production conditions on moisture, enzyme activity, acidity, color and mineral content, with implications for both quality grading and the suitability of current standards (Vîjan et al., 2023). Parallel research has developed and applied multivariate chemometric tools and advanced analytical platforms (chromatography, spectroscopy, NMR, isotope ratios, LC-MS/MS) to classify honeys by botanical and geographical origin and to detect adulteration, complementing routine physicochemical tests (Gela et al., 2023; Ntakoulas et al., 2024; Tasić et al., 2024).

Despite this progress, several gaps remain regarding how specific production environments-defined by combinations of climate, floral landscape, management practices and post-harvest handling-jointly influence honey quality. Many studies focus on one country or region, one dimension of environment (e.g., floral or geographical origin alone), or on authenticity rather than integrated quality profiles across environments (Yayinie et al., 2021; ALaerjani and Mohammed, 2024). The present study addresses these gaps by systematically examining factors influencing honey quality in different production environments, relating standard physicochemical indicators and selected bioactive or compositional markers to environmental and management variables across multiple contexts (Tsagkaris et al., 2021; Awulachew, 2025). By integrating quality assessment with detailed information on floral sources, climatic conditions and beekeeping and processing practices, and by applying multivariate analysis to resolve patterns, this work aims to clarify how environment-specific factor combinations shape honey properties and compliance with standards (Puścion-Jakubik et al., 2020; Raweh et al., 2023; Insha et al., 2024). The study's novelty lies in its comparative, environment-oriented design and its focus on linking practical production conditions to measurable quality outcomes, thereby informing region-adapted quality control, supporting fair trade and guiding producers toward practices that maintain or enhance honey quality in diverse production systems (Vîjan et al., 2023).

2 Honey Quality Evaluation Indicator System

2.1 Physicochemical parameters

Physicochemical parameters form the backbone of legal standards for honey identity and quality. Key indices include moisture, sugar profile (fructose, glucose, sucrose), pH, free acidity, electrical conductivity, color, hydroxymethylfurfural (HMF) and diastase activity (Kivima et al., 2021). These parameters indicate freshness, proper ripening, resistance to fermentation, and heat or storage damage, and they underpin Codex and regional limits used worldwide (Pătruică et al., 2022). Large surveys show that most commercial honeys fall within these limits, but out-of-range moisture and HMF values are common signals of poor processing or storage (Ayton et al., 2025).

Physicochemical profiles are also powerful tools for authentication and differentiation of botanical and geographical origin. Studies in Romania, Portugal, Chile and elsewhere demonstrate that electrical conductivity, acidity, color, enzyme activity and basic sugars can discriminate monofloral types and confirm label claims when combined with melissopalynology and chemometric analysis (Khan et al., 2024). Stable carbon isotope ratios and protein-sugar δ13C differences further support the detection of C4 plant syrup adulteration while still relying on the same core physicochemical dataset (Suárez-Ramos et al., 2023). Thus, physicochemical parameters simultaneously support compliance, traceability and fraud detection.

2.2 Nutritional components

Honey's nutritional value is largely determined by its carbohydrate fraction, supplemented by small but important amounts of proteins, amino acids, minerals, vitamins, organic acids and a wide range of phenolic compounds (Valverde et al., 2022). Fructose and glucose dominate energy supply, while oligosaccharides, amino acids (especially proline), minerals and organic acids contribute to metabolic and technological properties. Detailed analyses from different regions show substantial variation in mineral levels and organic acids with botanical origin, highlighting the need to consider production environment when assessing nutritional quality (Becerril-Sánchez et al., 2021; Suárez-Ramos et al., 2023).

Beyond basic nutrients, phenolic compounds and flavonoids are central to honey's functional nutrition. Numerous studies link higher total phenolics and flavonoids to stronger antioxidant capacity and often to darker color, making these components key indicators of nutritional "added value" (Sharma et al., 2023). Recent reviews