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Evaluation of Spring Barley Varieties for Post-Anthesis Drought Tolerance

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ABSTRACT

Heat stress is among the most critical abiotic constraints on cereal productivity, necessitating intensified breeding strategies. While elevated temperatures can occur at multiple developmental stages, heat stress during the post-anthesis period is particularly damaging, as it disrupts grain formation and filling, leading to substantial yield reductions. Although the study was conducted in a region traditionally favourable for barley cultivation, long-term meteorological records reveal a steady increase in post-anthesis temperatures over the past three decades, increasing crop vulnerability. Under these conditions, evaluating varietal performance and heat tolerance in line with current climatic trends is essential. In this study, chemical desiccation was applied to simulate heat stress by inhibiting photosynthesis, enabling assessment of the capacity of spring barley cultivars to remobilize assimilates from vegetative tissues to the grain. Ten cultivars were evaluated over three years under both stress and non-stress conditions, focusing on key yield components.

Keywords: spring barley, heat stress, chemical desiccation, assimilate remobilization, breeding.

INTRODUCTION

In a recent study, Bindereif et al. (2021) drew attention to climate change negatively affecting barley production in Europe, the continent that generates 60% of global production. High temperatures associated with periods of drought are found to severely disrupt the homeostasis of physiological processes in barley.

Of all the abiotic stress factors affecting cereal crop productivity, drought is considered the most devastating and the one that requires the most work from breeders (Tuberosa and Slavi, 2006).

Even though barley generally manages to escape the effects of drought and heat due to its phenology, current climate change conditions have increased its vulnerability, particularly in spring barley (von Korff et al., 2008; Petcu et al., 2014).

Even when water is not a limiting factor, cereal crops that experience periods of high temperatures towards the end of the growing cycle have lower yields, mainly due to the negative impact of heat during the grain filling period (Mcdonald et al., 1983; Tewolde et al., 2006).

Barley has certain advantages in terms of drought tolerance. These include good water use capacity and efficiency and increased photosynthetic activity, which favors productive performance under such conditions (Claesson and Nycander, 2013). It can be estimated that most of the barley production is achieved through photosynthesis that takes place during grain formation. It is estimated that the dominant role in ensuring the filling of the grains in the ear belongs to the flag leaf, with 92.5% of the substances produced by it being found in the grain (Salontai et al., 1996). These findings are consistent with those reported by Petcu et al. (2003) in winter wheat, who demonstrated a strong relationship between leaf area index, biomass accumulation, and grain yield, emphasizing the importance of photosynthetic capacity in determining final productivity.

Despite these advantages, barley remains sensitive to variations insoil moisture and

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temperature, especially in the ante-anthesis and post-anthesis phenophases (Anjum et al., 2011). Although drought can affect the crop in various phenophases, major crop losses are recorded when drought occurs during the post-anthesis period, as it directly influences the process of grain formation and filling.

Under the effect of terminal drought, there is a rapid decline in photosynthesis after anthesis, thus limiting the transfer of filling period (Johnson et al., 1981). Flag leaf photosynthesis cannot support both respiration and grain growth under the influence of terminal stress (Rawson et al., 1983). Therefore, a substantial amount of carbohydrates used during the grain filling period must come from reserves assimilated before anthesis (Gent, 1994).

The flow of assimilates to the ear is a dominant process of the plant during the grain filling period (Tianu and Bude, 1985). However, the rate of translocation of assimilates from the stem to the grain to compensate for crop losses depends on the ability of plants to store assimilates in the stem and on the efficiency with which stored assimilates are mobilized and translocated to the grains (Ehdaie and Waines, 1996).

The mechanism by which heat stress occurring in the post-anthesis phenophase is based on a decrease in grain mass resulting from premature leaf senescence induced by high temperatures, accompanied by a reduction in the duration of grain filling (Bergkamp et al., 2018).

This research integrated the analysis of temperature trends in June, highlighting an upward trend above the multi-year average in recent years. Although June was considered one of the rainiest months in the Transylvanian Plain, atmospheric drought phenomena have frequently occurred in this month in recent years.

Therefore, a better understanding of the effect of this abiotic stress factor on the harvest is urgently required. Current research has shown that the negative effect of drought on production can still be mitigated through the development of more drought-tolerant cultivars, combined with the implementation of appropriate agronomic practices.

MATERIAL AND METHODS

The experiment was carried out at the Agricultural Research and Development Station (ARDS) Turda, Romania (46°35′ N, 23°48′ E), over three growing seasons. Each genotype was manually sown, based on a randomized block design with four replications, at a row spacing of 25 cm, resulting in a harvestable plot area of 1 m².

The biological material consisted of 10 two-row spring barley cultivars from the germplasm collection of the Agricultural Research and Development Station Turda. These genotypes were selected for their high agronomic value and frequent use in breeding programs.

To simulate stress and suppress photosynthetic activity, plants were treated with an oxidizing agent, with sodium chlorate ($NaClO_3$) chosen for its established capacity to inhibit photosynthetic function (Russu et al., 2019). For each genotype, two of the four sown rows were subjected to treatment, while the remaining two rows served as untreated controls. The treatment involved uniform application of a 2% sodium chlorate solution to the entire plant using a portable sprayer. Applications were conducted two weeks post-anthesis, with the heading date serving as the reference point for timing.

The ability to sustain grain filling via the remobilization of assimilates stored in the stem was evaluated by determining the difference in grain weight between untreated and chemically treated plants for each genotype.

The chemical desiccation experiment, which induces a reduction in barley grain weight through stress, was shown to be strongly and significantly correlated with the effects of natural drought, demonstrating its validity as a proxy for simulating drought-induced stress (Blum et al., 1993; Nicolas and Turner, 1993).

The laboratory evaluation encompassed the assessment of morpho-productive traits in both treated and untreated variants. Parameters quantified included the number of grains per main spike, grain weight per spike, and thousand-kernel weight (TKW). Grain weight measurements were conducted using a high-precision electronic balance (Kern 573).

Variance analysis was conducted using ANOVA in the PoliFact software, which enabled comparison tests to assess the effect of treatment, experimental year and genotype on studied parameters. Mean values for the biometric traits were calculated based on measurements of 18 spikes per variant, encompassing a total of 20 variants, including 10 treated and 10 untreated genotypes. The analysis encompassed variants from three experimental years, yielding a substantial dataset of 1,080 spikes (18 spikes × 10 genotypes × 2 treatments × 3 years), providing a robust basis for statistical evaluation.

Graphical representations were performed using Microsoft Excel 2010 with the Data Analysis statistical add-in.

Thousand-kernel weight (TKW) was determined by dividing the grain weight per spike by the corresponding number of grains and multiplying the result by 1,000.

To assess the extent of variation in cultivar performance under control versus treatment conditions, the reduction rate (r) for morpho-productive traits was calculated using the formula (Petcu et al., 2014):

$$r = \frac{Gu - Gt}{Gu} x\ 100$$

Gu = Grain weight/spike of untreated plants;

Gt = Grain weight/spike of treated plants.

This metric provides a quantitative measure of the relative decline in performance attributable to the imposed treatment.

RESULTS AND DISCUSSION

This study took into account the evolution of temperatures in June, which in recent years has shown a steady upward trend above the multi-year average. This period corresponds to a critical phenophase for the water requirements of spring barley. Over the last 67 years, temperature fluctuations in Turda have been high, and the frequency of years in which average June temperatures exceeded the multi-year average was 47.69%, closely correlated with the intensification of heat waves. Analyzing temperature variations since 1992, relative to the multi-year average of 18°C, it can be seen that in the last three decades, temperatures have been below average only in 2001 and 2006. In the context of clear climate change prospects for the Transylvanian Plain, our research gains increased relevance and timeliness (Figure 1).

In terms of temperature, two of the experimental years showed relatively small deviations from the multi-year average, while in one year, positive temperature deviations were pronounced as early as April. An interesting aspect to note is that in June, average temperatures exceeded the multi-year monthly average in each of the experimental years (Figure 2).

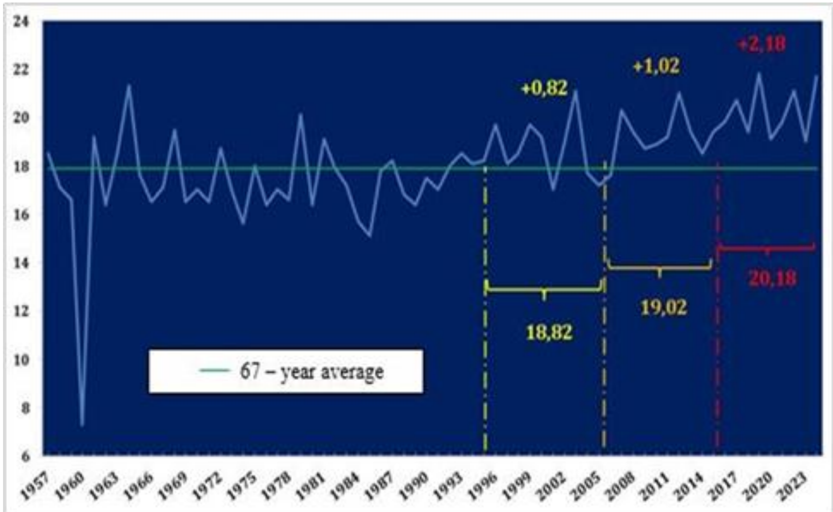

Figure 1. Variation of average monthly temperature during post-anthesis (stage) in the last 67 years (1957-2024)

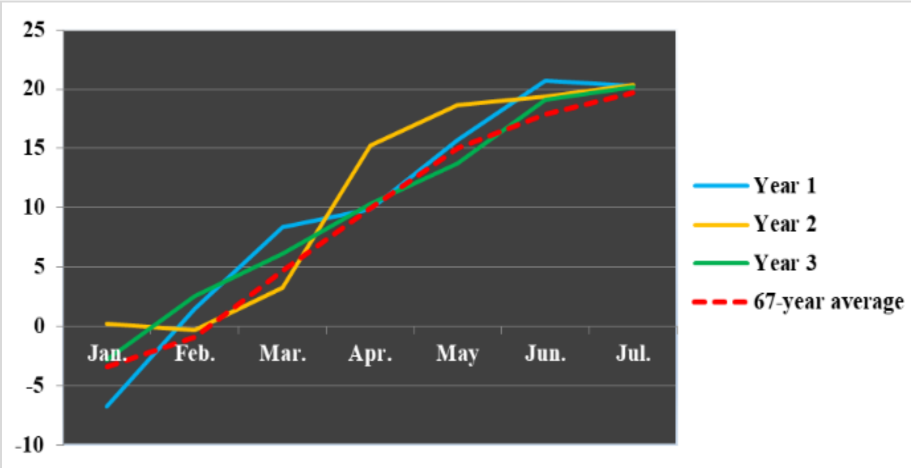

Figure 2. Thermal regime during three experimental years (ARDS Turda)

Under the applied stress conditions, several genotypes exhibited reductions in spike grain number, while others maintained stable performance (Figure 3). Most genotypes showed no significant losses in the first year, but reductions became apparent in the second and third years. Notably, Jubileu variety displayed a substantial decrease in the second year (-4.67 grains, highly significant), and in the third year, Xanadu (-3.33 grains, very significant), Marthe (-3.00 grains, significant), and Vienna (-6.00 grains, highly significant) were the most affected, reflecting strong sensitivity to stress. Romanița experienced minor, non-significant reductions in the second and third years (-2.00 and -1.67 grains), and Armada showed only a small, non-significant loss in the third year (-1.00 grain), indicating moderate stability. These results highlight that while some genotypes maintain spike grain number under stress, others, particularly Jubileu, Xanadu, Marthe, and Vienna, are markedly sensitive. Grain number formation is completed at the anthesis (flowering) stage, during which, in barley, the spike is enclosed within the boot (the sheath of the flag leaf) (www.grdc.com.au). Consequently, the application of treatments at the post-anthesis phenological stage is unlikely to have a significant effect on grain number. Nevertheless, in a comparable study conducted on wheat, Racz et al. (2020) reported a highly significant effect of treatment application, even though this yield component had already been initiated at the time of treatment. However, the number of grains per spike is less variable in barley than in wheat (Wade, 2003).

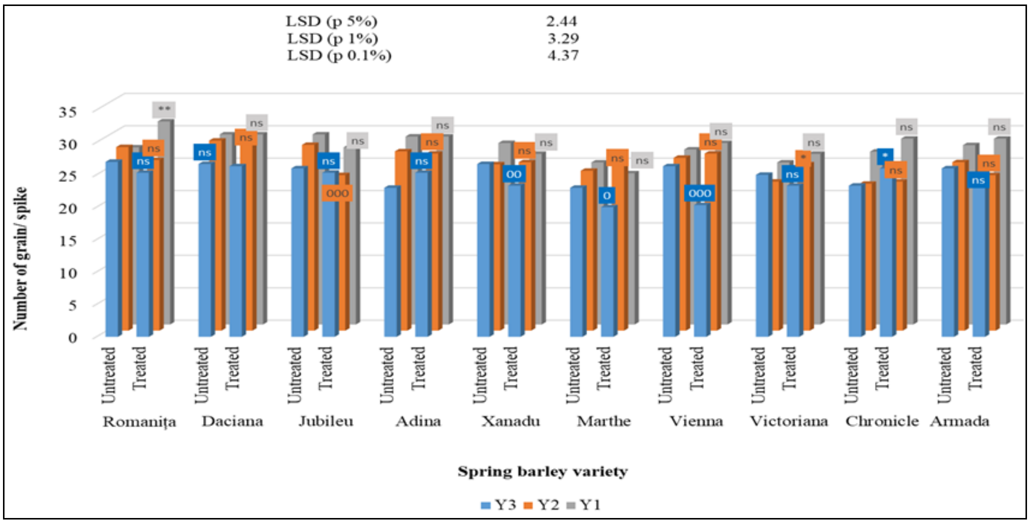

Figure 3. Triple interaction of treatment, experimental year, and genotype on number of grains/spike in spring barley (000: significant at 0.001; 00: significant at 0.01; 0: significant at 0.05; ns: not significant; negative)

The analysis of the triple interaction treatment × year × genotype for spike grain weight clearly highlights differences in drought tolerance, reflected by non-significant, significant, distinct significant, or highly significant reductions (Figure 4).

In the first experimental year, several genotypes showed non-significant reductions, indicating stability under moderate stress. This group included Adina, Vienna, Victoriana, Chronicle, and Armada, with losses close to the statistical detection limit. Marthe exhibited a significant negative reduction, suggesting slight impairment of grain filling without major impact. In contrast, Romanița and Jubileu had distinct significant reductions, while Daciana and Xanadu experienced highly significant reductions, indicating greater sensitivity.

In the second year, the tolerance of some genotypes was maintained. Chronicle showed an almost negligible reduction, while Jubileu, Marthe, Vienna, Victoriana, and Xanadu had small, non-significant losses. Armada exhibited a distinct significant reduction, reflecting a moderate stress response. Romanița, Daciana, and Adina experienced highly significant reductions, confirming sensitivity under these conditions.

In the third year, severe conditions minimized differences in tolerance, with most genotypes showing highly significant reductions in spike grain weight. Adina was the only exception, maintaining a non-significant reduction, demonstrating good stability even under stress. No other genotype exhibited solely significant or distinct significant reductions in this year.

Overall, genotypes Adina, Chronicle, Jubileu, Marthe, Vienna, and Victoriana stand out for their ability to maintain spike grain weight relatively stable for at least one experimental year, representing promising candidates for post-anthesis drought tolerance. In a recent comparable study conducted on 199 elite European winter wheat varieties, it was concluded that terminal heat stress had a strong impact, causing a 24% reduction in grain mass per main spike (Touzy, 2022).

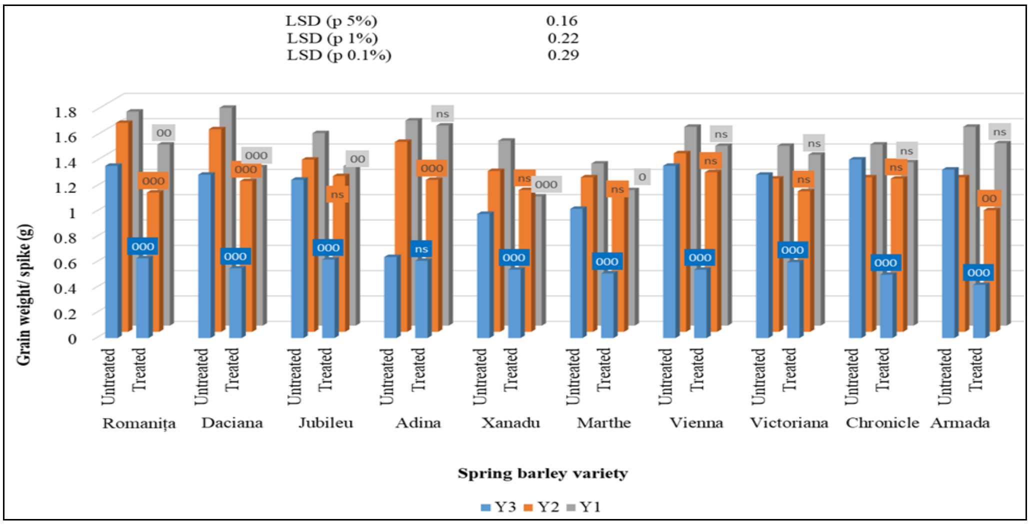

Figure 4. Triple interaction of treatment, experimental year, and genotype on grain weight/spike in spring barley (000: significant at 0.001; 00: significant at 0.01; 0: significant at 0.05; ns: not significant; negative)

The analysis of the triple interaction treatment × year × genotype revealed a differentiated response of the ten spring barley genotypes in terms of thousand kernel weight (TKW) to heat stress induced by chemical desiccation applied two weeks after anthesis (Figure 5). In the first and the second experimental years, genotypes such as Adina, Jubileu, and Marthe showed reductions of low magnitude in TKW, with differences that were only significant or distinctly significant in some cases, indicating a relatively good tolerance under moderate post-anthesis stress conditions. Chronicle was distinguished in the second experimental year by a statistically non-significant difference in TKW between treated and untreated variants, suggesting a high capacity to maintain grain weight under those specific climatic conditions. In contrast, genotypes such as Daciana, Xanadu, and Armada consistently exhibited large and very highly significant negative reductions in TKW across all three experimental years, reflecting a pronounced sensitivity to post-anthesis heat stress. In the third experimental year, the effect of desiccation on TKW was strongly amplified for almost all genotypes; however, Adina maintained comparatively smaller reductions than the rest of the genetic material, confirming a superior stability of grain filling under stress. These results highlight the existing genetic variability and emphasize the importance of multi-year evaluation for identifying spring barley genotypes with genuine tolerance to heat stress during the post-anthesis period.

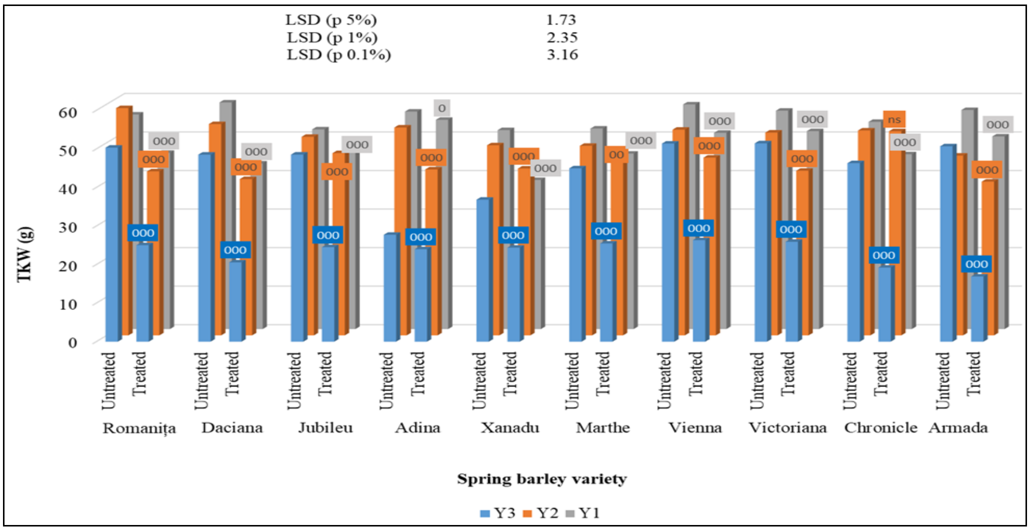

Figure 5. Triple interaction of treatment, experimental year, and genotype on TKW in spring barley (000: significant at 0.001; 00: significant at 0.01; 0: significant at 0.05; ns: not significant; negative

The stability of productivity traits under varying conditions is a key factor in achieving high yields. Analysis of TKW (thousand kernel weight), both before and after desiccation, shows higher values when the varieties were not chemically treated to accelerate ripening. On average, the variety Vienna consistently had larger grains after desiccation than the other varieties, while Romanița surpassed it in TKW only before desiccation. The variety Adina demonstrated the greatest stability, reflected in the shallow slope of the regression line across the two cultivation conditions (Figure 6).

Regarding grain weight per spike, the variety Romanița recorded the highest values before desiccation, while Adina had, on average over the three years, the highest grain weight per spike after desiccation (Figure 7). Moreover, Adina stood out not only for its high values but also, once again, for the most pronounced stability.

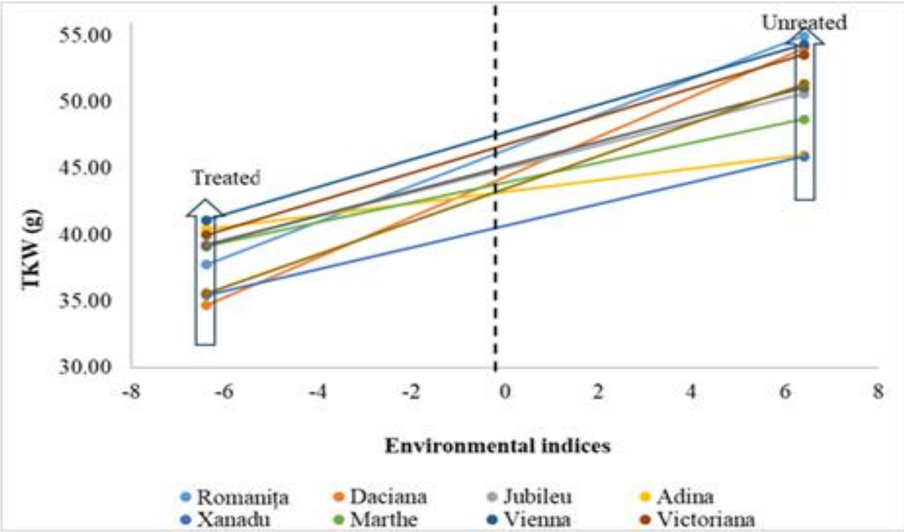

Figure 6. TKW stability for ten spring barley varieties dependin on environmetal indices

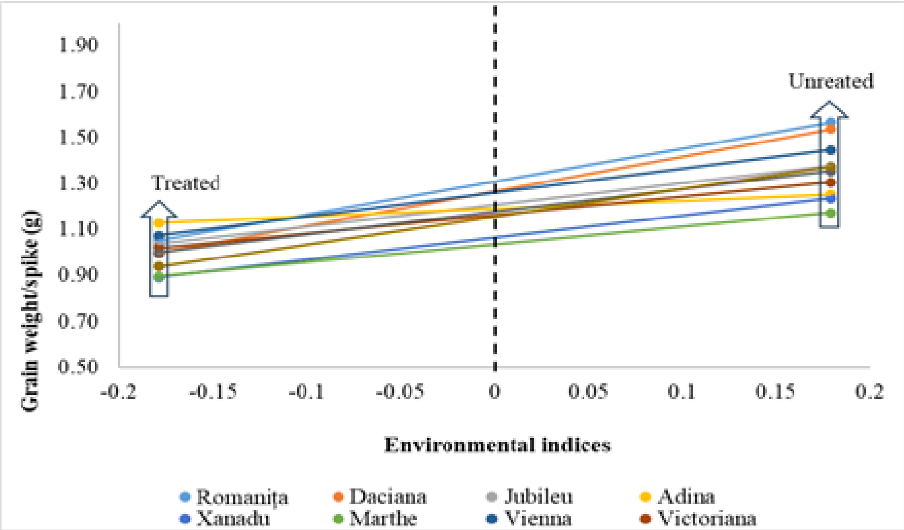

Figure 7. Grain weight/ spike stability for ten spring barley varieties depending on environmetal indice

Comparing the reduction rate of thousand kernel weight (TKW) and grain weight per spike across the 10 spring barley varieties, it is evident that TKW is slightly more stable, with an average reduction of 24.79% compared to 25.92% for grain weight per spike (Figure 8). Variability between varieties is similar for both traits, with a coefficient of variation around 27%. For TKW, reductions range from 12.13% to 35.81%, with a standard deviation of 6.65, while the median (23.82%) and the interquartile range (21.71-30.89%) indicate that most varieties cluster around moderate reductions. Grain weight per spike shows a slightly higher mean reduction and standard deviation (7.06), with a median of 25.96% and interquartile range 23.17-31.86%, suggesting somewhat more variability. Overall, these values suggest that while individual kernel weight is slightly more stable, both parameters experience moderate, comparable reductions across the varieties.

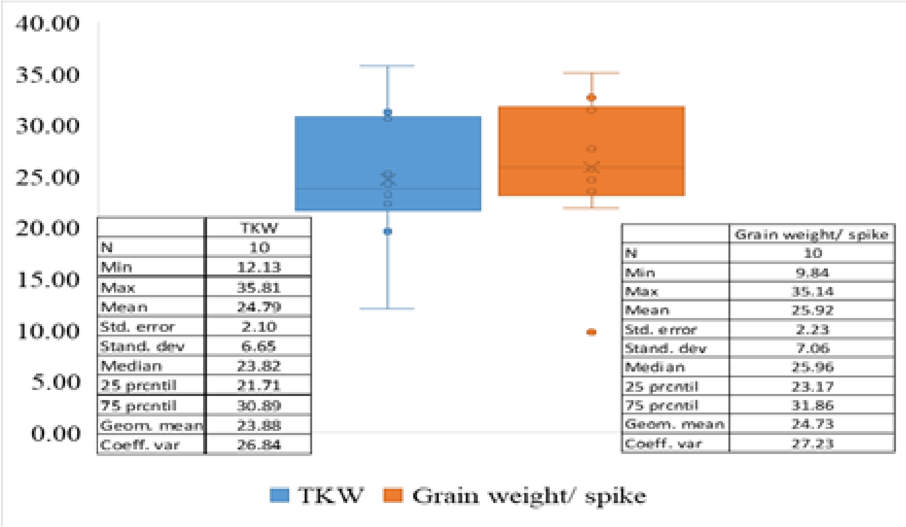

Figure 8. Descriptive statistics for the reduction rate of thousand kernel weight (TKW) and spike grain weight among the 10 spring barley varieties

Overall, varieties that exhibit low reduction rates for both TKW and spike grain weight combine high stability with reduced post-desiccation losses, making them the most advantageous for achieving high, reliable yields.

In this context, the varieties Adina, Jubileu, and Marthe (Figure 9) were notable for having reduction rates below the average of the 10 varieties for both TKW (<25%) and grain weight per spike (<26%). These genotypes are recommended as parental material in breeding programs targeting improved heat tolerance in new spring barley cultivars.

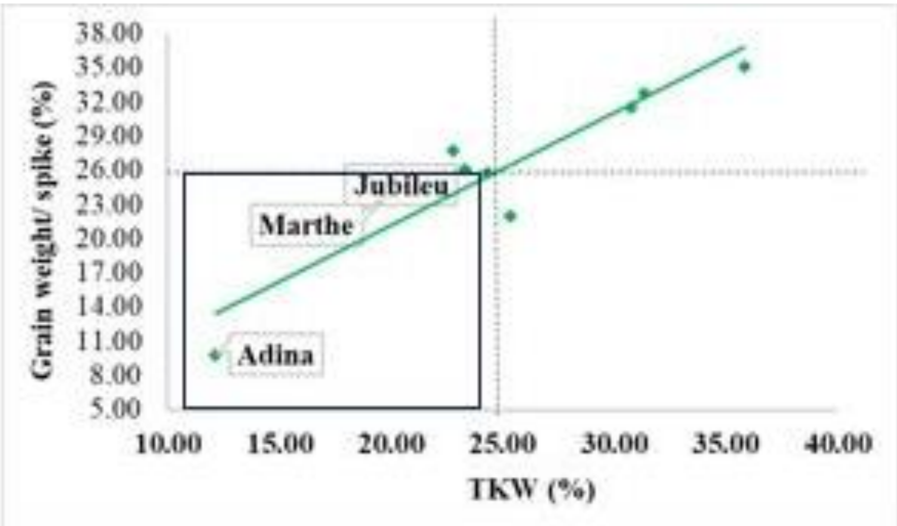

Figure 9. Reduction rate of TKW and grain weight per spike in 10 spring barley varieties

CONCLUSIONS

The high variability observed over the past 67 years highlights the need for multi-year evaluation of genotypes to identify those with consistent stress tolerance.

Analysis of grain number per spike revealed that some genotypes, such as Romanița and Armada, maintained moderate stability under stress, while others, including Jubileu, Xanadu, Marthe, and Vienna, were highly sensitive, showing substantial reductions in the second and third experimental years.

Similarly, evaluation of spike grain weight under the triple interaction of treatment × year × genotype showed considerable variation in drought tolerance, with Adina demonstrating the highest stability across all three years, whereas most other genotypes experienced significant losses under severe conditions.

Thousand kernel weight (TKW) responses mirrored these patterns. Adina, Jubileu, and Marthe exhibited relatively low reductions under moderate post-anthesis stress, while Daciana, Xanadu, and Armada were consistently sensitive. Across all genotypes, TKW proved slightly more stable than grain weight per spike, with average reductions of 24.79% and 25.92%, respectively, although both traits showed moderate, comparable variability.

Among the 10 varieties, Adina, Jubileu, and Marthe stood out for combining high values and low reduction rates for both TKW and spike grain weight, indicating superior stability and resilience to post-anthesis heat stress. These genotypes are particularly suitable as genitor material in breeding programs aimed at enhancing heat tolerance in new spring barley cultivars.

Overall, the study confirms the existence of genetic variability in heat tolerance and identifies specific genotypes with potential to improve the stability of yield components under increasing climatic pressures.

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