Chemometric Approaches in EU Food Origin Regulation: Statistical Foundations for Authenticity Verification

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Abstract

The European Union's Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) frameworks require robust, science-based verification of food origin to combat fraud and maintain consumer trust. This article explores the growing role of chemometric techniques, especially when applied to Fourier-transform infrared (FT-IR) spectroscopy, in supporting EU regulations such as Regulation 1151/2012 and Regulation 2017/625. By transforming complex spectral data into objective, court-admissible classification models, chemometrics enables rapid and accurate determination of food provenance. Case studies in honey, carob, and olive oil demonstrate classification accuracies exceeding 90%, while advances in portable FT-IR systems allow these methods to be used at various points along the supply chain. Satisfying EU criteria for traceability, sensitivity, and proportionality, chemometric approaches have become essential tools for food authentication and regulatory compliance in the modern European marketplace.

Introduction

In a global food market fraught with mislabelling and fraud, the European Union has established strict legal frameworks to protect the authenticity and integrity of traditional and regional food products (Miguel de *et al.*, 2013). Central to these efforts are Regulation (EU) No 1151/2012 on Protected Designations of Origin (PDO) and Protected Geographical Indications (PGI), and Regulation (EU) 2017/625 on official controls.

Figure 1: Protected Designations of Origin (PDO) and Protected Geographical Indications (PGI)

Regulation 1151/2012 defines and protects the geographical indications and designations of origin for agricultural products and foodstuffs (Özgür, 2015). However, in practice, it has led to a blurring of distinctions between the PDO and PGI schemes (Zappalaglio, 2021). Complementing this framework, Regulation 2017/625 establishes consistent rules for enforcing food law requirements in the digital single market (Plana Casado, 2021). These regulations require that any product bearing a geographical label must be verifiably sourced from the region it claims. As such, enforcement agencies and laboratories across Europe face mounting pressure to deliver analytical results that are not only rapid and cost-effective but also objective, reproducible, and legally defensible. Chemometric techniques, combined with spectroscopic methods like FT-IR, have revolutionized food authentication and quality control. These approaches offer fast, non-destructive, and cost-effective analysis of complex food matrices (Biancolillo *et al*., 2020; Rohman, 2017).

Spectroscopic fingerprinting techniques, particularly when paired with multivariate statistical analysis, enable the extraction of reliable "fingerprints" from foods, allowing for the verification of authenticity claims and compliance with PDO/PGI specifications (Casale *et al*., 2016). This is especially crucial for protecting regional foods and ensuring consumer trust (Miguel de *et al*., 2013). The integration of chemometrics with spectroscopy facilitates data exploration, calibration, and classification, converting thousands of spectral variables into meaningful information about food quality and origin (Biancolillo *et al*., 2020). These methods have proven valuable in various applications, from raw material evaluation to final product assessment and shelf-life monitoring, providing both scientific rigor and legal credibility (Casale *et al*., 2016; Rohman, 2017)

Honey Authentication

Chemometrics combined with spectroscopic techniques has shown great potential for detecting honey adulteration and verifying geographical origin. FT-IR spectroscopy, coupled with multivariate analysis methods like Partial Least Squares (PLS) regression, Factorial Discriminant Analysis (FDA), and Soft Independent Modeling of Class Analogy (SIMCA), has demonstrated high classification accuracy for honey samples from various countries (Hennessy *et al*., 2008; Woodcock *et al*., 2007). These techniques have achieved correct classification rates of 93-100% for honeys from different origins (Hennessy *et al*., 2008; Woodcock *et al*., 2007). Similar approaches have been successful in detecting honey adulteration with sugar syrups, with high accuracy above 7% adulteration levels (Limm *et al*., 2023; Kelly *et al*., 2004). The combination of FT-IR spectroscopy and chemometrics offers a rapid, non-invasive screening method for honey authenticity and origin verification, typically requiring less than 5 minutes per sample (Limm *et al*., 2023).

Chemometric Validation of Extra-Virgin Olive Oil Origin

Extra-virgin olive oil, regulated under EU legislation (EEC 2568/91 and its amendments), has similarly benefitted from chemometric validation. In a study by Bendini *et al*., ATR-FT-IR spectra collected from 84 monovarietal oils across eight Italian regions were analysed within the 1720–700 cm^{-1} fingerprint region. PCA explained more than 96% of spectral variance and enabled clear separation of samples from regions such as Emilia-Romagna, Sardinia, and Sicily. This statistical clarity provides customs officers and market inspectors with robust tools to verify labels like “Terra di Bari” independently. Similarly, Hennessy *et al*. (2009) employed ATR-FTIR and multivariate analysis to confirm the origin of Ligurian olive oils with sensitivities and selectivity around 0.80.

Mediterranean Products and the Defense of PDO/PGI Claims

Recent studies have explored the use of chemometric methods to authenticate the geographical origin of Mediterranean products, particularly carobs and wines. Christou *et al*. (2017) successfully employed FTIR spectroscopy combined with PCA and OPLS-DA to classify carob samples from seven countries, achieving near-perfect predictions. Kokkinofta *et al*. (2020) further analysed carobs' nutritional composition, using chemometrics to discriminate samples with 79% accuracy based on dietary fibers, carbohydrates, and specific minerals. Similar techniques were applied to Cypriot Commandaria wine by Ioannou-Papayianni *et al*. (2011), who achieved accurate classification using FT-IR spectroscopy and various chemometric methods. Hennessy *et al*. (2009) extended this approach to extra virgin olive oil from Liguria, Italy, using ATR-FTIR spectroscopy and multivariate analysis to confirm geographical origin with sensitivities and selectivities of approximately 0.8. These studies demonstrate the potential of spectroscopic techniques combined with chemometrics for authenticating protected geographical indication (PGI) products.

Portability and Risk-Based Monitoring

EU enforcement strategy emphasizes risk-based sampling across the entire supply chain, from production to retail. As a result, analytical methods must be portable as well as powerful. New research on hand-held FT-IR devices shows that these compact instruments, when used with chemometric models like PLS regression, can detect adulteration levels as low as 0.34% trans-fat ($R^2 > 0.98$). For instance, handheld FTIR devices can identify olive oil adulteration at levels as low as 5% (Pan *et al*., 2018). Similarly, portable NIR devices have shown comparable performance to benchtop instruments in detecting oregano and coriander seed adulteration

(McGrath *et al*., 2020; McVey *et al*., 2021). The classification accuracy of these portable devices ranges from 95.6% to 100% for authentic samples (McVey *et al*., 2021). Despite slightly higher noise levels, these tools offer rapid, non-destructive, and accurate screening capabilities for various food products (Çebi *et al*., 2023). Their portability enables real-time detection of food fraud at multiple points in the supply chain, enhancing overall food integrity assurance.

EU Validation Standards

Chemometric workflows align closely with EU guidance on analytical method validation by meeting key regulatory criteria. First, they ensure traceability, as latent-variable models and acceptance thresholds are archivable, auditable, and fully transparent. This is an essential requirement for legal defensibility. Second, they demonstrate high sensitivity and specificity, with multivariate classifiers routinely achieving over 90% classification accuracy and maintaining low false-positive rates, thereby supporting proportionate and justified enforcement actions. Finally, their speed and proportionality make them highly practical: a single spectral scan followed by automated classification can be completed in under a minute, enabling the high-throughput monitoring required by Regulation 2017/625.

Conclusion

By converting complex molecular data into clear, legally admissible classifications, chemometric analysis, particularly when integrated with FT-IR spectroscopy, has established itself as a cornerstone of food authenticity verification in the European Union. These techniques allow regulators to verify geographical origin claims with scientific accuracy, operational efficiency, and judicial transparency. Their application supports the enforcement of quality schemes such as PDO and PGI, helping to protect regional food identities and uphold the integrity of the internal market. At the same time, they offer a rapid, non-destructive, and scalable solution for monitoring a diverse range of products across the supply chain. Ultimately, chemometric approaches contribute to fair trade, strengthen consumer confidence, and ensure that EU food law keeps pace with the challenges of a globalized and increasingly complex food economy.

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