This Ph.D. thesis, a collaboration between the Politecnico di Torino's Ph.D. Program in Metrology and the National Metrology Institute of Turin (INRiM), explores the intersection of analytical chemistry and metrology to enhance food quality and safety. The research, which aligns with sustainability objectives through the application of circular economy principles, highlights the necessity of standardized, robust measurement systems within food analysis.

The core of this research lies in developing and validating analytical methods and metrological tools to assess food quality and safety. This is achieved through two main research pathways:

- The development of active food packaging by utilizing antioxidant-rich by-products from food processing;
- The detection and quantification of persistent organic pollutants (specifically PFAS) in food.

These research pathways are driven by the increasing need for environmentally friendly food systems and the necessity to comply with strict food safety regulations.

The initial phase of the thesis investigates how by-products from food production (e.g., olive stones, grape leaves, and apple pomace) can be transformed into functional packaging materials, following the circular economy model. This approach reduces waste and enhances food preservation. The by-products were extracted using ethanol, and the resulting extracts were analyzed for their antioxidant and antibacterial properties.

Packaging materials were then created by coating cellulose-based biopolymer films with the extracts exhibiting the highest antioxidant potential. Their effectiveness was evaluated in real-world scenarios, where they showed a significant delay in lipid peroxidation, thereby extending food shelf life.

The second phase of the research focuses on addressing food safety concerns by detecting PFAS in various plant-based food products.
The research aimed to enhance the accuracy of PFAS quantification by transitioning from a single-laboratory to a multi-laboratory method, thereby accounting for the inherent bias in the developed PFAS quantification. This approach is crucial due to the environmental persistence and potential human health risks associated with PFAS, which are industrial compounds.
They are frequently found in food due to environmental contamination. Samples of rice, maize, wheat flour, and various fruits and vegetables were analyzed using advanced LC-MS techniques. Multiple extraction protocols were optimized, and quantification was based on an isotopic dilution approach using labeled internal standards.

The quantification of PFAS in all food matrices was accurate; however, some challenging matrices resulted in limits of quantification that were not sufficiently low. The study also included calculations of measurement uncertainties, analytical recovery percentage, and matrix effects to ensure the reliability of the results.

A key characteristic of this research is the integration of a metrological framework into analytical chemistry. All experimental methods were validated not only for accuracy and precision but also with complete uncertainty budgets, aligning with European and international standards for food safety testing.

The thesis successfully demonstrates that combining food waste valorization with robust analytical and metrological methods offers a practical pathway towards sustainable food systems. The developed active packaging can extend food shelf life, reduce spoilage, and minimize waste. Simultaneously, the validated methods for PFAS detection contribute to ensuring food safety and protecting public health.

By integrating innovation in packaging with rigorous contamination assessment, this research provides valuable contributions to food science, environmental sustainability, and public health and serves as a model for applying metrology in complex, multidisciplinary contexts.