This PhD thesis investigates the application of Near-Infrared (NIR) spectroscopy combined with chemometrics to develop rapid, sustainable, and non-destructive analytical methods for food analysis. The growing demand for efficient and environmentally friendly techniques in the agri-food sector leads to the development of alternatives to traditional analytical methods, which are often costly, time-consuming, and involve the use of non-sustainable solvents. Furthermore, conventional approaches frequently require extensive sample preparation and lead to sample destruction, having an impact on large-scale applications. In response to these challenges, this research proposes the use of NIR spectroscopy as a powerful tool for the analyses in the agri-food field, with the advantages of being rapid, non-destructive and solvent-free. This technique is integrated with multivariate data analysis, to interpret and manage the complex amount of information provided by NIR spectroscopy. In order to achieve the aims of the present work, the principles of Process Analytical Technology (PAT), circular economy, and Industry 4.0 were followed, with particular attention to process efficiency, real-time monitoring, and sustainability in food quality assessment.

This thesis is organized into three main projects. The first project, named "NEWPOW," carried out in collaboration with the Department of Agricultural, Forest and Food Science of the University of Turin, evaluates the potential of NIR spectroscopy in the quantification of total lipids in hazelnut samples from different growing regions of origin. The analyses were performed by means of two NIR instruments: a benchtop FT-NIR spectrometer equipped with an integrating sphere and an optic fibre probe, and the pocket-sized, battery-powered SCiO molecular sensor. Then, partial Least Square (PLS) regression models were developed to predict the percentage of lipid content in the samples.

The second project, which was a research line of a larger project, is named "Help2Grow", and investigates the application of both portable SCiO and Hyperspectral Imaging (NIR-HSI) for the detection of two diseases affecting grapevine leaves: powdery and downy mildew. Conducted in partnership with the University of Turin and the University of Modena and Reggio Emilia, this study explores the potential of NIR-based techniques for early disease detection, also providing interesting insights regarding the type of treatment applied on the plants.

The third and final project focuses on the characterization and classification of 47 rice varieties using NIR-HSI and chemometric modelling. Developed in collaboration with the University of Barcelona and Ente Nazionale Risi, this study aims at providing robust classification models for rice authentication, supporting traceability and quality control in the food industry.

The results of this research demonstrate the effectiveness of NIR spectroscopy, coupled with chemometrics, as a valuable tool for rapid, cost-effective, and sustainable food analysis. By avoiding the use of chemical reagents, reducing analytical time, and enabling non-destructive sample analyses, this methodology contributes to the progresses of modern food analysis techniques. This Thesis underlines the importance of innovative analytical strategies to face the challenges in food safety, quality control, and sustainability, reinforcing the role of NIR spectroscopy and chemometrics as key technologies in the future of agri-food science.