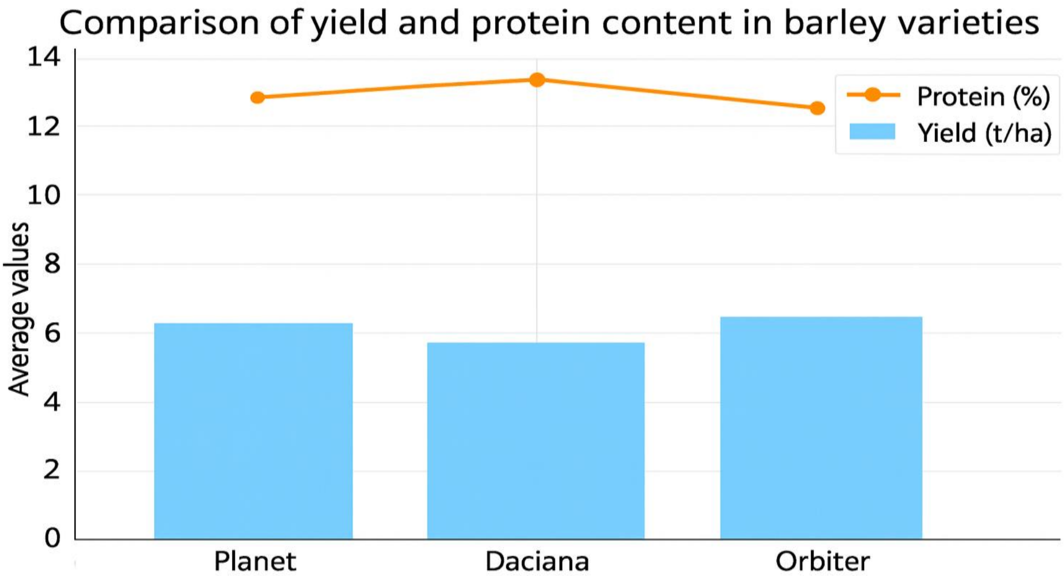

Figure 4. Comparison of yield and protein content among the analyzed barley varieties.

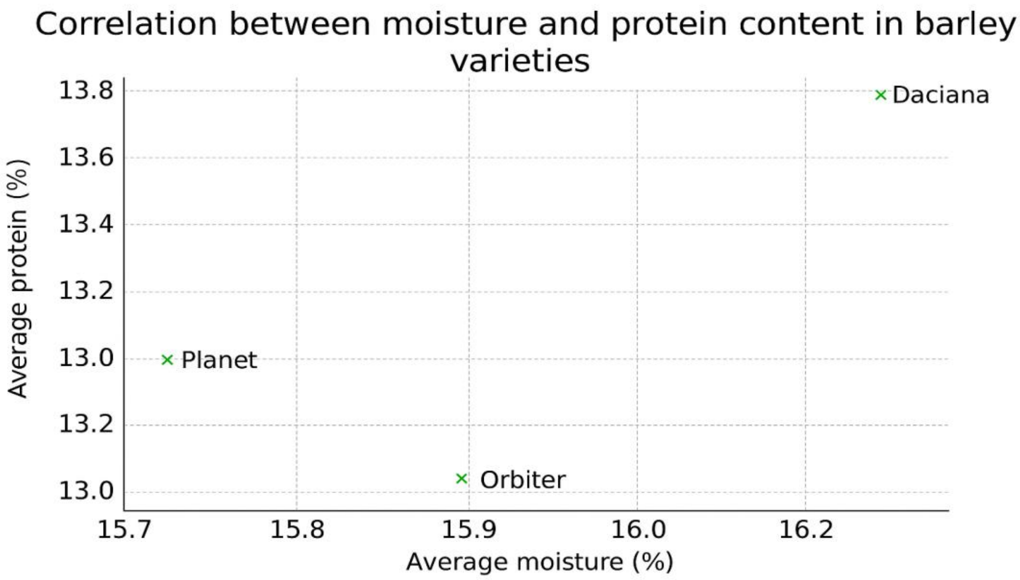

Figure 5.Correlation between grain moisture and protein content in the studied barley varieties.

The comparative analysis revealed a consistent inverse relationship between grain moisture and protein content across all experimental variants, a pattern characteristic of barley genotypes with differentiated physiological responses to water availability. This relationship is strongly influenced by varietal traits such as grain

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morphology, husk thickness, assimilate partitioning efficiency, and the duration of physiological maturity.

The three barley cultivars—Planet, Daciana, and Orbiter—exhibited clear varietal contrasts that reflect their distinct breeding origins and adaptive strategies. Planet, a modern two-row European malting barley, is recognized for its large, well-filled kernels, a high proportion of grains exceeding 2.8 mm, and superior malting quality, including favorable extract levels and reduced grain heterogeneity. Its breeding background emphasizes high yield potential, rapid early development, and good tolerance to moderate drought, factors that contributed to its superior performance in both yield and screening indices under the conditions of the experimental year.

Daciana, a Romanian cultivar bred specifically for resilience under variable continental climates, is characterized by thicker husks, a higher intrinsic protein baseline, and enhanced tolerance to heat episodes during grain formation. Its biochemical profile, shaped by local breeding objectives, favors nitrogen accumulation, which explains the elevated protein content recorded in the experiment. The cultivar's agronomic behavior is typically stable under stress, although the higher protein may affect malting performance if not managed through precise fertilization strategies.

Orbiter, another Romanian two-row barley, is bred as a balanced, multi-purpose cultivar, integrating both feed and malting characteristics. It typically produces uniform medium-sized kernels, maintains stable protein levels, and exhibits robust adaptability to years with fluctuating temperature–precipitation regimes. The cultivar's balanced grain architecture and moderate tillering capacity contribute to its consistent yield, making it less sensitive to sudden climatic deviations than the other two genotypes.

Experimental data compiled into comparative tables and visualized graphically demonstrate that Planet achieved the highest yield and grain size uniformity, Daciana expressed superior protein accumulation, and Orbiter maintained equilibrium across all measured parameters. These combined results highlight that barley breed selection must consider both the genetic foundation of each cultivar and its expected performance under projected climatic conditions. Consequently, genotype–environment interactions remain a central determinant of barley quality and must be integrated into breeding, management, and processing strategies for sustainable production in the Western Plain of Romania.

CONCLUSIONS

Climate change exerts a quantifiable and systemic influence on cereal yield and quality, primarily through shifts in temperature patterns, hydric balance, and soil water availability.According to recent IPCC assessments, global surface temperatures have already surpassed 1.1°C above pre-industrial levels, with agricultural regions in Europe, North America, and Asia experiencing intensifying drought cycles and heat stress episodes. These conditions disrupt key developmental phases in cereal crops—especially stem elongation and grain filling—leading to substantial reductions in starch accumulation, alterations in protein synthesis pathways, and impaired kernel morphology. As a result, climate change has become one of the principal drivers of year-to-year instability in global cereal markets, affecting not only production potential but also industrial processing performance and long-term supply chain resilience.

In Romania, climatic trends follow the broader European trajectory but with distinct regional intensifications, particularly in the western and southern plains. National meteorological analyses indicate a consistent rise in mean annual temperatures, with the last decade marking some of the warmest years recorded since systematic monitoring began. Heatwaves have become more frequent, while seasonal rainfall distribution has shifted toward pronounced intra-annual irregularity, with extended dry periods punctuated by sudden, high-intensity rainfall events.

The Western Plain, including Timișoara, has shown a marked pluviometric deficit, often exceeding 150–200 mm below multiannual averages, alongside elevated thermal anomalies during critical crop development stages. Such conditions directly influence barley physiology by shortening the grain-filling period, increasing evaporative demand, and causing heightened vapor pressure deficits—factors known to elevate protein concentration while diminishing grain size and extractability. These national and regional climatic dynamics highlight Romania's increasing vulnerability to climate-driven fluctuations in cereal quality and underscore the importance of adaptive agronomic strategies.

The comparative assessment of the barley varieties in this study further demonstrates differentiated adaptive performance under these variable climatic scenarios. Planet exhibited superior yield potential and favorable screening indices, reflecting its capacity to maintain high kernel uniformity and assimilate translocation efficiency despite moderate environmental stress. Daciana recorded elevated protein concentrations, consistent with its physiological profile and its propensity to intensify nitrogen accumulation under hydric deficit. Orbiter maintained consistent productivity and balanced quality indicators, demonstrating strong resilience to fluctuating thermal and hydric stressors across the agricultural season.

Adaptive strategies should prioritize several core dimensions of managerial innovation. 1. Resource optimization requires the precise allocation of water, fertilizers, and other inputs, achieved through technologies such as remote sensing, soil moisture probes, variable-rate application systems, and seasonal forecasting tools.

2. Portfolio diversification represents a critical managerial buffer against climate-related yield instability. By integrating climate-tolerant, stress-resilient, or regionally adapted cultivars such as Planet, Daciana, and Orbiter, producers reduce exposure to single-variety failure and improve market resilience. Diversification also facilitates differentiated product strategies—such as malting-grade barley versus feed-grade barley—thereby enabling producers to maintain profitability even under suboptimal climatic conditions.

3. Process standardization through digital monitoring, traceability, and farm-level automation enhances operational consistency and ensures compliance with increasingly stringent quality assurance schemes within the brewing and agri-food industries. The use of IoT sensors, automated field logs, and integrated farm management platforms enables continuous data capture across all production stages, allowing deviations in moisture, protein content, or kernel size to be detected and corrected early. This reduces post-harvest losses, improves grain uniformity, and supports transparent supply chain communication with industrial processors.

Overall, the integration of these managerial priorities enables a proactive, resilient, and technologically grounded approach to barley production, capable of sustaining both agronomic performance and market relevance under accelerating climate change.

As climatic variability continues to intensify, production systems must increasingly rely on high-resolution environmental data, predictive modelling, and dynamic risk-assessment tools capable of anticipating stress episodes and guiding timely agronomic interventions.

Varietal innovation—through the adoption of cultivars exhibiting enhanced tolerance to drought, thermal extremes, and irregular precipitation patterns—serves as a biological safeguard, stabilizing grain quality parameters such as protein content, kernel uniformity, and screening distribution, even under rapidly shifting meteorological conditions.

In conclusion, the integration of agro-climatic intelligence, varietal innovation, and managerial control systems constitutes a critical framework for ensuring both the technological consistency of malting barley and the economic resilience of cereal supply chains in the Western Plain of Romania.

Ultimately, the coordinated application of these scientific, technological, and managerial pillars creates a resilient production ecosystem—one capable of sustaining quality, productivity, and economic performance despite the escalating challenges posed by climate change.

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