among regions in soil composition and climate generate distinctive mineral fingerprints and variations in sugars, conductivity, acidity and HMF, allowing discrimination of honeys from contrasting landscapes within the same country. In multi-regional datasets, altitude and regional climate interact with floral composition to produce significant variability in fructose, glucose, sucrose, electrical conductivity and acidity, while some parameters such as moisture remain relatively stable across sites (Shakoori et al., 2023; González et al., 2024). Altitudinal gradients also influence phenolic content and antioxidant capacity, with honeys from higher elevations frequently showing increased phenolic levels compared with lowland counterparts of similar botanical origin (Mărgăoan et al., 2024; Ayton et al., 2025).

Vegetation distribution driven by geography determines the mix of nectar and honeydew sources, which has strong effects on phenolic profiles, antioxidant activity and color. Comparative studies across bioclimatic zones show that Mediterranean and forest-type vegetation, or honeydew-rich environments, yield darker honeys with higher phenolics, flavonoids and antioxidant capacity than honeys from more open or agricultural areas (Mračević et al., 2020; ALaerjani and Mohammed, 2024). Spatial contrasts between arid, sub-humid and humid regions are reflected in clear groupings of samples by physicochemical and antioxidant traits, underlining the joint influence of regional flora and environmental conditions. Thus, geographic environment acts primarily through its control of soil-climate-vegetation mosaics, shaping both the inorganic and organic fraction of honey and providing geographical signatures that can be exploited for authentication and quality differentiation (González et al., 2024; Inaudi et al., 2025).

3.3 Ecological Environment

The broader ecological environment—including contamination resulting from heavy metals, pesticides, and industrial activities—alters the composition of honey and may compromise its safety, while simultaneously enabling it to serve as a bioindicator (Inaudi et al., 2025). Even when basic physicochemical parameters remain within acceptable limits, honey sourced from areas impacted by mining or intensive agriculture typically exhibits higher concentrations of metals—such as lead, cadmium, iron, copper, and zinc—compared to honey from protected areas (Vîjan et al., 2023). In these contaminated environments, elevated metal levels coincide with reduced concentrations of phenolic and flavonoid compounds, as well as diminished antimicrobial activity, indicating that pollution is accompanied by a decline in functional quality attributes. Consequently, chemical fingerprinting based on inorganic elements can aid in assessing the bioactivity of honey. This approach plays a pivotal role in tracing geographical origins while simultaneously reflecting the status of environmental pollution, thereby closely linking honey quality control with ecosystem monitoring (Inaudi et al., 2025).

Biodiversity and landscape quality also shape the characteristics of honey by enriching the sources of pollen and nectar and by buffering the effects of environmental stressors (Petrova et al., 2024). Regions characterized by rich and heterogeneous vegetation provide a wide array of pollen types and diverse nectar chemistries; this manifests in the honey as a complex profile of phenolic compounds, alongside robust antioxidant and antimicrobial activities (ALaerjani and Mohammed, 2024). Conversely, simplified or degraded ecosystems—including highly urbanized areas or regions under intensive cultivation—may limit plant diversity and expose honeybees to higher pollutant loads, thereby narrowing the spectrum of phytochemicals found in the honey and potentially increasing the risk of residue levels exceeding regulatory limits (Raweh et al., 2023). By integrating botanical data, physicochemical properties, and pollutant data, a series of recent studies has highlighted the dual role played by honey: it serves both as a product whose quality is contingent upon ecological integrity, and as a sensitive indicator for monitoring environmental health across diverse production settings (Inaudi et al., 2025).

4 Influence of Botanical Origin and Nectar Source Structure

4.1 Differences between monofloral and multifloral honey sources

Monofloral honeys are characterized by the predominance of pollen and nectar from a single plant, confirmed by melissopalynology and supported by distinctive physicochemical and volatile profiles. Reviews of monofloral honeys (e.g., acacia, chestnut, lavender, thyme, sunflower) show that each type tends to present specific patterns of volatile organic compounds that generate characteristic aroma fingerprints, even when produced in different