Improving efficiency and sustainability with a new smart device for the olive oil chain

Marco Menegon, Valentina Giovenzana, Andrea Casson, Alessia Pampuri, Alessio Tugnolo, Roberto Beghi, Riccardo Guidetti

Department of Agricultural and Environmental Sciences
Production, Territory, Agroenergy
Università degli Studi di Milano, via Celoria 2, 20133 Milano, Italy

✉ CORRESPONDING AUTHOR:
Valentina Giovenzana
valentina.giovenzana@unimi.it, +39 025021974

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The control of the fruit ripening phase in the olive oil production chain has always been an important aspect of managing the quality of the final product. Currently, laboratory analyses are applied to olives to assess their degree of ripeness. However, these chemical analyses are destructive, require qualified operators, and expensive equipment, and are often unsustainable due to chemical reagents.

Optical technologies offer a promising alternative for estimating quality parameters. These methods are non-destructive, rapid, objective, and environmentally friendly. Unfortunately, commercially available spectrophotometers are mainly benchtop instruments, expensive, and they are difficult to use for field measurements.

Nowadays, technological innovation has led to the miniaturization of optical sensors and the development of portable devices with performance like benchtop instruments. SmartHAND (Smart Handheld Analyzer Non Destructive) is a low-cost optical prototype that operates in the visible (Vis) and near-infrared (NIR) spectra; this device consists of photodiodes, optical filters, and LEDs capable of analysing 12 different wavelengths. Using field-collected data, and applying different chemometric processing, it is possible to develop predictive models to estimate quality parameters such as water and oil content in olives.

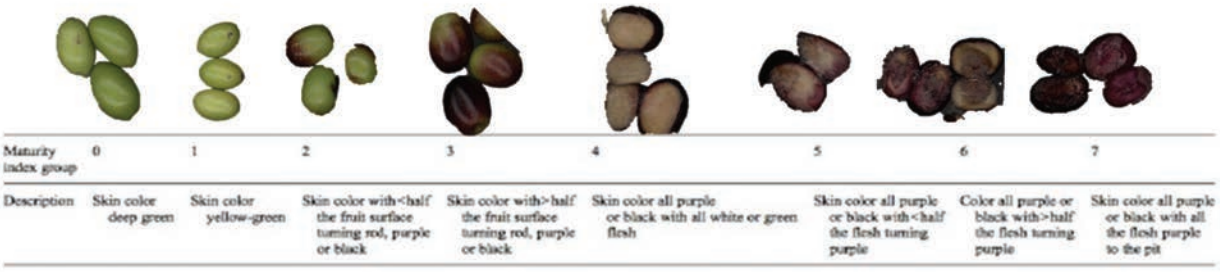
Furthermore, the environmental impact of using vis/NIR optical technologies instead of conventional laboratory analyses (chemical analyses performed on olives and olive oil) has been evaluated using the internationally recognized Life Cycle Assessment (LCA) method (ISO 14040 and 14044 standards). The results demonstrate the advantages of innovative optical methods over traditional chemical approaches.

In conclusion, the adoption of portable optical technologies could revolutionize the monitoring of olive ripening, allowing for faster and more accurate assessments directly in the field.

Keywords: optical sensor, agrifood sector, life cycle assessment, quality, vis/NIR, spectroscopy

INTRODUCTION

In the olive oil sector monitoring the fruit ripening is a very important aspect to consider for obtaining a high-quality finished product. The evaluation of the degree of maturation is undergoing an evolution from a technological point of view. In the past (1975) a colorimetric index was developed to evaluate the degree of ripeness of olives: the Uceda and Farias ripeness index (Figure 1). The index does not determine the degree of ripeness with scientific methodologies but it is based on the visual evaluation of the epicarp of the fruit and the farmer's experience. This method, still partially in use, is not completely objective, implying a high variability in the evaluation of the sample [5].



Maturity index group	0	1	2	3	4	5	6	7
Description	Skin color deep green	Skin color yellow-green	Skin color with<half the fruit surface turning rod, purple or black	Skin color with>half the fruit surface turning rod, purple or black	Skin color all purple or black with all white or green flesh	Skin color all purple or black with<half the flesh turning purple	Color all purple or black with>half the flesh turning purple	Skin color all purple or black with all the flesh purple to the pit

Figure 1 – Uceda and Frias index, developed in 1975 [5]

Nowadays, however, the analysis of drupe ripening through the use of chemical analyses is consolidated, as they are objective measures, but on the other hand not very sustainable in several respects. Chemical analyses require qualified staff to be carried out, require very expensive instrumentation, and sample preparation, are time-consuming, require the use of chemical reagents, and for this reason, could have a high impact on the environment [1]. A modern alternative to chemical analyses is represented by optical technologies, capable of estimating the desired parameters, after careful calibration of the instrument. Despite chemical analyses, optical analyses do not require the use of chemical reagents and are simpler to use, have a real-time response time (from a few milliseconds to a maximum of one minute), and in most cases they are non-destructive as no preparation of the sample is required, highlighting a potential low environmental impact [3].

Spectroscopy is an optical technique by which light radiation, characterized by a specific wavelength range, hits the matrix to be analysed, returning an optical fingerprint (spectrum) based on how much of this energy is absorbed, reflected, or transmitted by the sample itself. The characteristics of light radiation allow different information to be obtained from spectral acquisitions related to the nature of the molecules, since their bonds vibrate differently at certain wavelengths, making them recognisable. The optical range most used in the agri-food sector is the visible (vis, 350 nm – 700 nm) and near-infrared (NIR, 700 nm – 2500 nm). The information deriving from the spectra is subsequently processed using chemometrics, a statistical science that deals with the analysis of multivariate data to extract useful information relating to the characteristics of the analysed matrix [4].

At a commercial level, the spectrophotometers on the market are often large, expensive instruments, classified as "benchtop" and they can only be used in laboratories or large companies. Technological innovation, however, has made it possible to miniaturize optical sensors in an increasingly significant way, leading to the development of a new generation of devices, compact, portable, and with excellent performances comparable to benchtop instruments. The Department of Agricultural and Environmental Sciences of the University of Milan has developed and patented a new optical, smart, cost-effective, user-friendly, and environmentally sustainable prototype to support the olive supply chain, the SmartHAND [3].

EXPERIMENTAL PART

To develop a new smart device for analysing olive ripening and identifying the ideal harvest time, it was necessary to proceed through well-defined steps, namely (i) a feasibility study, which involved chemometrics analysis with multivariate statistical analysis, sampling at different ripening stages, optical acquisition, and corresponding reference measurement (ripening index), and model creation for ripening degree identification, (ii) selection of representative wavelengths for drupe ripening, and (iii) prototype development (SmartHAND) for analysing olive ripening directly in the field.

APPLICATION OF vis/NIR SPECTROSCOPY FOR MATURITY DEGREE ANALYSIS

For the feasibility study, a commercial portable instrument (Jaz, OceanOptics, The Netherlands) was used to acquire the optical spectra necessary for final device development. Jaz is a portable vis/NIR spectrophotometer that operates in a wavelength range between 400 and 1000 nm. It consists of a halogen lamp as a light source, an optical fiber cable that works in reflectance (i.e., acquiring light reflected from the sample), a measurement management module, and a microprocessor for spectrum acquisition, which are saved on a microSD memory card for data storage. The instrument acquires spectra in reflectance; therefore, the light radiation from the lamp is guided through the optical fiber to the sample. The light reflected from the sample, through the optical fiber reaches the spectrophotometer, recording for each wavelength the intensity signal of light reflected from the olive. The feasibility study used the Maturity Index (MI) as a reference [4].

SELECTION OF WAVELENGTHS

The selection of wavelengths characterizing olive ripening degree started from the Uceda and Frias 1975 index. The 8 classes of the index were reduced to 4, creating a new index called S.C.I. (Superficial Colorimetric Index). This method involves a visual evaluation of skin colour only, and was applied to simplify the MI procedure, classifying olives as green, less than 50% ripe, more than 50% ripe, and fully ripe [4].

Figure 2 – S.C.I. Superficial Colorimetric Index

The experimentation involved dividing the samples into the 4 S.C.I. classes (Figure 2) and acquiring optical spectra using the portable Jaz spectrophotometer. From the spectra obtained, chemometric techniques were used to select the most informative wavelengths for ripening degree estimation.

PROTOTYPE DEVELOPMENT

The idea of using a simplified instrument with a reduced number of wavelengths, and thus low cost, is to directly assess olive ripeness in the field by farmers, providing immediate, easily interpretable information on olive ripeness (Figure 3). This allows for standardizing harvesting time and consequently oil quality. The information gathered in the field is then sent to a service cloud for data management. Speed of response is one of the strengths of these technologies, along with no training costs, transportation costs, use of chemical reagents, and time savings, all of which classify these technologies as low-impact and entirely green.

Figure 3 – Representation of olive ripeness assessment directly in the field using a portable optical instrument

ENVIRONMENTAL IMPACT ASSESSMENT

Optical instrumentation can be considered a green technology, and therefore, the environmental impact of these optical analyses compared to conventional chemical analyses was evaluated using the Life Cycle Assessment (LCA) method, recognized internationally according to ISO 14040 and 14014 standards.

The LCA study took a "cradle-to-grave" approach (Figure 4), considering all inputs and outputs contributing to the environmental impact by measuring three key analytical parameters for olive ripening: moisture content, oil content, and phenols content [2].

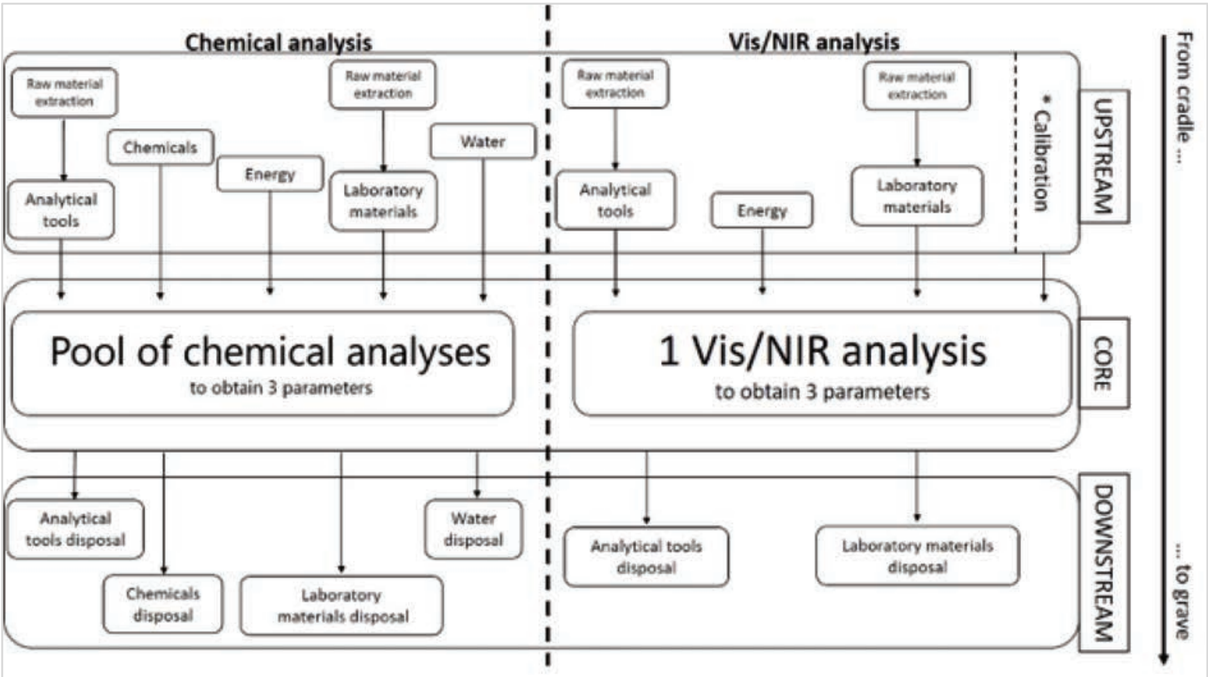


Figure 4 – Cradle-to-grave approach for assessing the environmental impact of chemical and optical analyses

As regards chemical analyses as input, the impact on the construction of the analytical instruments was considered, also considering their energy consumption and their average life (10-15 years), the chemical reagents used, the laboratory material useful for analysis and consumption of water; for all the components considered, the impact of their disposal was then assessed. Similarly, as regards optical analyses, the impacts of the creation of vis/NIR analytical instruments, their duration over time, their energy consumption, and the laboratory material necessary for their operation were considered, in addition to the evaluation also in this case of their disposal costs [1].
Using 16 indicators, the environmental impact relating to the two measurement methods (traditional and optical) used to measure the three reference parameters was assessed using LCA. The impact categories taken into consideration are reported in Table I.

Table I – Impact Categories

Impact category	Acronyms	Unit
Climate change	CC	kg CO_2 eq
Ozone depletion	OD	kg CFC-11 eq
Human toxicity, non-cancer effects	HT-NC	CTUh
Human toxicity, cancer effects	HT-C	CTUh
Particulate matter	PM	kg PM2.5 eq
Ionizing radiation HH	IRHH	kBq U235 eq
Ionizing radiation E (interim)	IRE	CTUe
Photochemical ozone formation	POF	kg NMVOC eq
Acidification	ACID	molc H^+ eq
Terrestrial eutrophication	TEU	molc N eq
Freshwater eutrophication	FEU	kg P eq
Marine eutrophication	MEU	kg N eq
Freshwater ecotoxicity	FECO	CTUe
Land use	LU	kg C deficit
Water resource depletion	WRD	m^3 water eq
Mineral, fossil & ren resource depletion	RRD	kg Sb eq

RESULTS WITH DISCUSSION

Spectroscopic analysis using the full-range Jaz instrument yielded spectra highlighting differences based on harvest time and therefore olive ripening degree (Figure 5). Variations at specific wavelengths can be observed both in the visible and near-infrared regions.

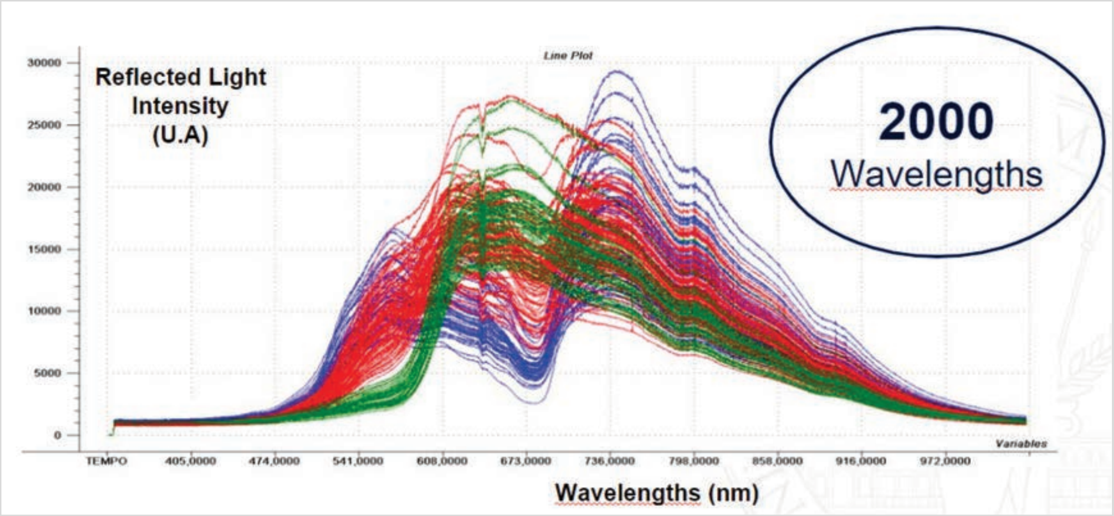


Figure 5 – Dataset of olive spectra acquired using the portable Jaz instrument, color-coded according to different ripening times

Data analysis through chemometric techniques involved applying appropriate preprocessing to eliminate instrumental and environmental noise, providing precise information on wavelength bands showing significant variability related to ripening degree. Three wavelength bands correlating best with a ripening degree were selected, all belonging to the visible region (Figure 6). Indeed, components expressing maximum variance during olive ripening are also responsible for the concurrent change in fruit epicarp colour.

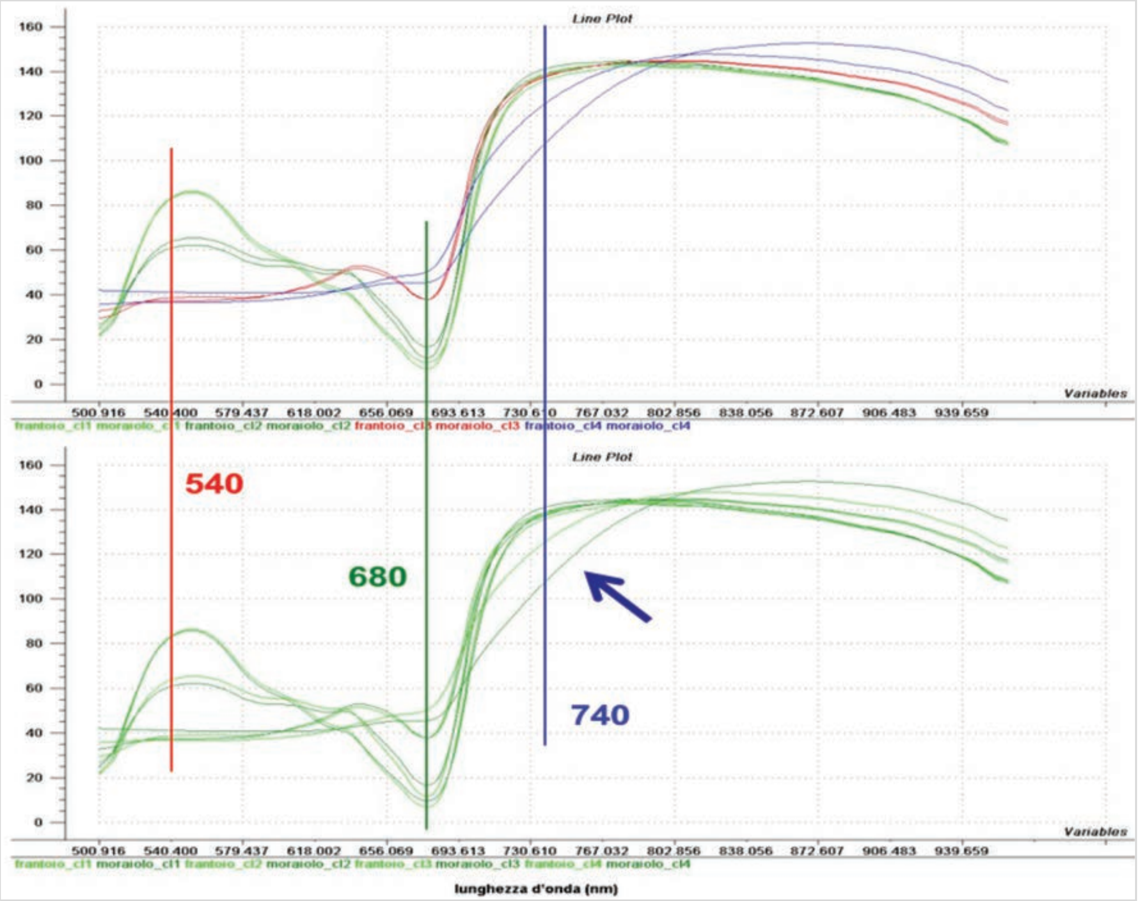


Figure 6 – Identification of the most informative wavelengths for measuring olive ripeness

Based on this data analysis, a new optical prototype was developed, focusing on acquiring optical data at specific wavelengths to simplify data collection and processing, providing preliminary information on olive ripening in a rapid and environmentally sustainable manner without the need for laboratory analysis. Specifically, three wavelengths were selected for measuring olive ripeness (Figure 6), and using 3D printed components, the prototype of the small new device, called 'SmartHAND' (Smart Handheld Analyzer Non-Destructive, Figure 7), was developed. The SmartHAND prototype has been patented in 2022 by Università degli Studi di Milano as “Portable device for analysing vegetable matrices on the field and related system and method” (patent n. WO 2022/172153).

SmartHAND is a low-cost portable instrument operating in the visible (Vis) and near-infrared (NIR) spectra, composed of photodiodes, optical filters, and a LED capable of analysing at 12 wavelengths (Vis sensor measures at 450, 500, 550, 570, 600, and 650 nm, while the NIR sensor measures at 610, 680, 730, 760, 810, and 860 nm). The device is still in the prototype phase TRL 5 approx. (technology demonstrated in a relevant environment) on a scale 1 to 9, where 9 is a fully qualified system ready for commercialization. The wavelengths present in SmartHAND are 12 (a miniaturized optical bench already available on the market was used for simplicity and reliability), but these include the 3 obtained from the specific selection as seen earlier. Sample illumination is provided by a wide-spectrum white LED.

Figure 7 – The SmartHAND prototype

SmartHAND returns as acquisition result a discontinuous spectrum composed of the set of wavelengths installed on the device (Figure 8). This spectrum is simplified compared to a full-range spectrum but retains useful information associated with epicarp colour evolution, and thus ripening.

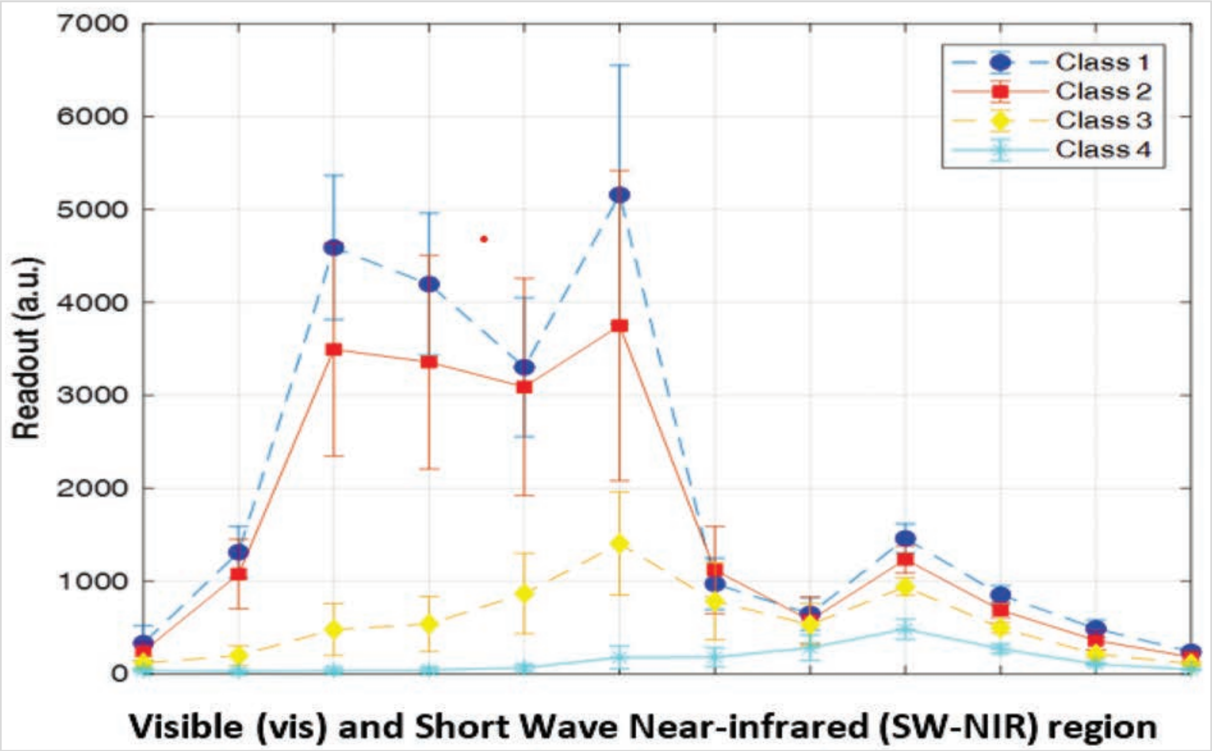


Figure 8 – Spectral dataset acquired using SmartHAND prototype at different harvest times. Each class represents a different time and ripeness degree.

LCA EVALUATION

Regarding the comparative LCA study on the impact of optical and traditional analysis instrumentation, extremely positive results emerged for optical instrumentation.

In Figure 8, it can be observed how traditional chemical analyses have a significantly higher impact compared to spectroscopic techniques. To achieve the same results, traditional methods require three different analyses, while optical instrumentation only necessitates a single spectral measurement.

Considering the analysis frequency relative to the total oil production, the impact of the analyses on the entire process of extra virgin olive oil production can also be estimated. Laboratory chemical analyses account for a maximum of 21% of the total impact when the analysis frequency involves analysing a sample for every 10 litres of oil, decreasing to 0.2% of the total impact for samplings conducted every 1000 litres of oil. Comparing the two analysis scenarios (laboratory chemical vs. optical analyses), it emerged that optical analysis has an average impact 36 times lower than traditional analysis on oil samples.

Furthermore, traditional laboratory and optical analyses were compared, even on whole olive sample analyses, resulting in a reduced impact of 15 times for optical compared to traditional methods.

By using predictive models capable of simultaneously estimating a larger number of parameters and/or increasing the number of samples analysed during the life cycle of optical instrumentation, the impact gap between the two methodologies becomes even wider [2].

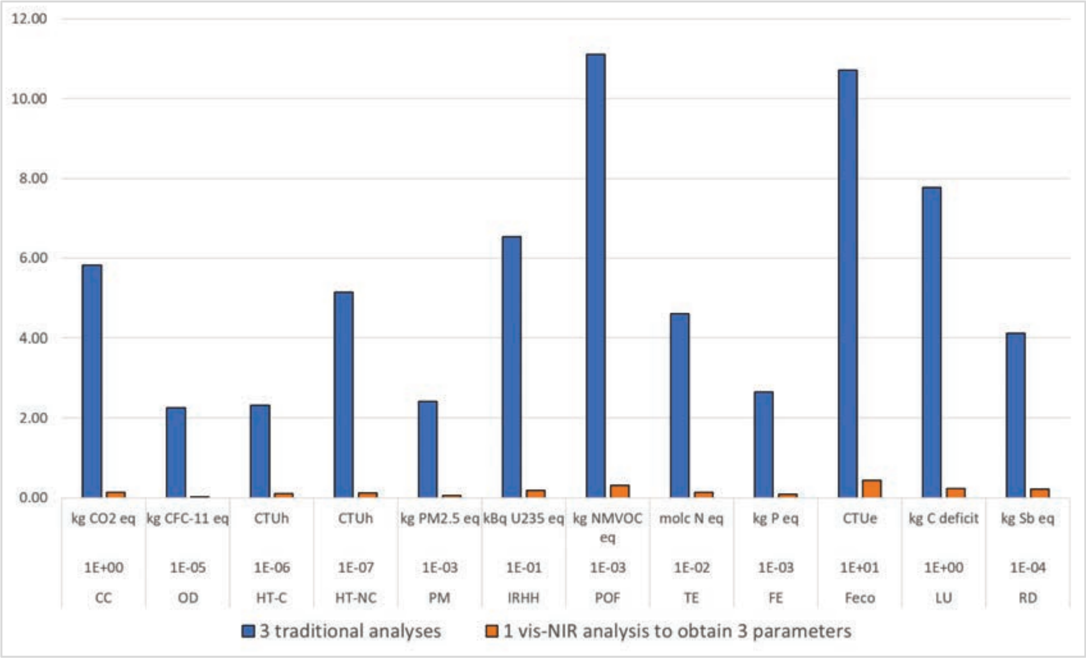


Figure 9 - Comparison of environmental impact between traditional chemical and optical analyses [2]

Overall, quantifying the environmental damage, the results have shown clear advantages for optical analysis, confirming that vis/NIR spectroscopy can be rightly considered a green analytical technology. Among the various techniques available, vis/NIR and NIR spectroscopy are valid tools for the monitoring of qualitative parameters and control in the olive oil sector. The optical instruments currently available on the market are mainly laboratory instruments with dimensions and costs that are not suitable for use in real pre- and post-harvest applications, especially for SMEs. To overcome recent years, research has focused on feasibility studies and simulations of simplified simulations of simplified systems. This study has focused on the preliminary design, build, and test of a cost-effective, real-time measurement, device to support operators of the olive sector who want to use a sustainable approach and olive-growing 4.0.

BIBLIOGRAPHY

[1] A. Casson, R. Beghi, V. Giovenzana, I. Fiorindo, A. Tugnolo, R.Guidetti, Visible near infrared spectroscopy as a green technology: An environmental impact comparative study on olive oil analyses. *Sustainability*, *11*(9), 2611, (2019).

[2] A. Casson, R. Beghi, V. Giovenzana, I. Fiorindo, A. Tugnolo, R.Guidetti, Environmental advantages of visible and near infrared spectroscopy for the prediction of intact olive ripeness. *Biosystems Engineering*, *189*, 1-10, (2020)

[3] A. Pampuri, A. Tugnolo, V. Giovenzana, A. Casson, C. Pozzoli, L. Brancadoro, R. Beghi, Application of a Cost-Effective Visible/Near Infrared Optical Prototype for the Measurement of Qualitative Parameters of Chardonnay Grapes. *Applied Sciences*, *12*(10), 4853, (2022).

[4] A. Tugnolo, V. Giovenzana, R. Beghi, S. Grassi, C. Alamprese, A. Casson, R. Guidetti, A diagnostic visible/near infrared tool for a fully automated olive ripeness evaluation in a view of a simplified optical system. *Computers and Electronics in Agriculture*, *180*, 105887, (2021).

[5] M. Uceda, L. Frías, Épocas de recolección. Evolución del contenido graso del fruto y de la composición y calidad del aceite. Proceedings of II Seminario Oleícola International. Córdoba, Spain, 25-46, (1975).

[6] M. Zambelli, V. Giovenzana, A. Casson, A. Tugnolo, A. Pampuri, S. Vignati, R. Guidetti, Is there mutual methodology among the environmental impact assessment studies of wine production chain. A systematic review. *Science of The Total Environment*, *857*, 159531, (2023).