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Winter Wheat (*Triticum aestivum*) in a Warming Climate: Key Agroclimatic Indicators Shaping Yield Variability in Slovenia

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In the context of climate change, plant-based food production is heavily dependent on changing weather conditions, which can lead to crop instability, reduced self-sufficiency, and consequently, a decline in the competitiveness of the region's agricultural economy. Wheat (*Triticum aestivum*) is the most important cereal crop in Slovenia, cultivated on approximately 57% of arable land. Rising temperatures have already resulted in earlier phenological phases, and further warming is expected to shorten the grain filling period for wheat and other cereals. Even under unchanged photosynthetic capacity, yield reductions are projected to be directly proportional to the shortening of this critical growth stage. The relationship between temperature and water deficit is also important.

This study presents a comprehensive assessment of 34 agroclimatic indicators relevant to winter wheat production in Slovenia, including indicators related to frost and dormancy conditions, temperature regimes during the growing season, heat stress, and extreme precipitation events. To reduce dimensionality and identify dominant climatic patterns, Principal Component Analysis (PCA) was applied to transform the correlated indicators into orthogonal principal components (PCs). In addition, Spearman correlation analysis was used to determine the most influential agroclimatic indicators driving winter wheat yield variability, accounting for non-linear crop responses to climatic factors. The analysis was conducted using historical climate data (1981–2010), climate model projections from six regionally downscaled EURO-CORDEX simulations (RCP4.5 and RCP8.5), and long-term winter wheat yield data from two field experiments spanning 1993–2023.

Climate projections of the dominant PCs indicate substantial increases in Temperature conditions during the growing season, Night-time heat stress and high humidity, Moderate heat stress, and High precipitation compared with the 1981–2010 reference period. Statistically significant positive correlations were identified between winter wheat yield at the Rakičan site and the PCs representing High precipitation conditions, Spring frost conditions, and Dormancy period conditions. These findings provide an improved understanding of how future climatic conditions are likely to affect winter wheat production in Slovenia and contribute to broader insights relevant for cereal production across Europe under climate change.

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