



Stable isotope signatures of Asparago Verde di Altedo PGI (*Asparagus officinalis*) along an inland-coastal soil gradient at the Po River Delta (NE Italy)

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Climate change is intensifying environmental pressures on coastal agroecosystems, particularly through increased salinization, drought, and soil degradation. These processes strongly affect soil-plant interactions and may alter the biogeochemical signatures of crops, with direct implications for food quality, traceability, and territorial resilience. Stable isotope analysis provides a sensitive integrative tool to link climatic drivers, soil properties, and plant metabolic responses.

This study investigates soil-plant continuity in Asparago Verde di Altedo PGI (*Asparagus officinalis*) cultivated in the eastern Po River Delta (Ferrara province, NE Italy), a low-lying coastal area highly vulnerable to climate-driven salinization, saltwater intrusion, and historical land reclamation. The PGI production area is characterized by sandy to sandy-clayey soils forming a marked inland-coastal gradient, which offers an ideal natural laboratory to assess environmental controls on isotopic signatures. Specifically, it was hypothesized that the inland-coastal gradient in soil properties had a counterpart in asparagus.

Soils were characterized from different fields cultivated with asparagus with respect to pH and elemental composition using X-ray fluorescence and ICP-MS, with particular attention to salinity-related markers (e.g. Na enrichment) and trace elements. Stable carbon and nitrogen isotope ratios ($\delta^{13}\text{C}$, $\delta^{15}\text{N}$) and C/N ratio were determined in soils and asparagus turions by EA-IRMS to evaluate isotopic transfer and the influence of soil geochemistry and water availability on plant metabolism. To complement isotopic evidence, the turions were phenotyped through JIP-test parameters calculated from fast chlorophyll a fluorescence induction, a non-destructive technique providing insights into photosynthetic efficiency.

Multivariate analysis shows that isotopic signatures effectively capture environmental gradients associated with salinization and soil heterogeneity, enabling discrimination of asparagus samples according to their geographical origin even at local spatial scales. Variations in $\delta^{13}\text{C}$ reflect differences in water-use efficiency and carbon assimilation linked to salinity and drought stress, while $\delta^{15}\text{N}$ records soil-related and anthropogenic influences within the PGI area. C and N parameters had interesting relationships with JIP-test parameters, strengthening their anticipated link with photosynthetic modulations as determined by soil features.

The results demonstrate the potential of stable isotope approaches to connect climate change impacts with crop biogeochemistry and metabolism, supporting food traceability, PGI valorization, and adaptive management strategies in vulnerable coastal agricultural systems.

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