Hyperspectral Imaging

Practical and technological issues, perspectives, challenges and opportunities
Applications in the Agro-Food sector

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Quality and Authentication of Products Unit
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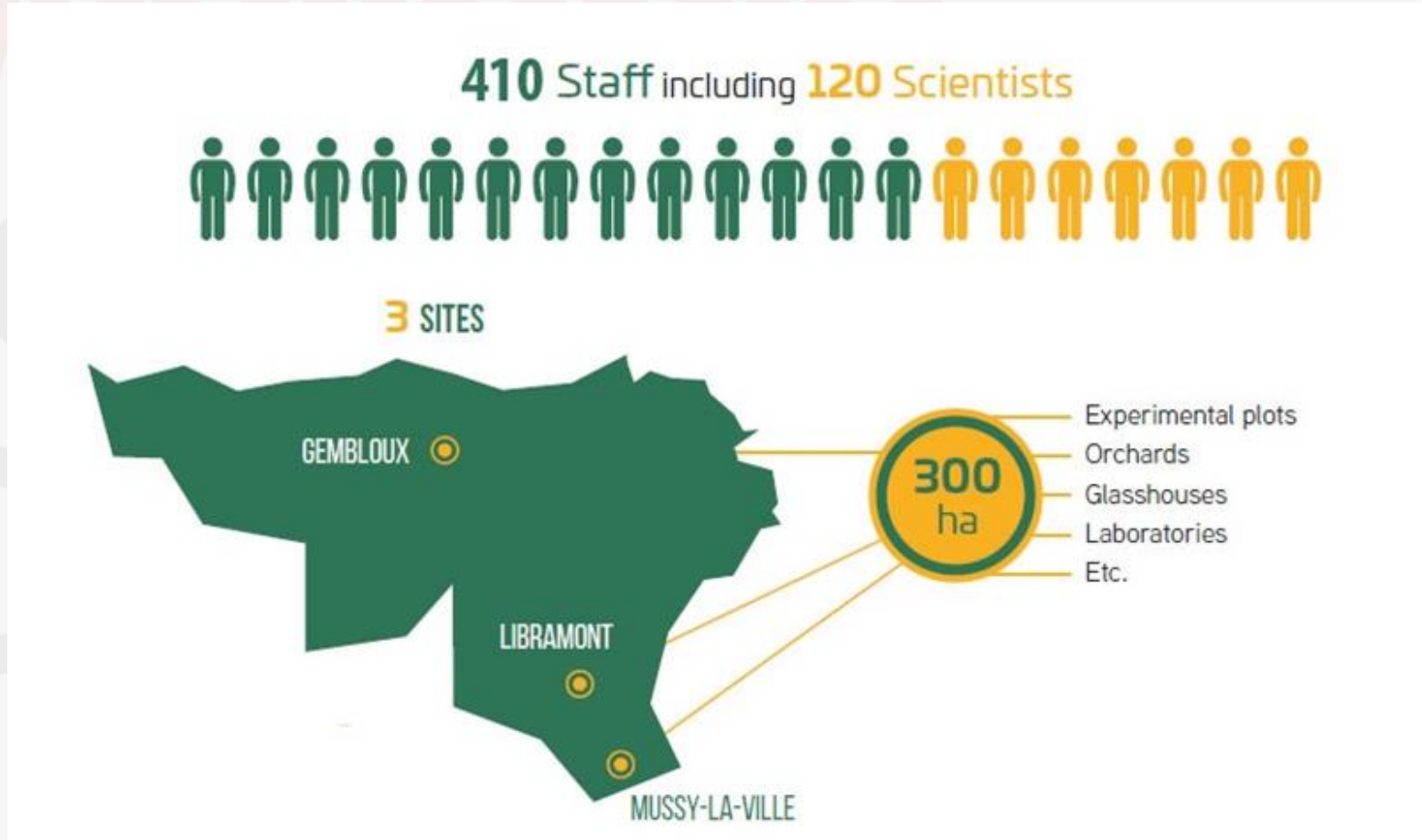
Helsinki, 9 /12 /2024

Wallonie
recherche
CRA-W



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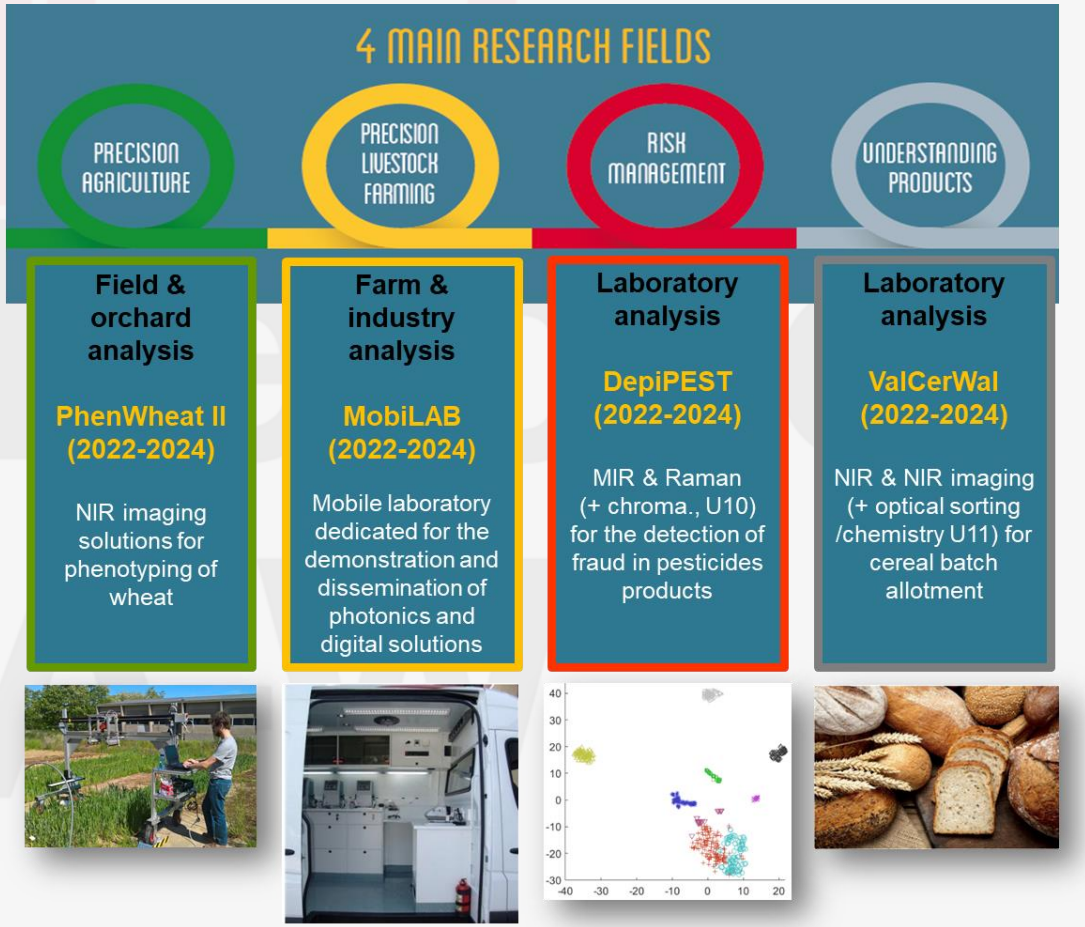

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Quality and authentication of agricultural products Unit

Implementing and validating various operations with a view to being a dynamic, innovative and sustainable research player committed to the quality and authentication of agricultural and agri-food products. The unit also seeks to boost the Walloon agri-food sectors by improving the quality, traceability and typicality of their products, focusing in particular on products from the short distribution and organic sectors.

Objectives

Developing and applying knowledge, analytical methods and innovative tools to ensure product quality and authentication.

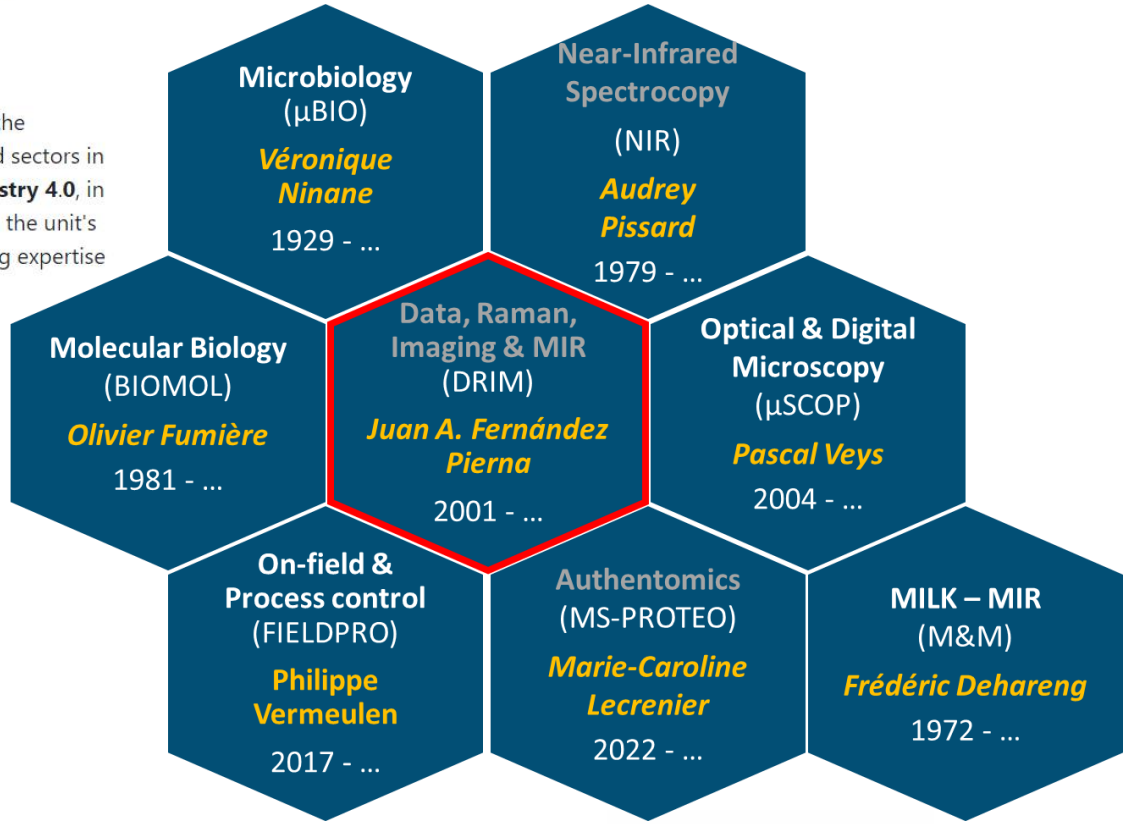
Developing knowledge in the field of agri-food product quality and authentication

Participating in the **European Research Area** (ERA).

Ensuring a **technological and analytical watch** in the field of molecular biology, chemometrics, bioinformatics, imaging, database management, microbiology, microscopy and vibrational spectroscopy.

Lending support to the agricultural and food sectors in the **roll-out of Industry 4.0**, in particular by sharing the unit's sensor and modelling expertise

Developing **innovative, rapid and sustainable analytical methods**.



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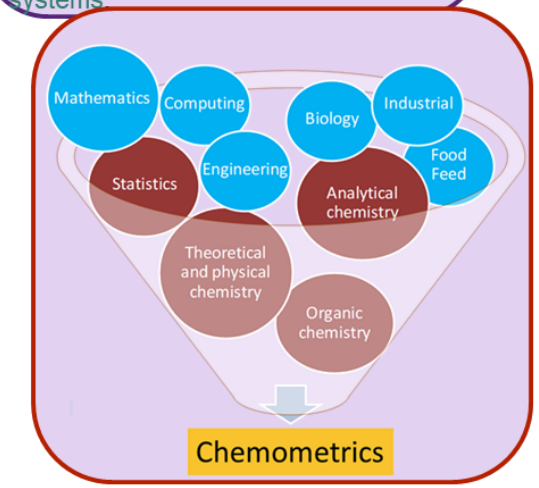
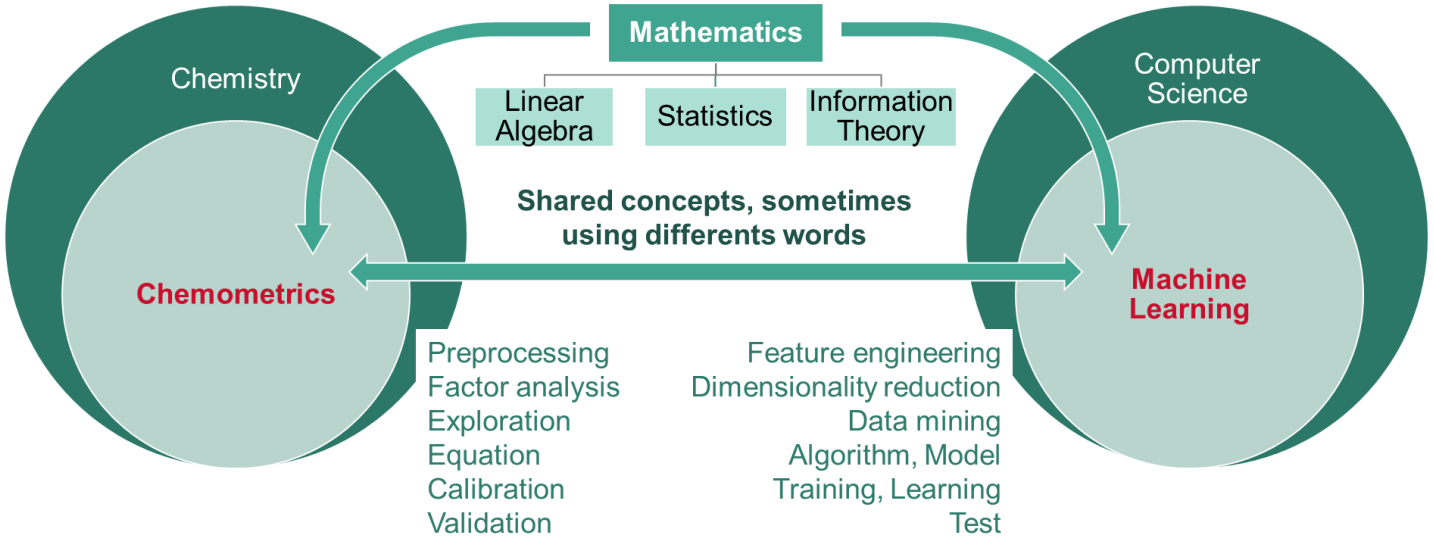
Juan Antonio Fernández
Maxime Joissains / Nicaise Kayoka / François Stevens

Data Sciences – Chemometrics, Machine Learning

Chemometrics

"Chemometrics is a chemical discipline that uses mathematics, statistics and formal logic to design or select optimal experimental procedures; to provide maximum relevant chemical information by analyzing chemical data; and to obtain knowledge about chemical systems."





Source: Massart, D.L., et al. (1997) Data Handling in Science and Technology 20A: Handbook of Chemometrics and Qualimetrics Part A, p1

Techniques – Raman, Imaging & MIR

VERTEX 70

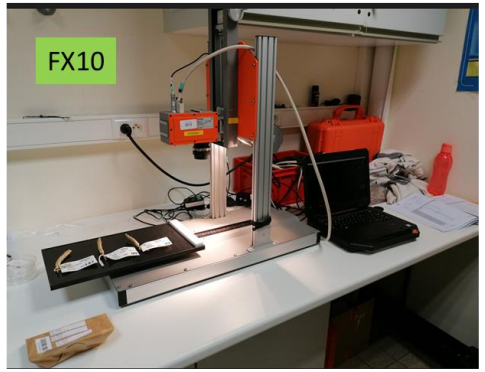
RAM II

Hyperion

Senterra

Progeny

Configuration labo



Configuration terrain

Configuration terrain

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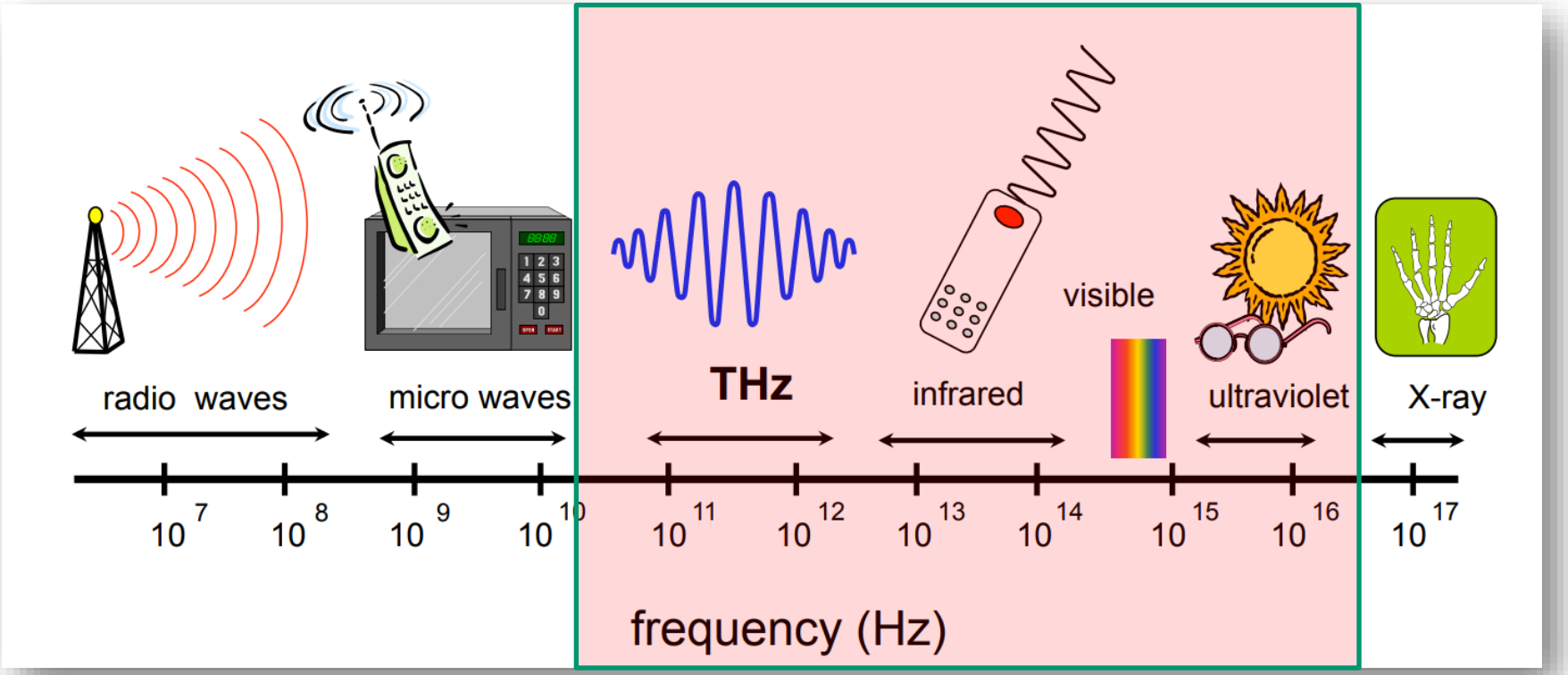
Waves at our service…

electromagnetic spectrum of light



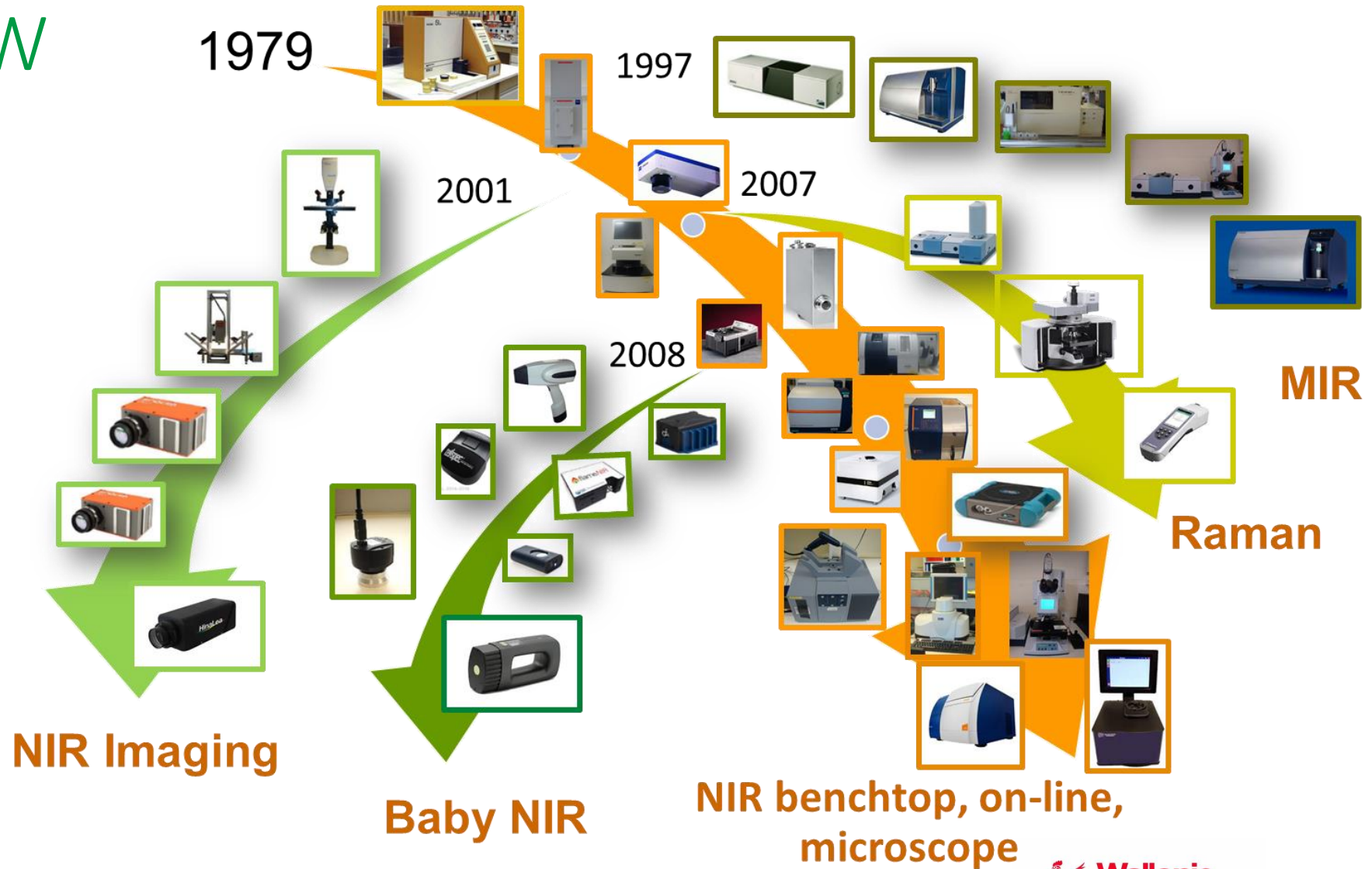
Source : R. Gente, N. Born, A. Rehn, M. Koch
CROP.SENSe.net Symposium, Bonn, 29.9.1014.

Vibrational Spectroscopy

At the CRA-W

Vibrational Spectroscopy

- No or limited sample prep (drying, grinding, …)
- No additional reagents necessary
- Fast measurement even on moving sample (conveyor belt, ..)
- Non-invasive (do not alter the sample)
- Simultaneous determination of different constituents



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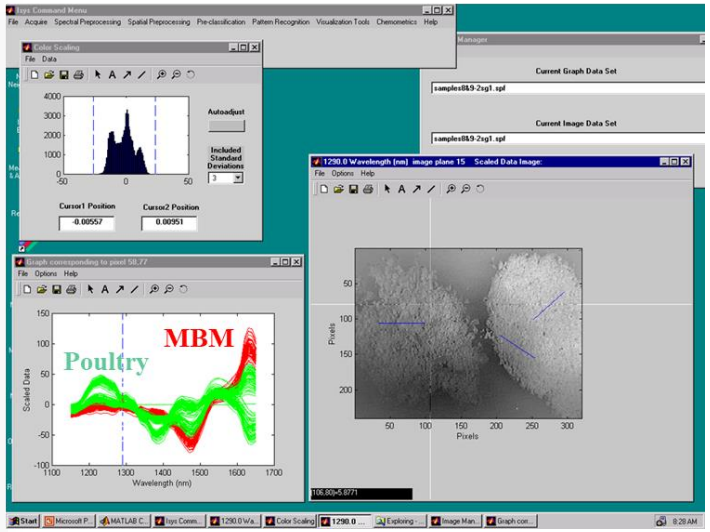
Hyperspectral Imaging

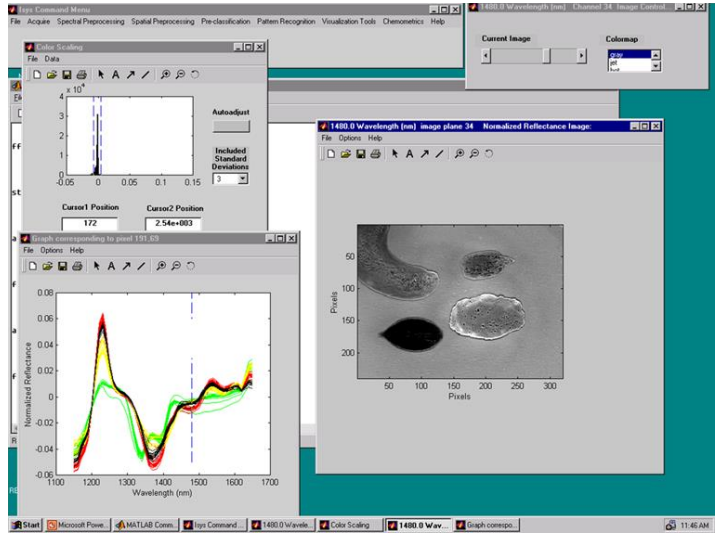
CRA-W story

20 years ago…

Feedingstuffs



Dried fruits



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Hyperspectral Imaging

CRA-W story

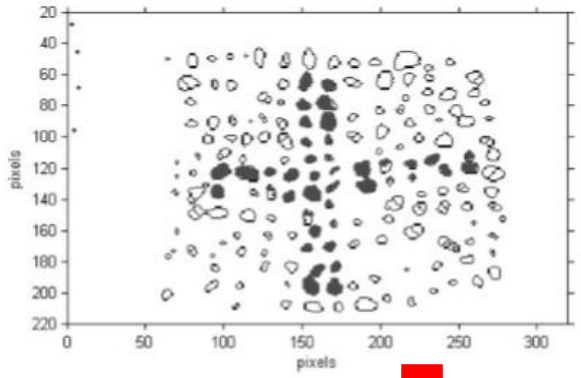
20 years ago…

- 2006 • EASIM – 06 Umeå
- 2009 • **EASIM – 09 Gembloux**
- 2010 • IASIM-10 Dublin
- 2011 • Hyperfest-2011 – Riga
- 2012 • IASIM 2012 – Sigulda
- 2014 • IASIM-14 Rome
- 2016 • IASIM-16 Chamonix-Mont-Blanc
- 2018 • IASIM-18 Seattle
- 2022 • IASIM-22 Esbjerg
- 2024 • **IASIM-24 Bilbao**

JOURNAL OF CHEMOMETRICS
J. Chemometrics 2004; **18**: 341–349
Published online 31 December 2004 in Wiley InterScience (www.interscience.wiley.com). DOI: 10.1002/cem.877

Combination of support vector machines (SVM) and near-infrared (NIR) imaging spectroscopy for the detection of meat and bone meal (MBM) in compound feeds

J. A. Fernández Pierna[1], V. Baeten[1], A. Michotte Renier[1], R. P. Cogdill[2] and P. Dardenne[1]*



From machine learning to chemometrics

Hyperspectral Imaging

The CRA-W now

8 DIFFERENT IMAGING SYSTEMS

> 45 PEER REVIEW PAPERS

> 10 BOOK CHAPTERS

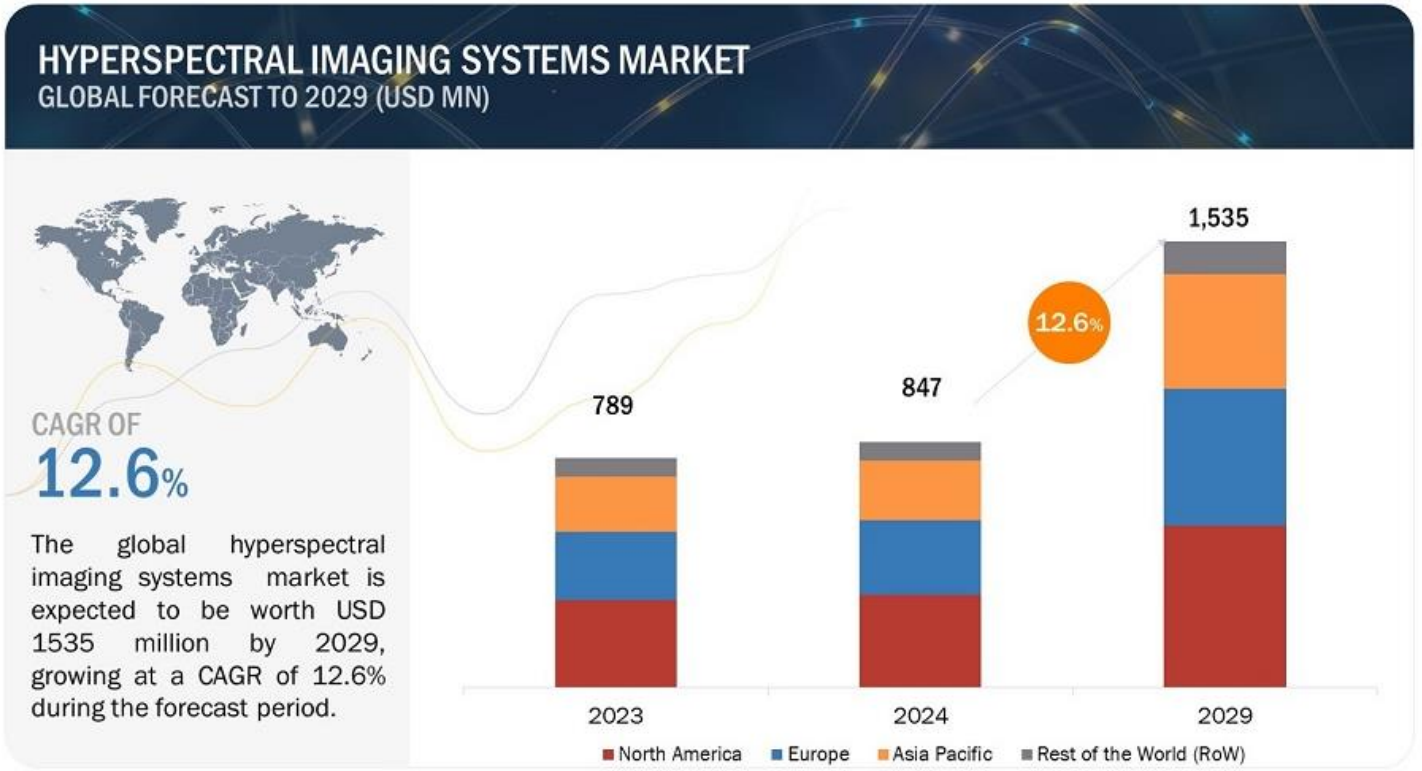
> 15 PROJECTS

NUMEROUS CONFERENCES AND TRAINING COURSES

Wallonie recherche CRA-W

Market growth projections

The hyperspectral imaging market is set for robust growth, driven by technological advancements and expanding applications across multiple industries.



https://www.marketsandmarkets.com/Market-Reports/hyperspectral-imaging-market-246979343.html

Hyperspectral Imaging

Growth drivers

- **Technological Advancements**: Improvements in sensor technology and data processing.
- **Expanding Applications**: Increased use in agriculture, environmental monitoring, healthcare, and defense.

- **Investment and Funding**: Growing interest from venture capital and government grants.

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Hyperspectral Imaging

Growth drivers – industry insights

The hyperspectral imaging market is dynamic, with **established players** driving innovation and **new entrants** pushing the boundaries with cutting-edge technologies.

Key Players

neo NORSK ELEKTRO OPTIKK AS

SPECIM A Konica Minolta Company

imec

Headwall

Emerging Startups

cubert

Photon etc

BAYSPEC

HySpex by neo

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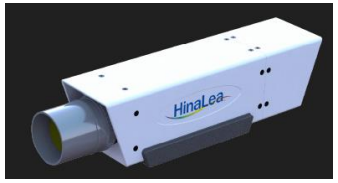
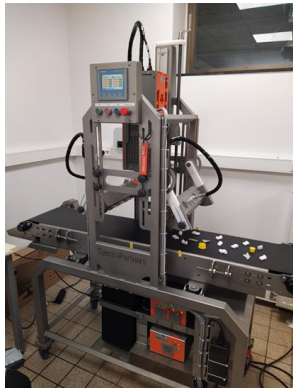
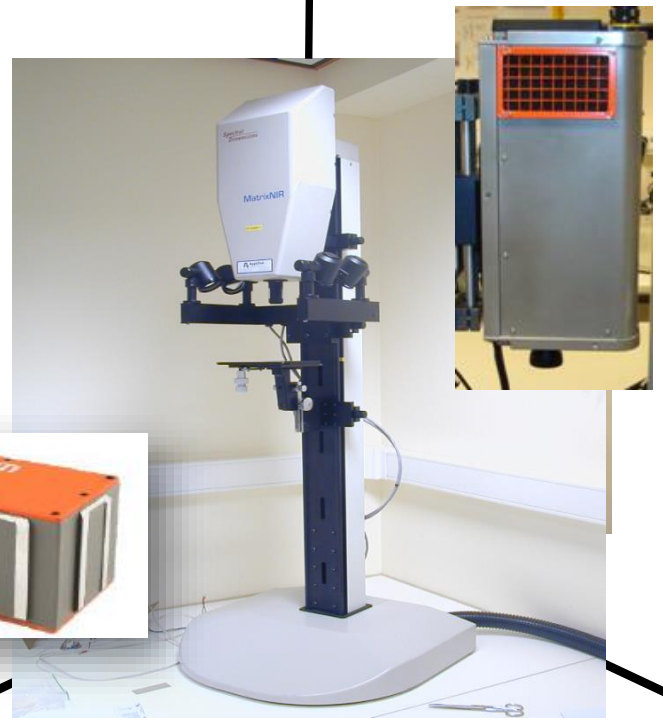
Hyperspectral Imaging

Technology





Spatial information (i.e. pixels)



Frequency information (i.e. wavelengths)

Intensity information (i.e. absorbance)

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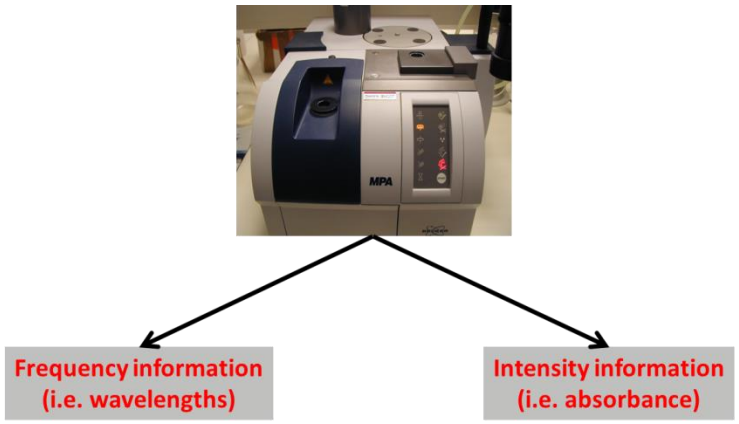
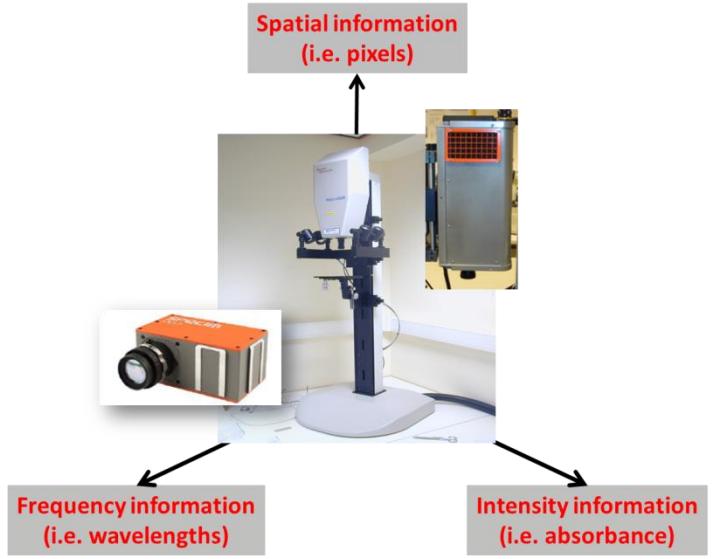
Hyperspectral Imaging

Technology





From 1 spectrum/sample

to 10^n spectra/sample with n>> 3

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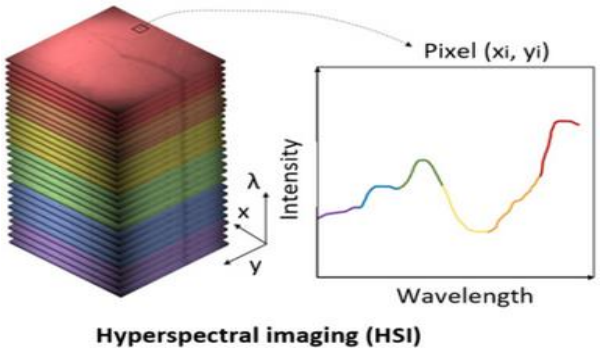
Hyperspectral Imaging

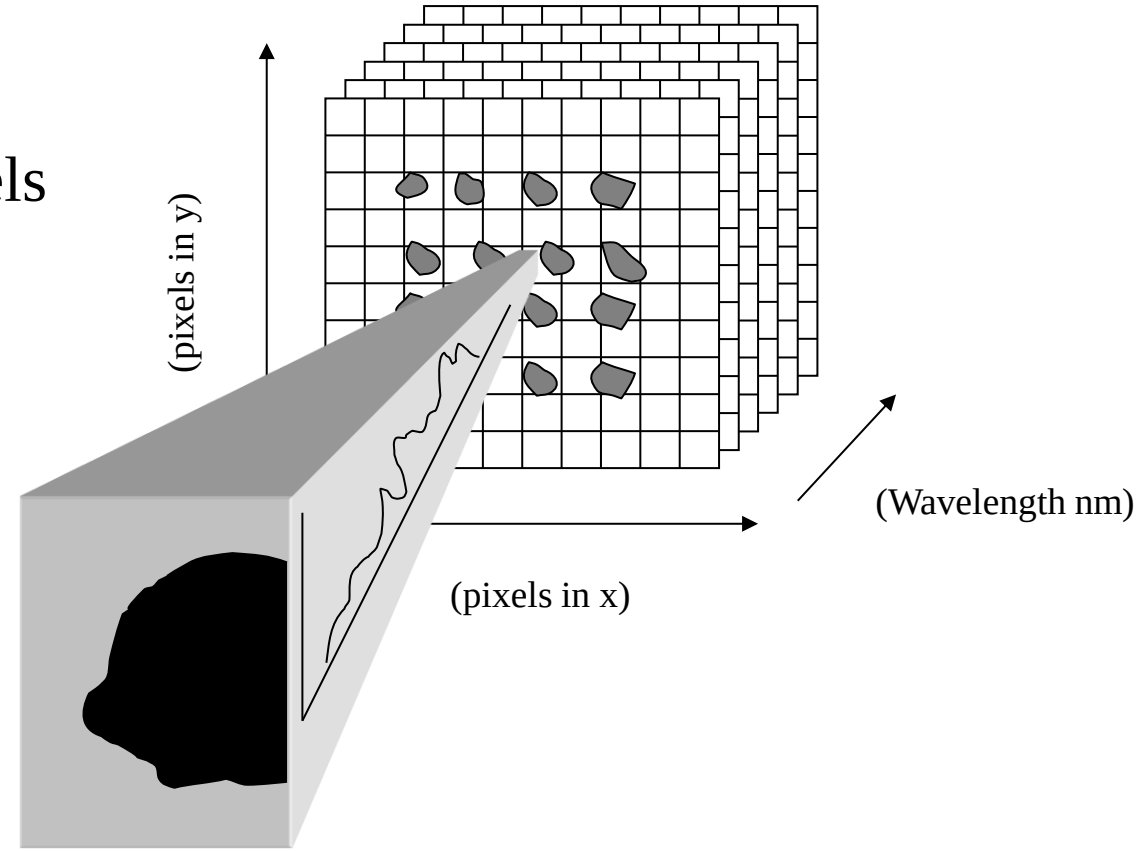
Technology

Datacube (or **Hypercube**) is a matrix of **I x J** pixels and **K** wavelengths



Hyperspectral imaging (HSI)

Source: https://www.pyroistech.com/hyperspectral-and-multispectral-imaging/



pixel = spectrum

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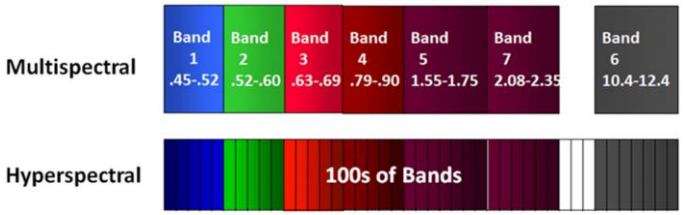
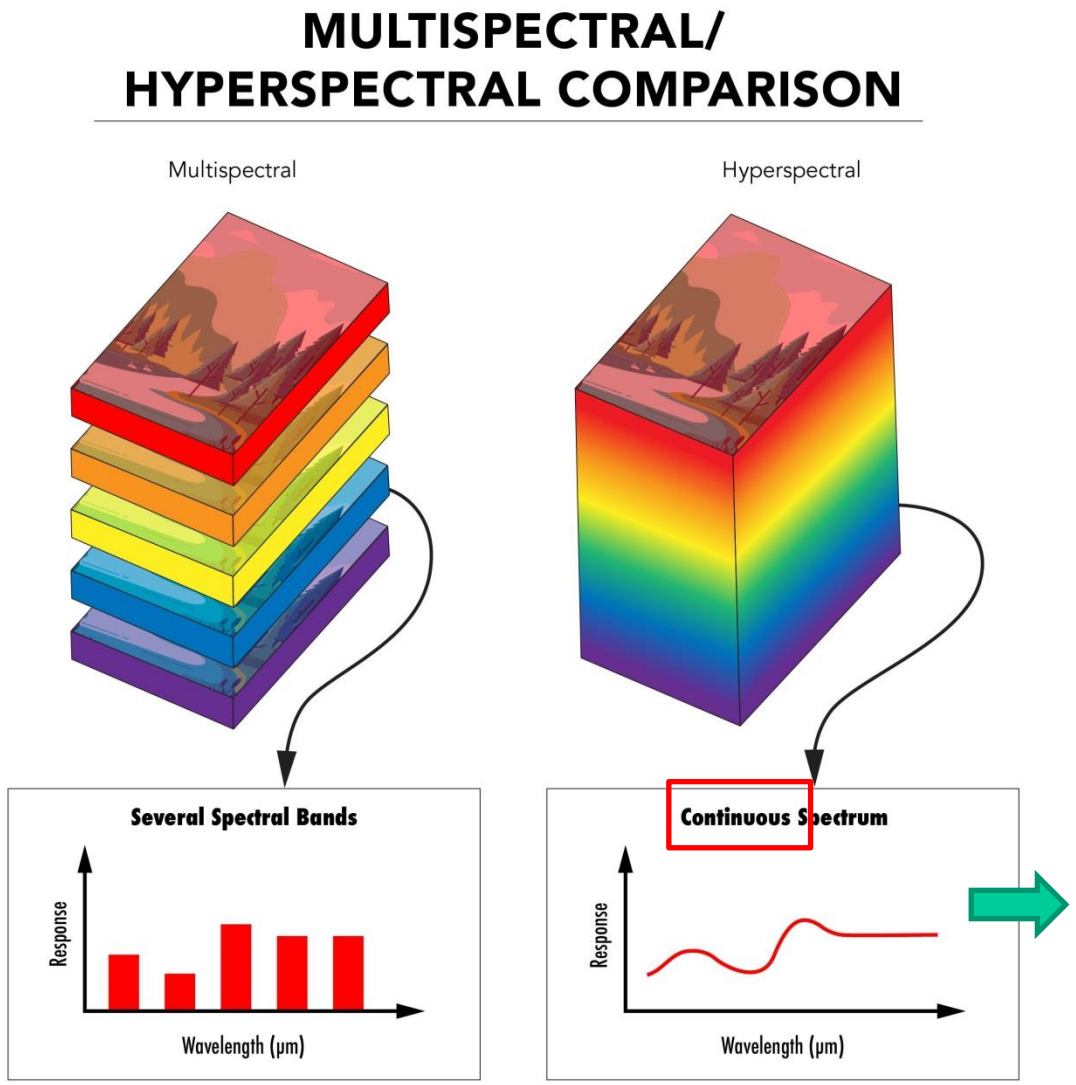
Hyperspectral Imaging

Technology



Hyperspectral demixing: identify the 'materials' in the image and their proportions in each pixel.

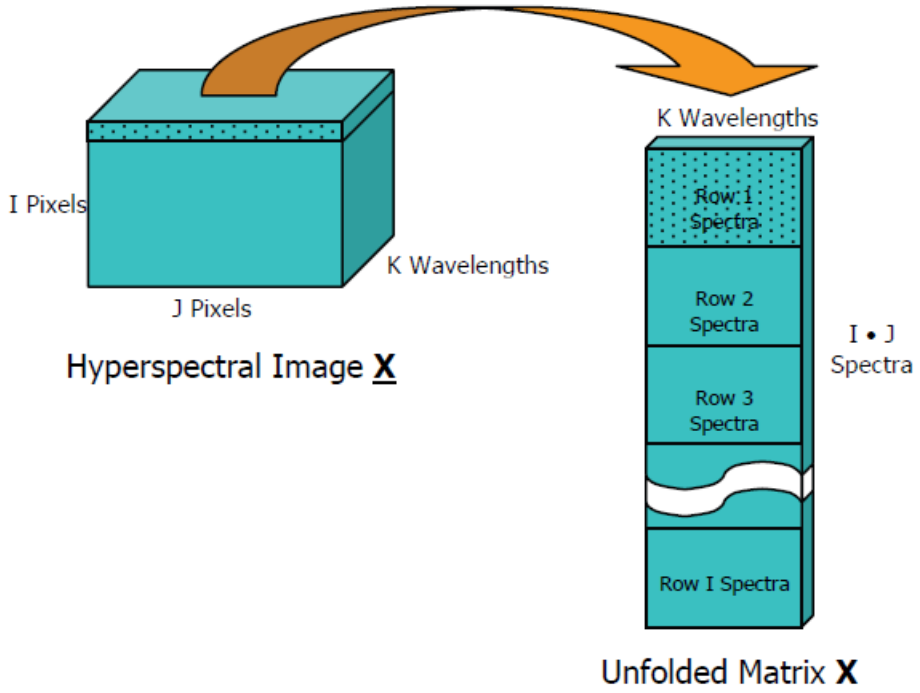


Possibility to apply tools and mathematical methods for continuous functions

Source: Edmund Optics

Hyperspectral Imaging

Technology - Unfolding



The three dimensional hyperspectral image **X** is unfolded into a two dimensional matrix **X**.

Source: James E. Burger, PhD Thesis, Umeå, 2006

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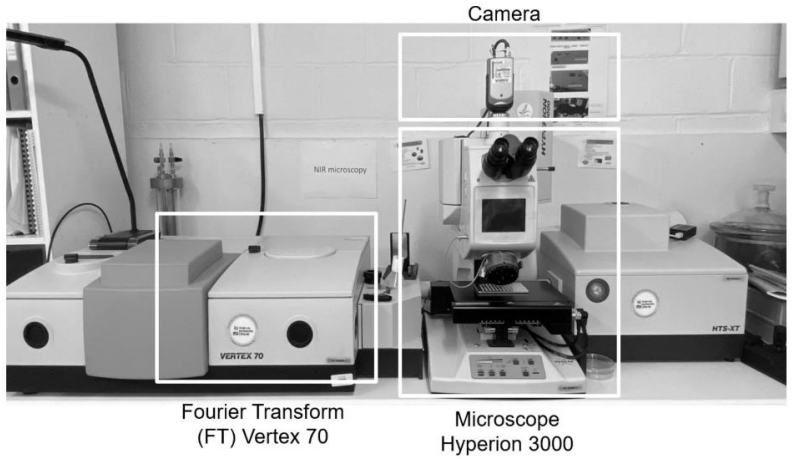
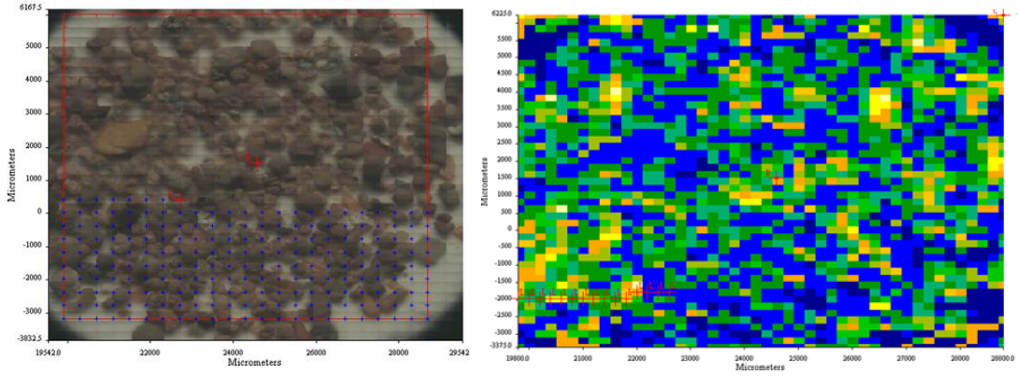
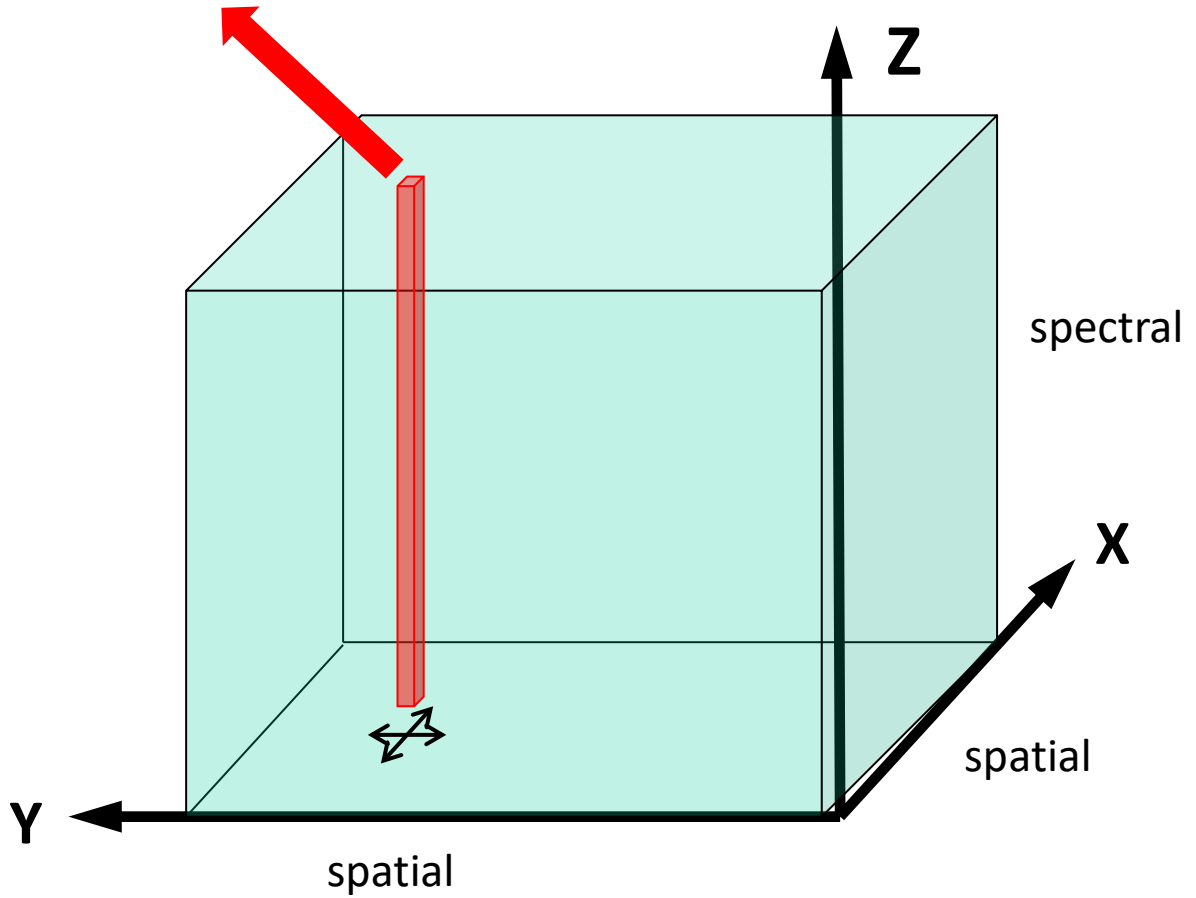
Hyperspectral Imaging

Technology





staring (point) scan



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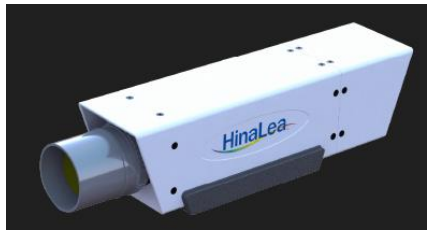
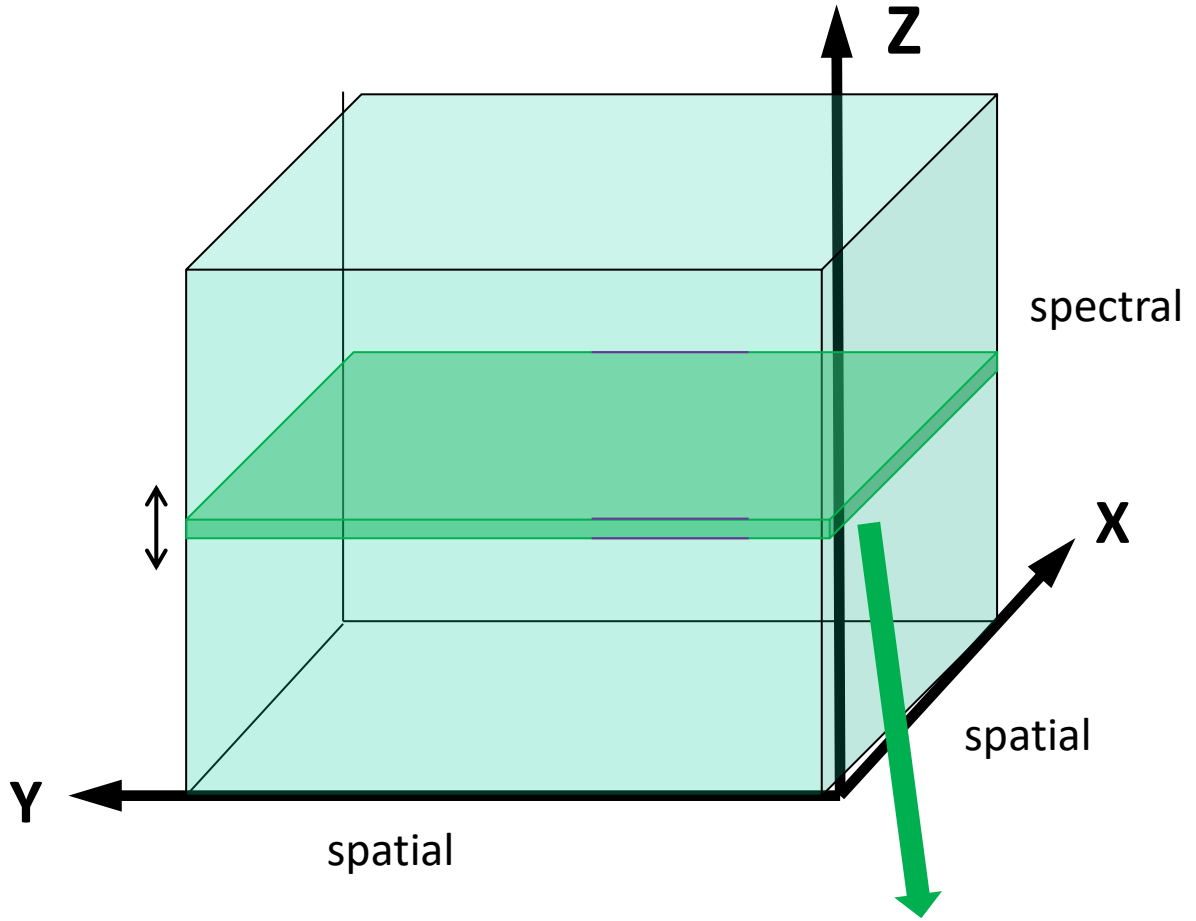
Hyperspectral Imaging

Technology





***plane* scan**

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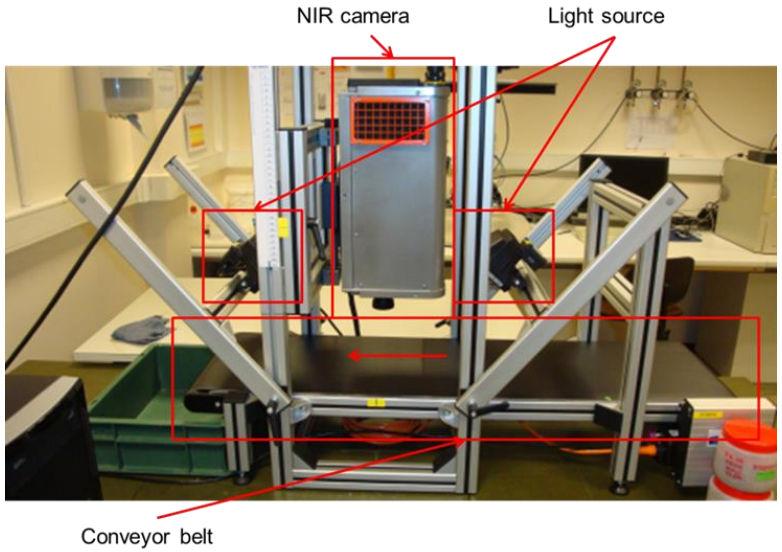
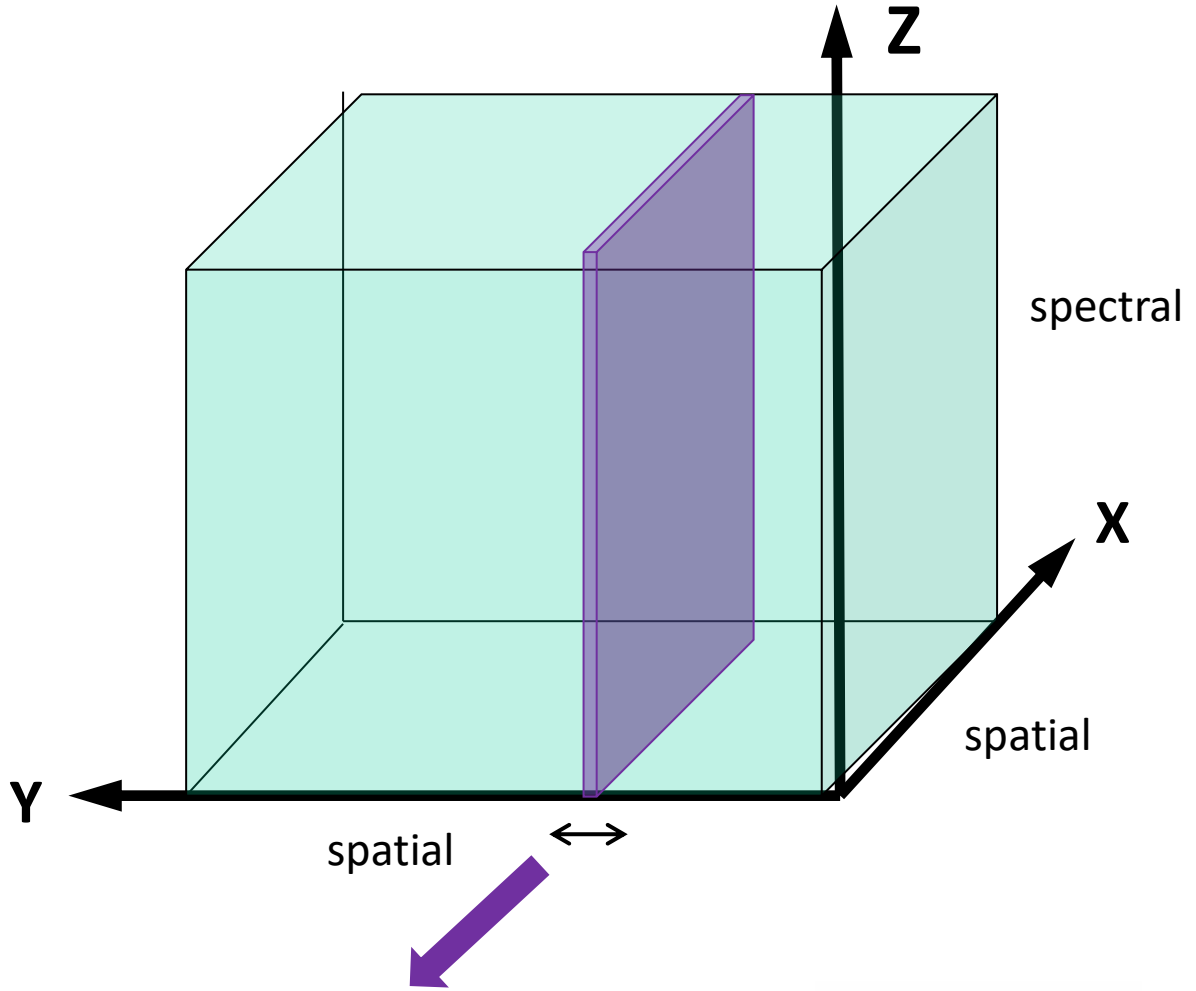
Hyperspectral Imaging

Technology





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Hyperspectral Imaging

CRA-W story

Now…

VNIR and NIR

Cameras: FX10 (Specim, FI) → 400 – 1000 nm
FX17 (Specim, FI) → 900 – 1700 nm
Set-up: LabScanner (Specim, FI)
Software: LumoScanner (Specim, FI)

LabScanner, FX10 and FX17 cameras

Point-scan microscopy

System: Vertex 70 Bruker → 1100 – 2500 nm
Hyperion 3000

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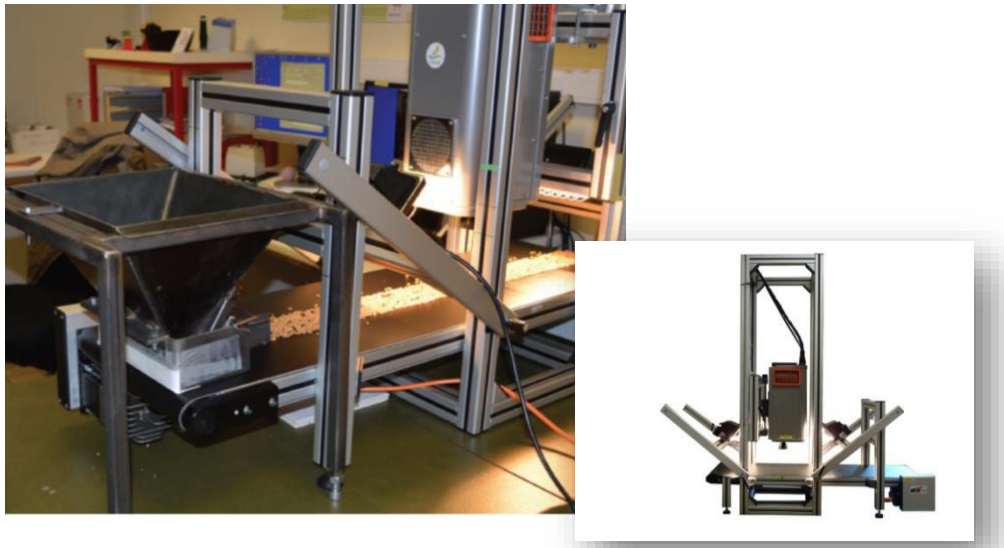
Hyperspectral Imaging

CRA-W story

Now…

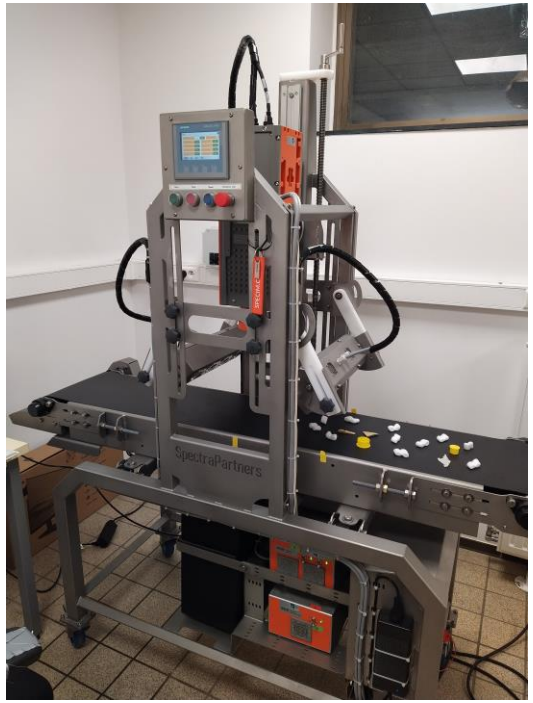
SWIR

Camera: SWIR XEVA CL 2.5 320 TE4 (Specim, FI)
→ 1100 – 2400 nm
Set-up: Conveyor belt system (BugerMetrics, LV)
Software: HyperProVB (BugerMetrics, LV)



SWIR XEVA camera paired with a conveyor belt

Camera: Specim → 1000 – 2500 nm



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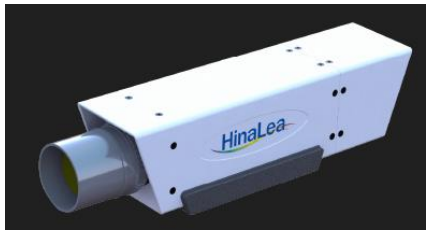
Hyperspectral Imaging

CRA-W story

Now…

Snapshot

Camera: HinaLea → 900 – 1700 nm



Qsorter

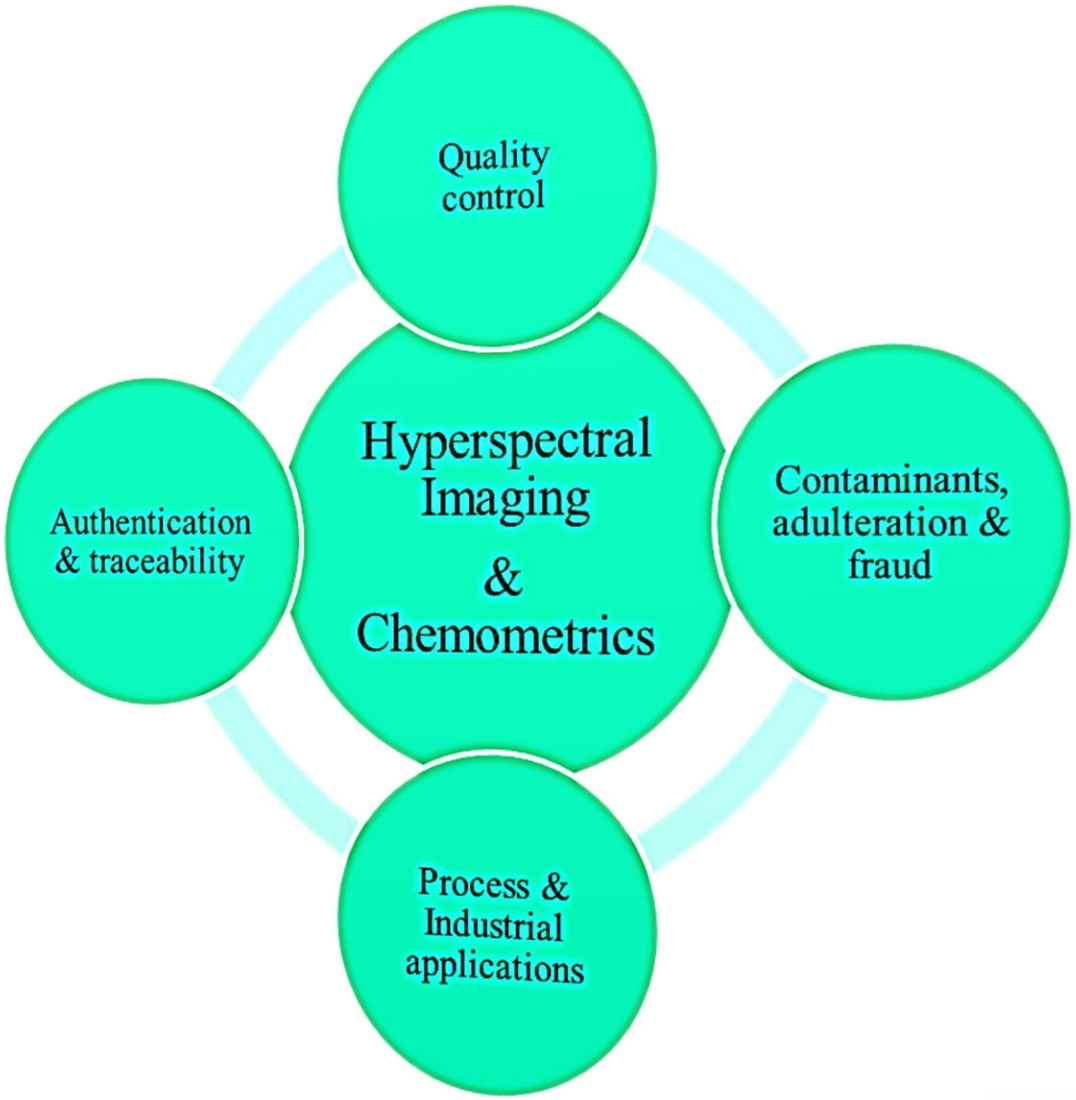
RGB images

Predictions

NIR spectra 900 -1700 nm

Hyperspectral Imaging

Applications



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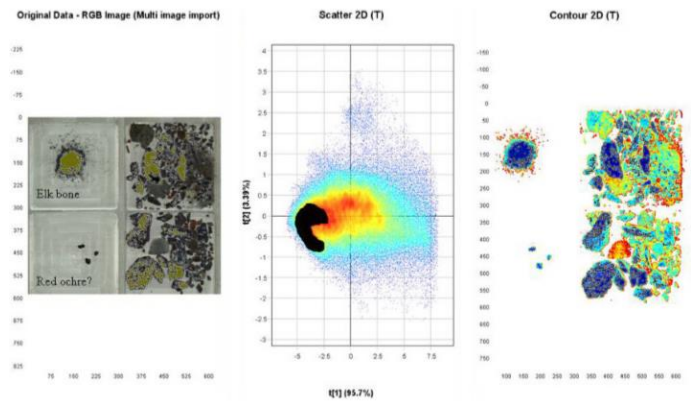
Archaeology

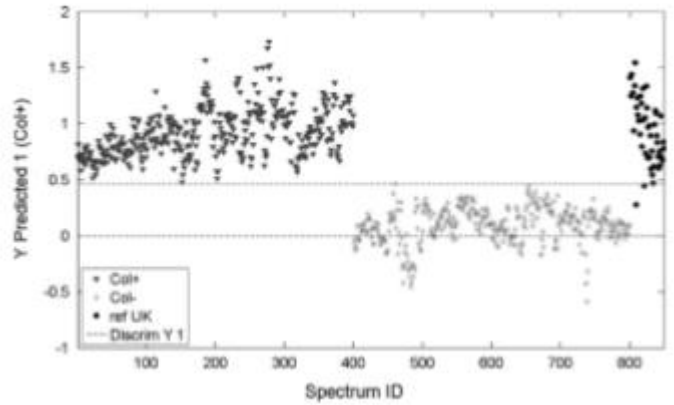
Bone fragments



JNIRS JOURNAL OF NEAR INFRARED SPECTROSCOPY

Identification of fragmented bones and their state of preservation using near infrared hyperspectral image analysis

Johan Linderholm,[a] Juan Antonio Fernández Pierna,[b,*] Damien Vincke,[b] Pierre Dardenne[b] and Vincent Baeten[b]



Contents lists available at ScienceDirect

Talanta

journal homepage: www.elsevier.com/locate/talanta

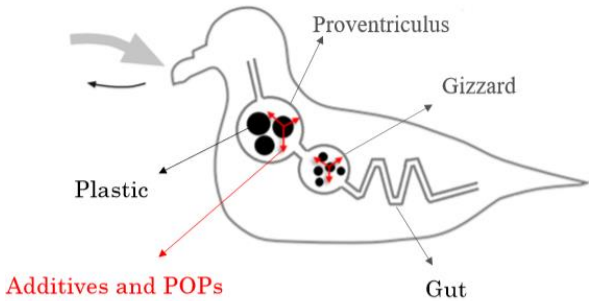
Analysis of collagen preservation in bones recovered in archaeological contexts using NIR Hyperspectral Imaging

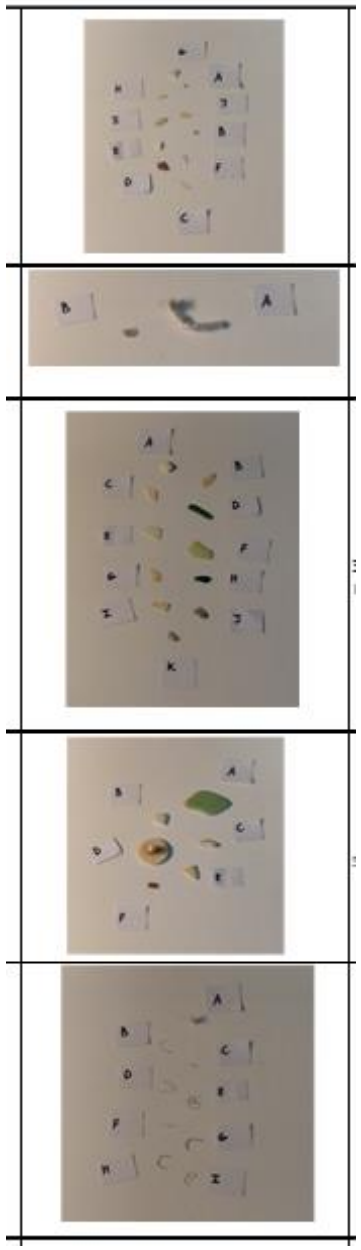
Damien Vincke[a], Rebecca Miller[b], Édith Stassart[b], Marcel Otte[b], Pierre Dardenne[a], Matthew Collins[c], Keith Wilkinson[d], John Stewart[e], Vincent Baeten[a], Juan Antonio Fernández Pierna[a,*]

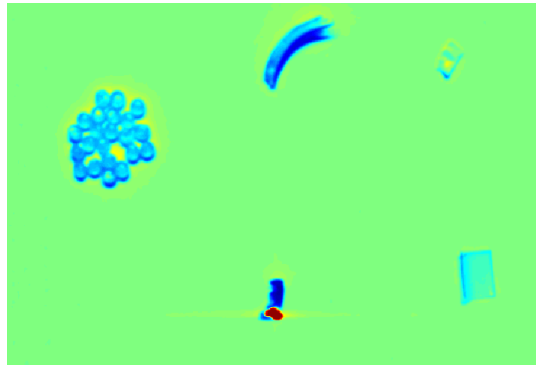
Wallonie recherche CRA-W

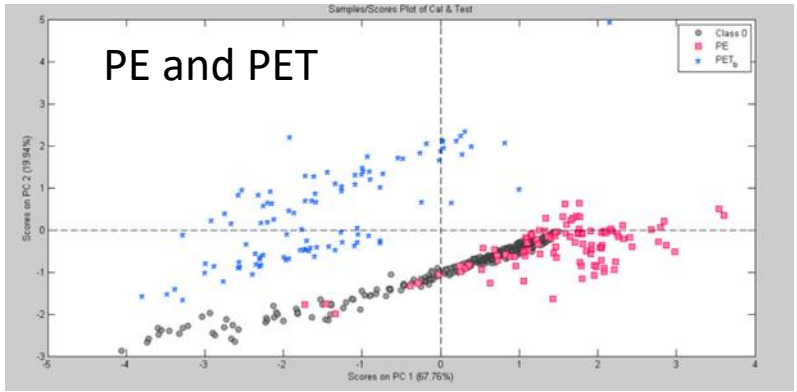
Contaminants, adulteration & fraud

Plastics and POPs









Plastics are usually accompanied by additives and persistent organic pollutants (POPs).

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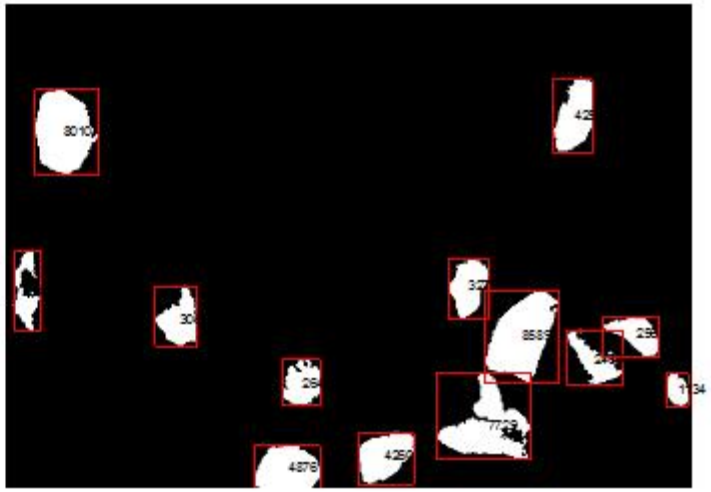
Quality control

Impurities



KNN - PCA models

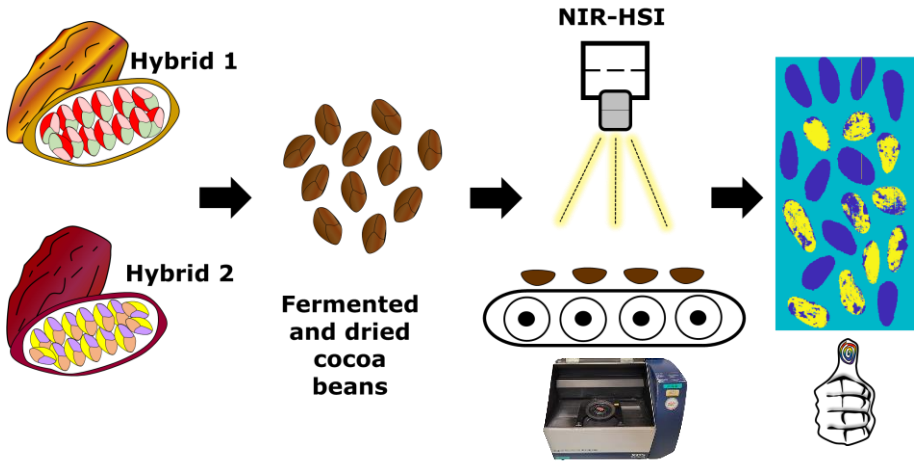
'Using a visible vision system for on-line determination of quality parameters of olive fruits'. E. Guzmán, V. Baeten, J.A. Fernández Pierna, J.A. García Mesa. Foof and Nutrition Sciences, 4, 90-98 (2013).

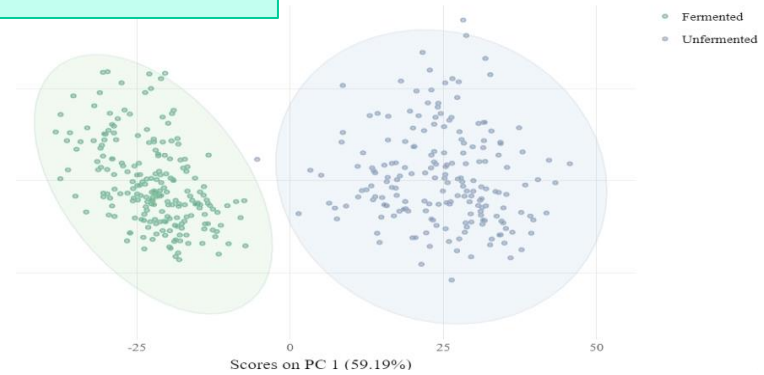
Wallonie recherche CRA-W

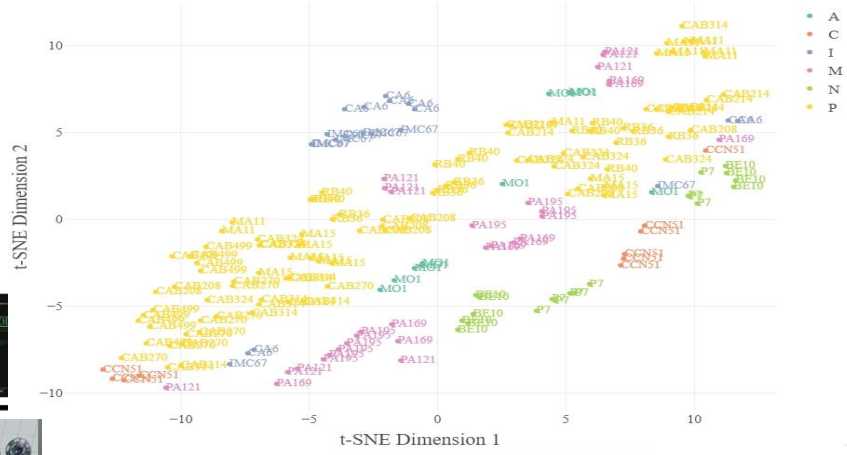
Authentication & Traceability

Cocoa beans

Discrimination of fermented vs unfermented cocoa beans & discrimination of 19 hybrid genotypes







Food Control 118 (2020) 107445

Contents lists available at ScienceDirect

Food Control

journal homepage: www.elsevier.com/locate/foodcont

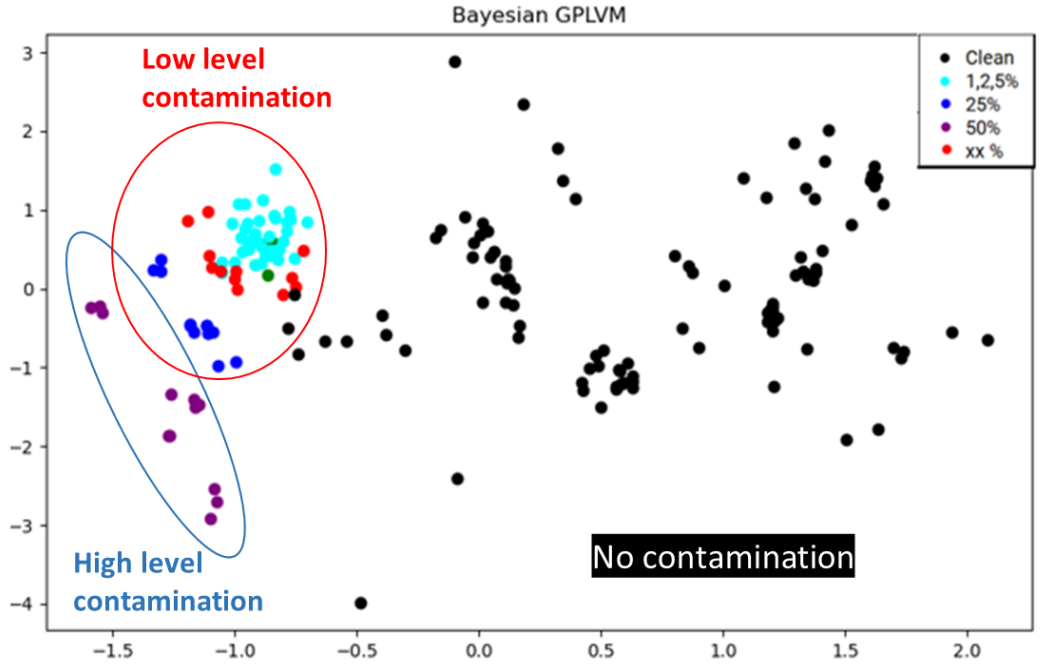
ELSEVIER

Authentication of cocoa (*Theobroma cacao*) bean hybrids by NIR-hyperspectral imaging and chemometrics

J.P. Cruz-Tirado [a], Juan Antonio Fernández Pierna [b], Hervé Rogez [c], Douglas Fernandes Barbin [a,*], Vincent Baeten [b]

Contaminants, adulteration & fraud

Oregano adulteration



Hyperspectral NIR

- **2 origins: Turkey and Italy**
- **4 adulterants: cistus, olive leaves, myrtle & sumac**
- **Mixed at: 1, 2, 5, 25 & 50% level**

CIBORIS
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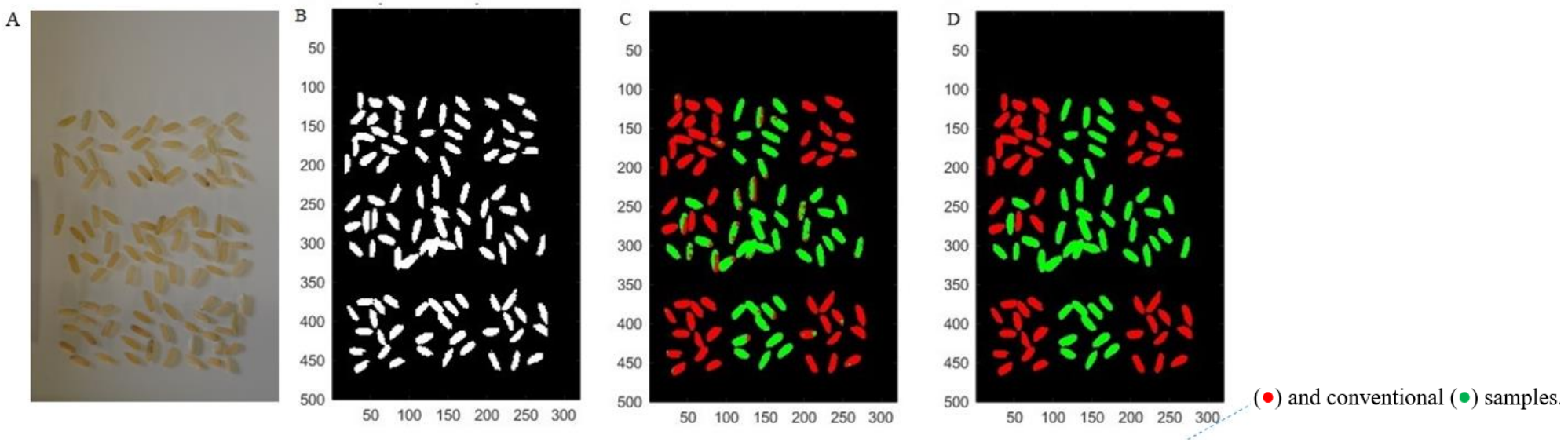
Nicaise Kayoka

Wallonie recherche CRA-W

Contaminants, adulteration & fraud

Organic vs conventional rice

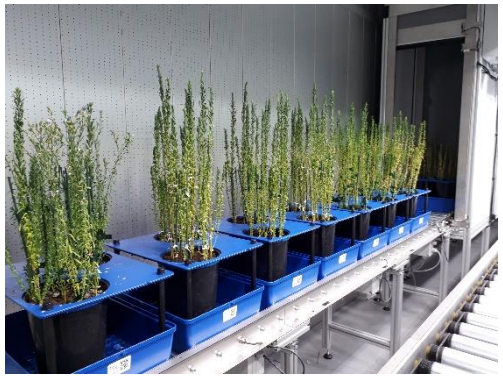


Discriminant analysis of intact organic and conventional brown rice by benchtop, hand-held and hyperspectral imaging NIRS coupled to chemometric tools

Elem Tamirys dos Santos Caramês[1], Michel Rocha Baqueta[1], Juan Antonio Fernández Pierna[2], Juliana Azevedo Lima Pallone[1], Vincent Baeten[2]

Authentication & Traceability

Flax disease

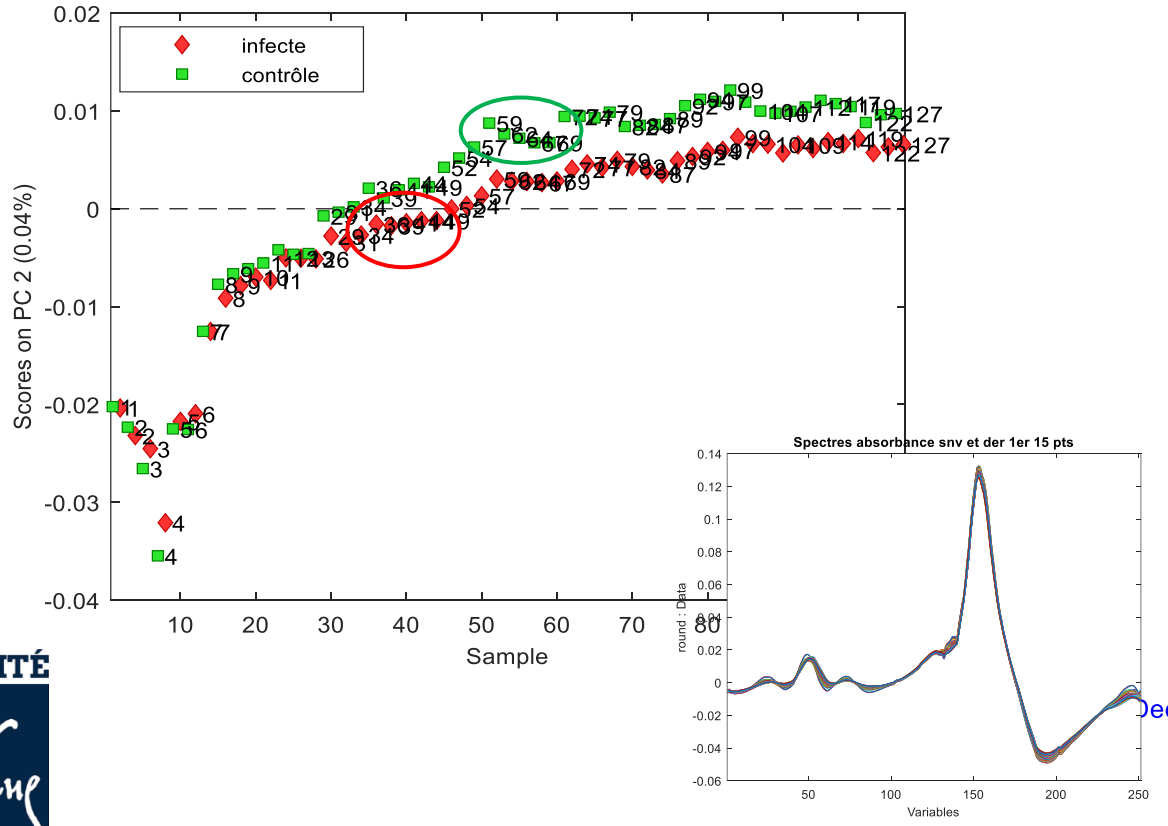


Control plant

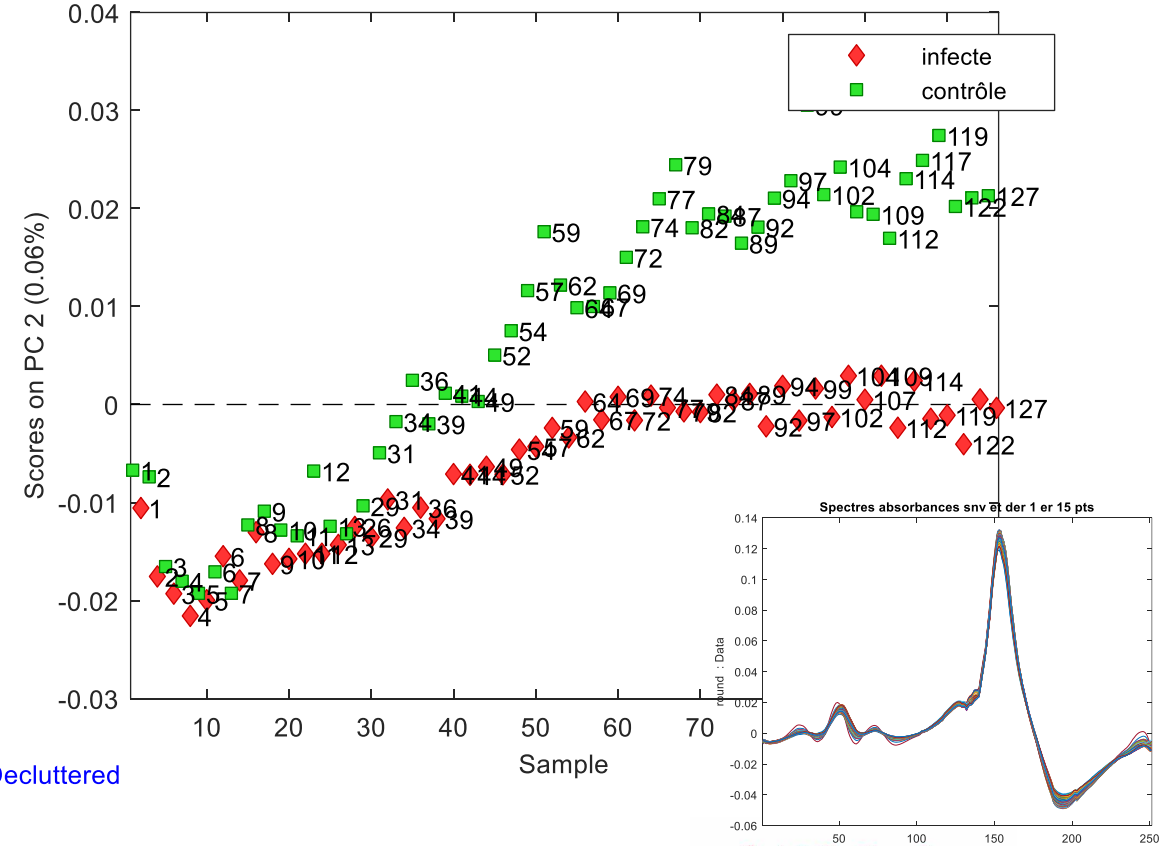
Inoculated plant

Flax disease

Variety more resistant

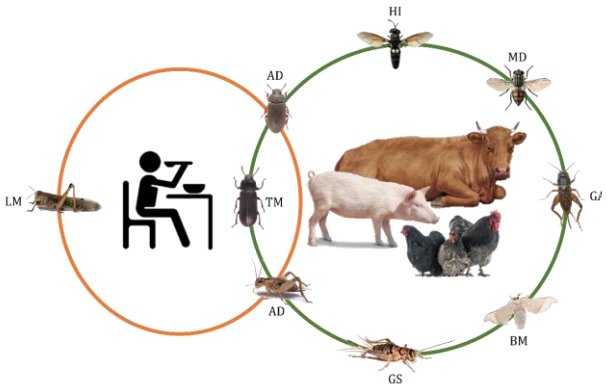


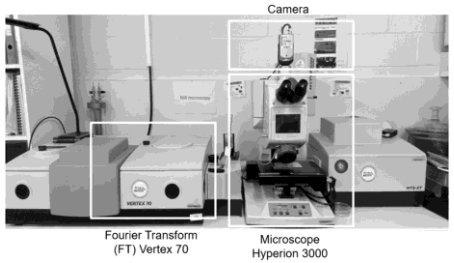
Variety less resistant

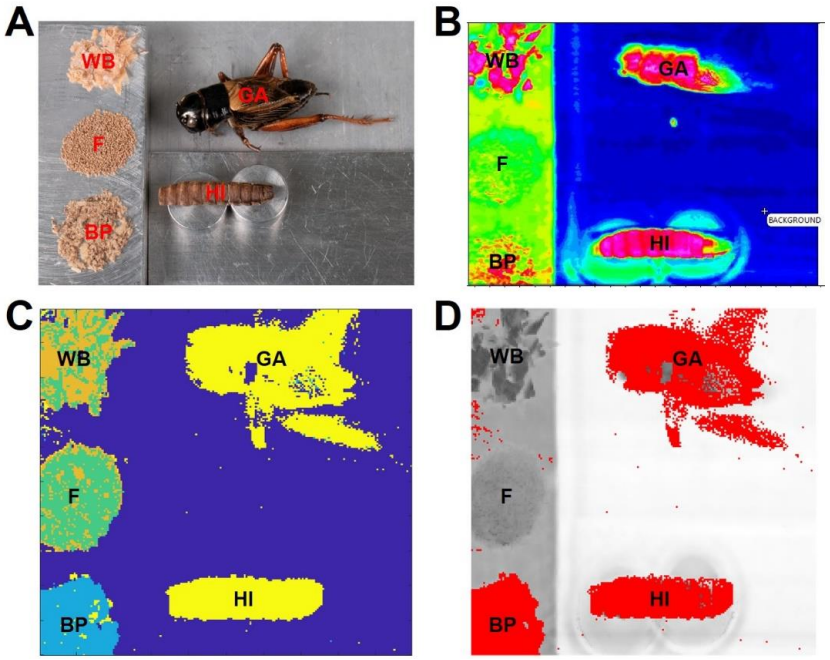


Decluttered

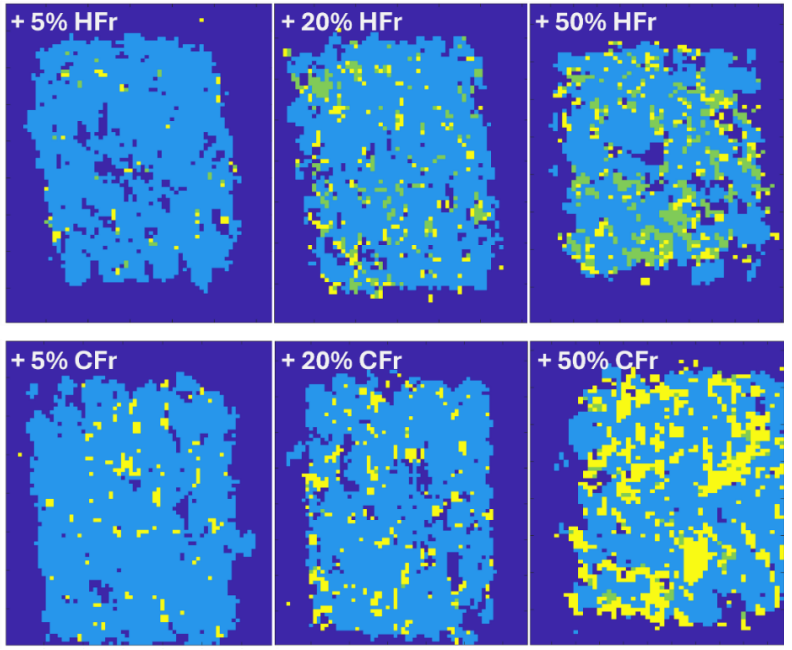
Detection & characterisation of insect meal intended for feedingstuffs







Photograph (A), spectral image (B), PLS-DA image processing (C) and absorbance equation image processing (D) of different samples analysed by NIRM.
WB: Wheat bran; F: Frass; BP: Bovine PAP; GA: Gryllus assimilis; HI: Hermetia illucens larvae.



PLS-DA image processing of the six samples of *T. molitor* larvae meal adulterated with 5% of HFr or CFr (**left**), 20% of HFr or CFr (**middle**) and 50% of HFr or CFr (**right**). **Dark blue**: background; **Light blue**: *T. molitor* larvae meal; **Green**: HFr; **Yellow**: CFr.

Abigaël ANSELMO

UMONS University of Mons

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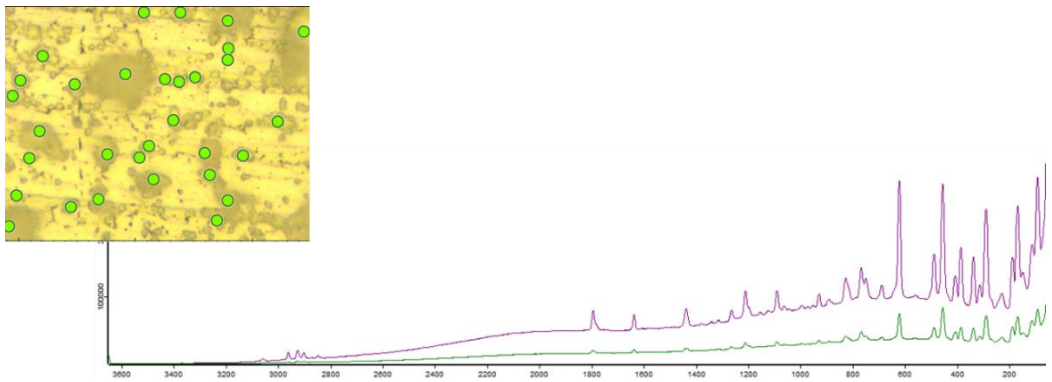
Pesticides

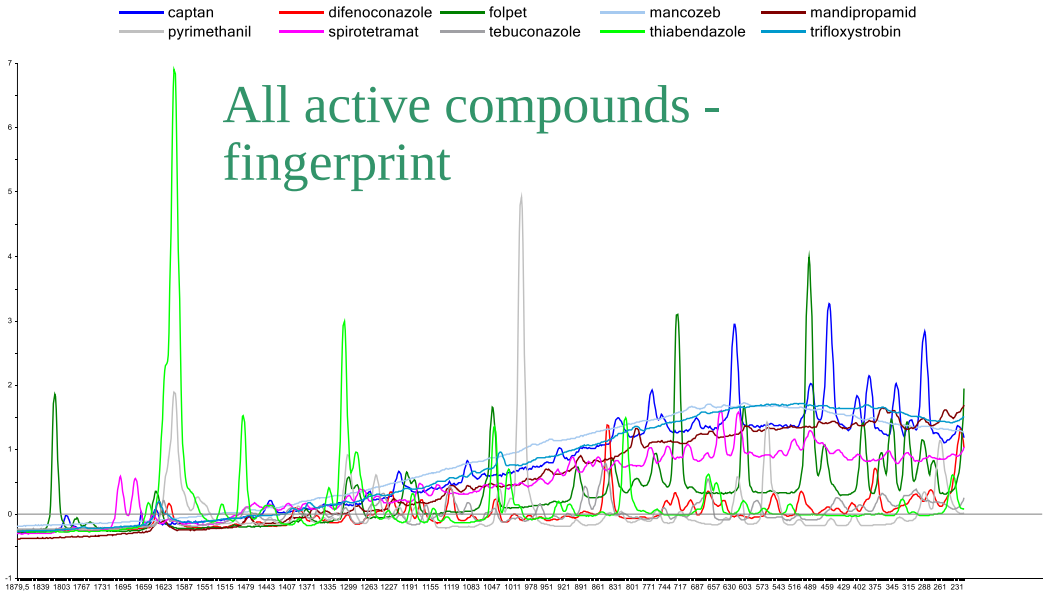
Pesticide spraying

Pesticide recovery

Raman microscopy

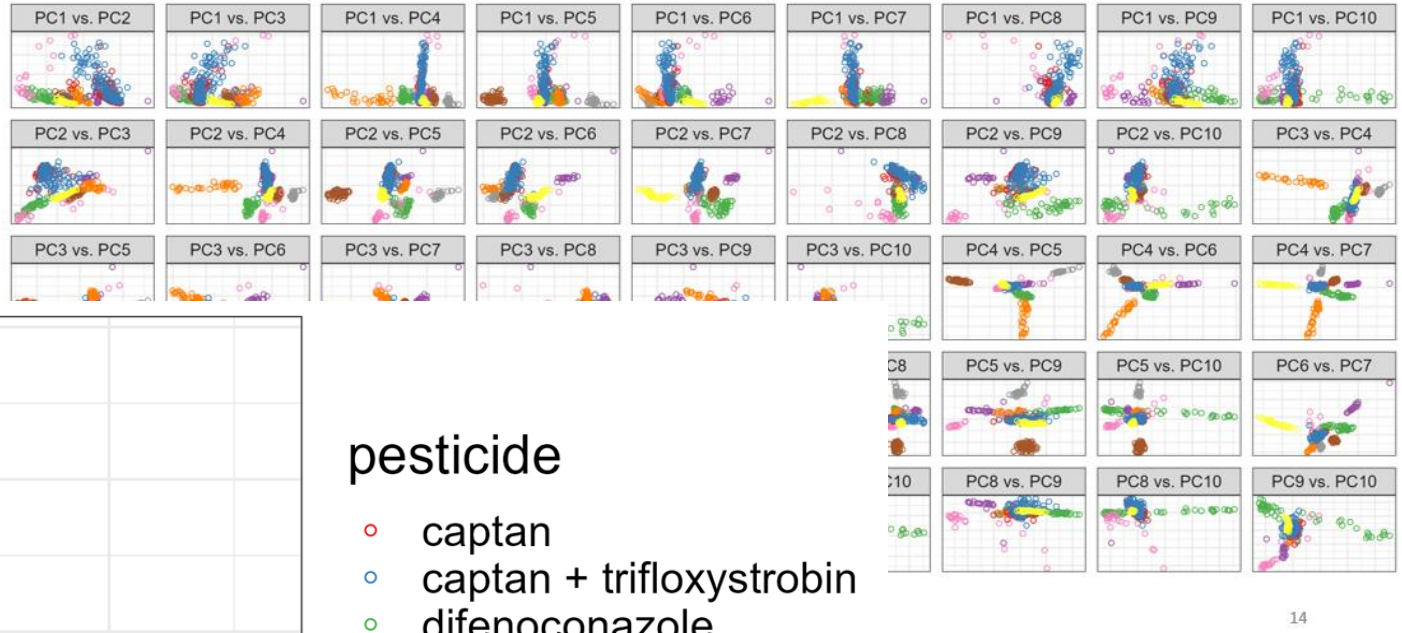
Detection of synthetic chemical pesticides by Raman spectroscopy in apple fruits

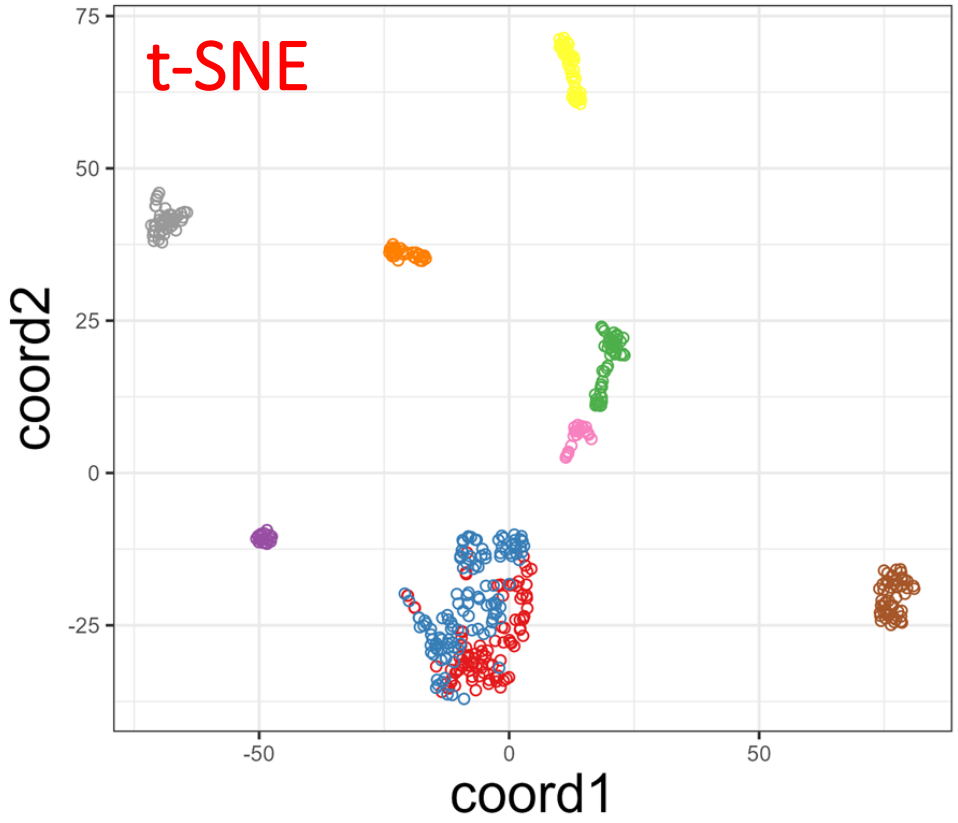




Authentication & Traceability

Pesticides





pesticide

- captan
- captan + trifloxystrobin
- difenoconazole
- folpet
- mancozeb
- pyrimethanil
- spirotetramat
- tebuconazole
- thiabendazole

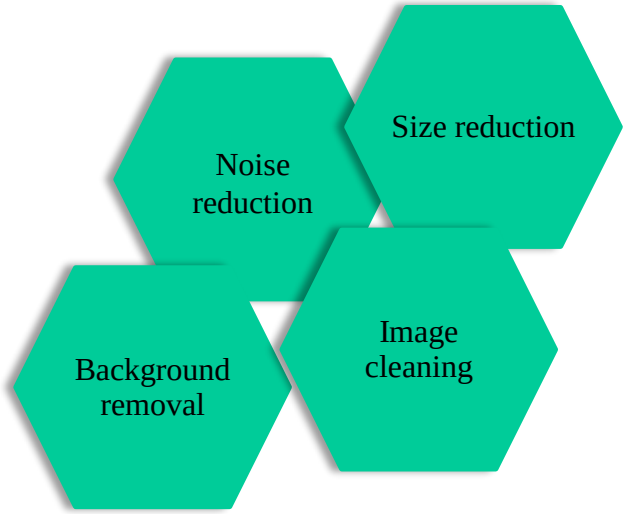
14

Use of t-distributed stochastic neighbour embedding (t-SNE) in vibrational spectroscopy

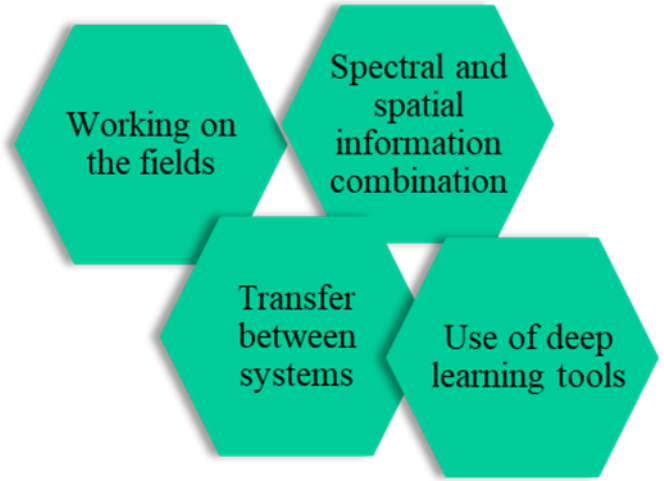
F. Stevens[a], V. Baeten[a], J.A. Fernández Pierna[a]

Challenges

Technical challenges

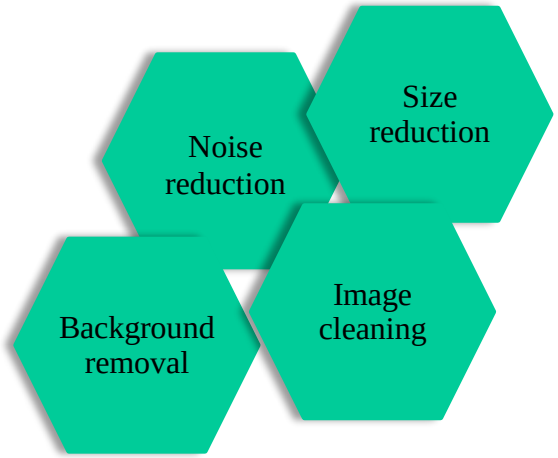


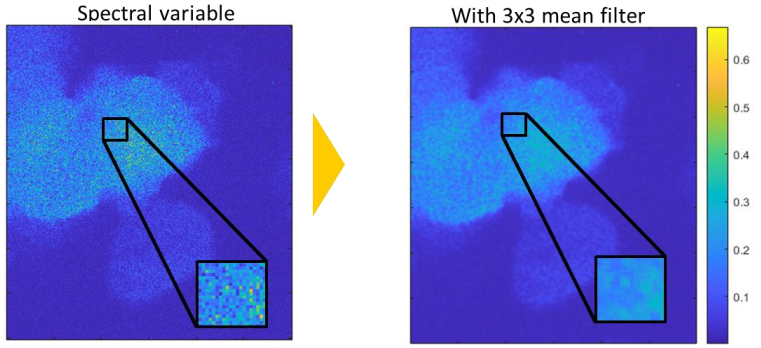
Practical challenges

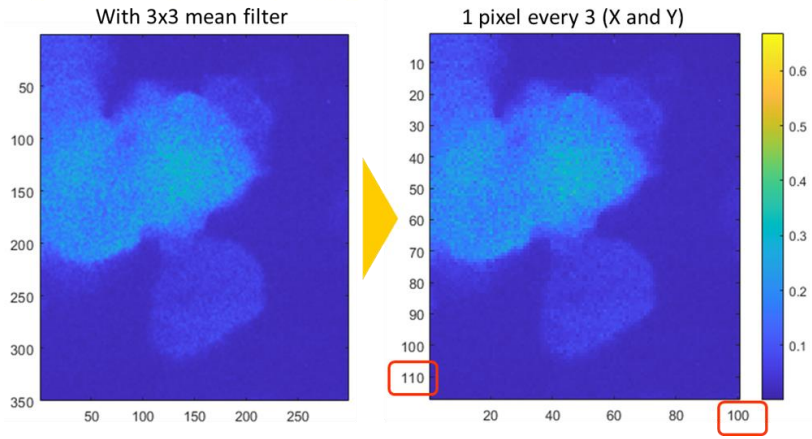


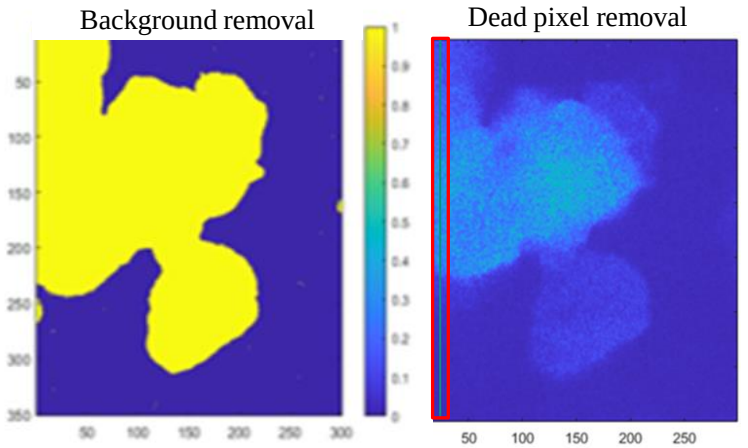
Hyperspectral Imaging

Challenges









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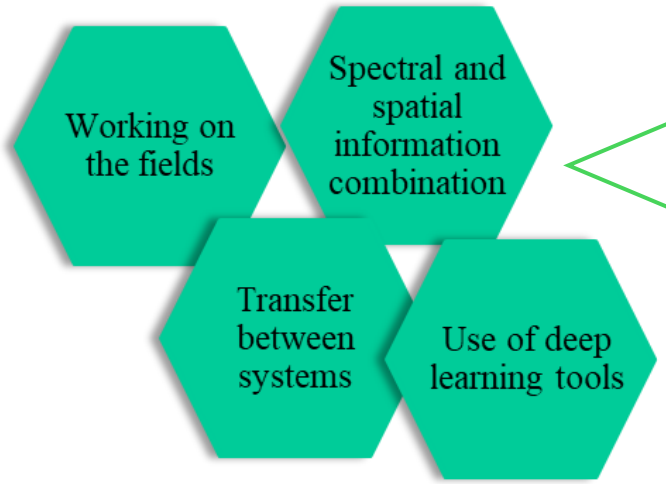
Challenges

Practical challenges



- Need of imaging techniques to enable objective, non-destructive, repeatable and rapid observation of samples, not only at laboratory level but also **on the fields**.
- Need for methods to **transfer** already developed models and spectral libraries to HIS systems for rapid and reliable detection of contaminants/anomalies in food product flows.
- The **spatial dimension** is often overlooked in the analysis of hyperspectral images but is nevertheless rich in information.
- Need to exploit advanced **machine/deep learning techniques** to analyse images.

Challenges

Working on the fields

Working on the fields

The miniaturization and portability of hyperspectral cameras are revolutionizing their application on the fields as well as across various industries, making high-resolution spectral imaging more accessible and practical than ever before.

Significant reduction in size and weight of hyperspectral cameras.
Enhanced **flexibility** and deployment on the fields.

- **Advanced Materials**: Use of lightweight, high-performance materials.
- **Compact Designs**: Integration of components into smaller form factors without compromising performance.
- **Portable Power Solutions**: Development of efficient, lightweight power sources for extended field use.

Benefits

- **Ease of Use**: Greater accessibility for non-experts.
- **Cost Efficiency**: Reduction in deployment and operational costs.
- **Versatility**: Increased range of applications due to enhanced mobility.

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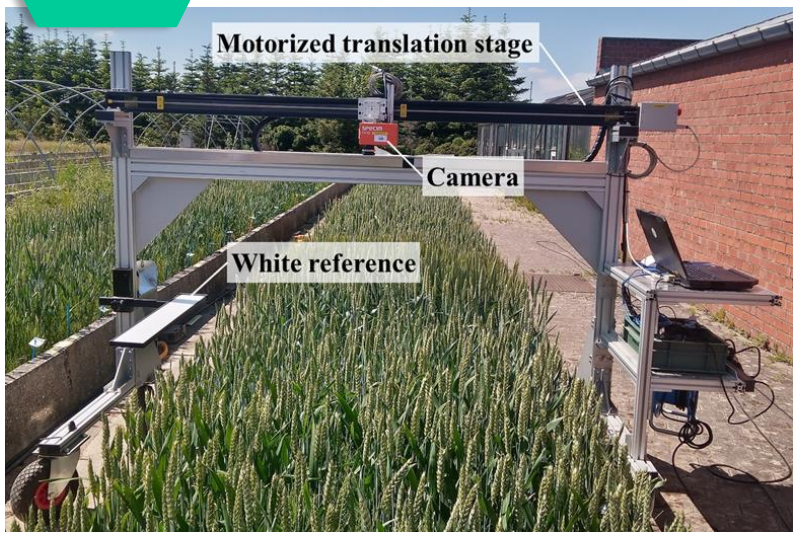
Challenges

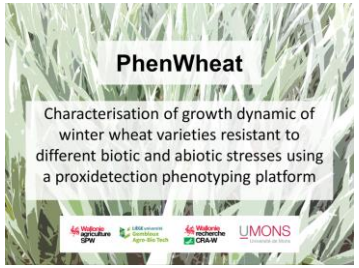
Working on the fields

Working on the fields



Translation stage on mobile platform

Rotating stage



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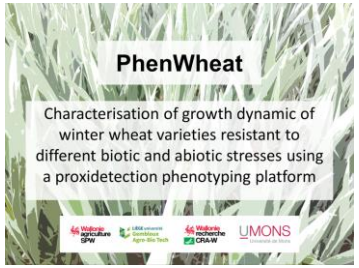
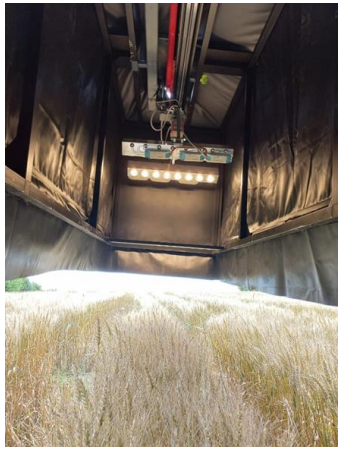
Challenges

Working on the fields

Working on the fields

Translation stage on spray boom



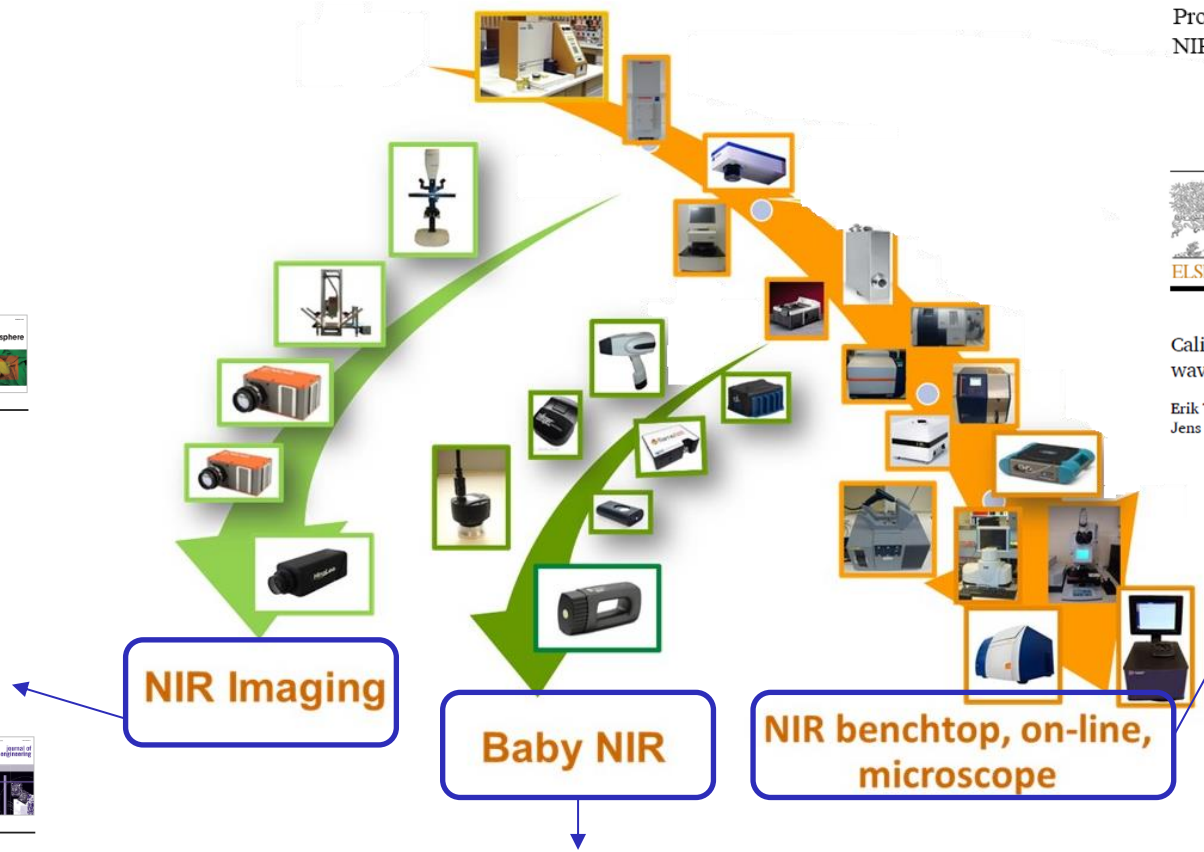


Wallonie recherche CRA-W

Hyperspectral Imaging

Data / model transfer

Transfer between systems



ELSEVIER
Chemosphere
Volume 272, June 2021, 129908

Transfer learning strategy for plastic pollution detection in soil: Calibration transfer from high-throughput HSI system to NIR sensor

Shutao Zhao, Zhengjun Qiu, Yong He

ELSEVIER
Journal of Food Engineering
Volume 339, February 2023, 111284

From lab to factory: A calibration transfer strategy from HSI to online NIR optimized for quality control of green tea fixation

Yujie Wang, Zhengyu Ren, Maoyu Li, Chengye Lu, Wei-Wei Deng, Zhengzhu Zhang, Jingming Ning

Calibration transfer in near infrared spectroscopy

P. Dardenne[a]

Proceedings of the 11th International NIR conference
NIR Publications, 2004

Vibrational Spectroscopy 132 (2024) 103667
Contents lists available at ScienceDirect
Vibrational Spectroscopy
journal homepage: www.elsevier.com/locate/vibspec

Calibration transfer between different spectrometers by wavelength correspondence

Erik Tengstrand *, Lars Erik Solberg, Katinka Dankel, Tiril Aurora Lintvedt, Nils Kristian Afseth, Jens Petter Wold

Calibration Transfer from Dispersive Instruments to Handheld Spectrometers

J. A. FERNÁDEZ PIERNA, PH. VERMEULEN, B. LECLER, V. BAETEN, and P. DARDENNE*

APPLIED SPECTROSCOPY Volume 64, Number 6, 2010

Wallonie recherche CRA-W

Data / model transfer from/to HSI systems

Transfer between systems

Key Challenges in Data/Model Transfer

- **System Differences/Spectral Signature Variations**
  - Variations in spectral resolution, wavelength range, and calibration standards.
- **Environmental Factors**
  - Variability due to lighting conditions, atmospheric effects (especially for remote sensing).
- **Data Quality Issues**
  - Noise, resolution differences, and sensor-specific distortions.
- **Computational Complexity**
  - Large datasets and high dimensionality of hyperspectral data pose challenges for transferring complex models.

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Data / model transfer from/to HSI systems

Transfer between systems

Model Transfer Techniques

- **Transfer via calibration models**
  - Transfer existing calibration models to new instruments without rebuilding them.
  - Slope and Bias correction (SBC)
  - Model updating (augmentation)

- **Advanced Multivariate Approaches**
  - Capture and model complex variability between instruments
  - Canonical Correlation Analysis (CCA)
  - Transfer Component Analysis (TCA)

- **Standardization techniques**
  - Align spectral responses of different instruments
  - Piecewise Direct Standardization (PDS)
  - Direct standardization (DS)

- **Preprocessing Techniques**
  - Noise reduction, spectral normalization, and atmospheric correction methods.

Hyperspectral Imaging

Data / model transfer

Transfer between systems

To benefit from HSI advantages for quantitative analysis : to tackle the sampling bottelneck

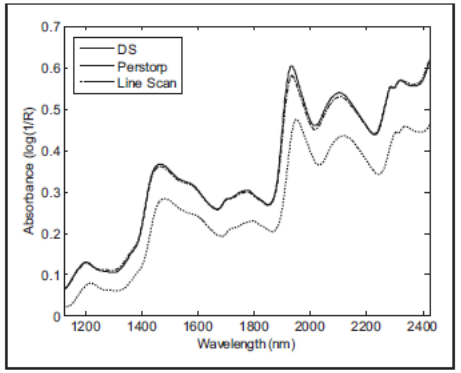

Figure 1. Mean spectrum of wheat flour obtained with the NIRS-DS, NIRS-Perstop and NIR-HSI instruments.

Original research article

JNIRS

Journal of Near Infrared Spectroscopy
2018, Vol. 26(3) 186–195

DOI: 10.1177/0967033518780506
journals.sagepub.com/home/jns
SAGE

Quantification of protein in wheat using near infrared hyperspectral imaging: Performance comparison with conventional near infrared spectroscopy

Ana Morales-Sillero[1], Juan A. Fernández Pierna[2], George Sinnaeve[2], Pierre Dardenne[2] and Vincent Baeten[2]

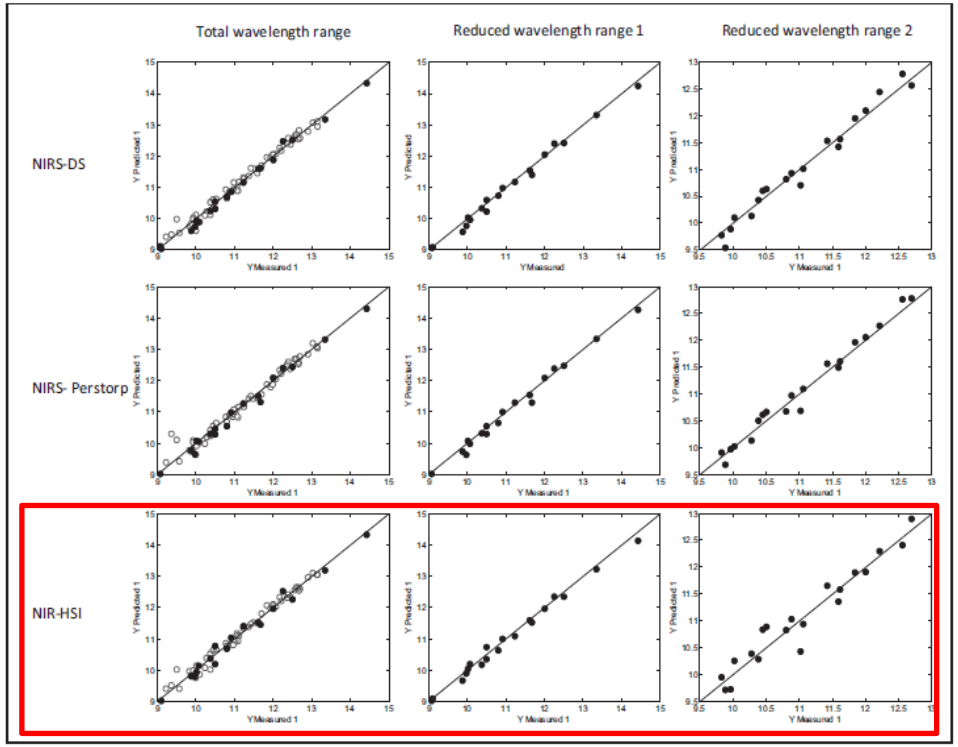

Figure 3. NIR predicted data versus reference data for protein content, for total wavelength range (strategy 1) and common wavelength range (strategy 1 and 2).

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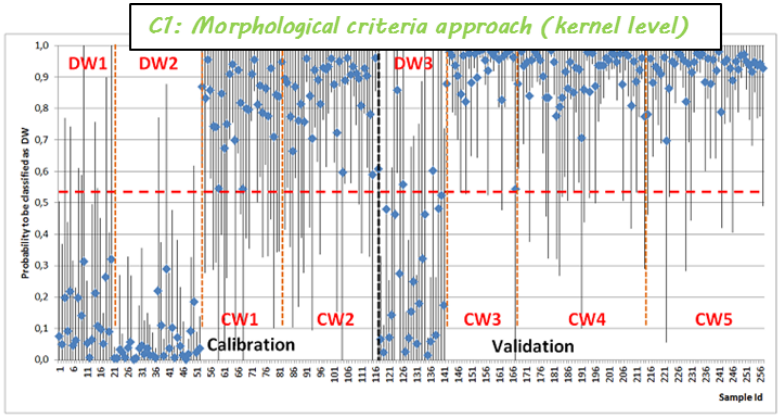
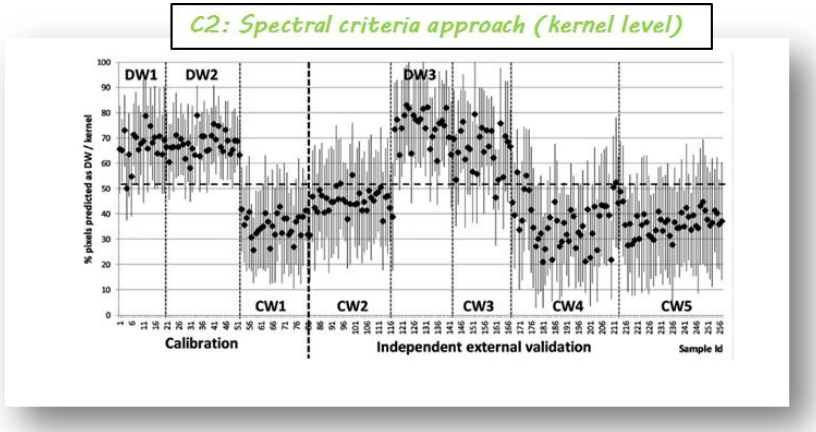
Hyperspectral Imaging

Spectral and spatial information combination

Spectral & spatial combination



Probability to be classified as DW (*: mean by kernel +/- 2SD) after applying PLSDA model performed on 8 morphological criteria (area, perimeter, circularity, maxFeret, minFeret, aspect ratio, roundness and solidity), on the 257 images of 16 kernels.



Percentage of pixels predicted as DW (*: mean by kernel +/- 2SD) after applying PLSDA model performed on NIR data, on the 257 images of 16 kernels.

Data fusion – 2 approaches combination

		on 4,105 grains				on 257 samples			
		DW (1,231 grains)		CW (2,874 grains)		DW (77 samples)		CW (180 samples)	
		Nb	%	Nb	%	Nb	%	Nb	%
	1 criterion	*1 right criteria*		*0 right criteria*					
Morphological criteria	C1 (16 grains)	1,084	88.1	2,712	94.4	73	94.8	180	100
NIR spectral profile	C2 (16 grains)	1,156	93.9	2,618	91.1	77	100	174	96.7

2 criteria	*1 or 2 right criteria*		*0 right criteria*		*mean 2 criteria*		*mean 2 criteria*	
C1+C2 (16 grains)	1,216	98.8	2,471	86.0	77	100	180	100

Discrimination between durum and common wheat kernels using near infrared hyperspectral imaging

Philippe Vermeulen[a,*], Michele Suman[b], Juan Antonio Fernández Pierna[a], Vincent Baeten[a]

[a] Food and Feed Quality Unit (U15), Valorisation of Agricultural Products Department (D4), Walloon Agricultural Research Centre (CRA-W), Henseval Building, Chaussée de Namur 24, 5030, Gembloux, Belgium

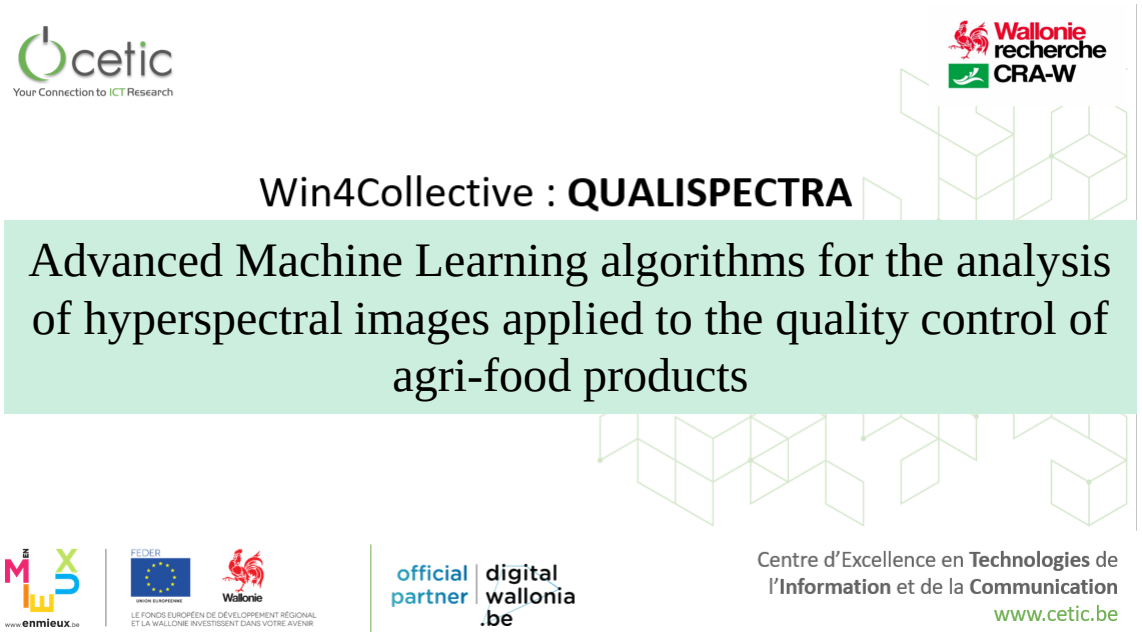
[b] Research Development & Quality, Barilla G. & R. Fratelli S.p.A, Via Mantova 166, 43100, Parma, Italy

Ing Philippe Vermeulen

Hyperspectral Imaging

Use of deep learning tools

Use of deep learning tools



Hyperspectral Imaging

Use of deep learning tools

Use of deep learning tools

Win4Collective : **QUALISPECTRA**

Advanced Machine Learning algorithms for the analysis of hyperspectral images applied to the quality control of agri-food products

official partner digital wallonia .be

Centre d'Excellence en **Technologies** de l'**Information** et de la **Communication**
www.cetic.be

AIM: to improve food safety by developing **advanced imaging techniques**, particularly hyperspectral, combined with **artificial intelligence**.

FOCUS on exploiting the often neglected **spatial dimension** of images to identify contaminants, guarantee product homogeneity and understand variations in spectra over time.

The project aims to demonstrate the **many industrial applications** of imaging to enhance food quality and safety.

Hyperspectral Imaging

Use of deep learning tools

Use of deep learning tools

Win4Collective : **QUALISPECTRA**

Advanced Machine Learning algorithms for the analysis of hyperspectral images applied to the quality control of agri-food products

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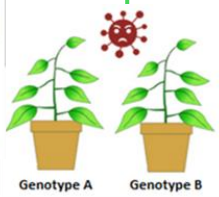
Centre d'Excellence en Technologies de l'Information et de la Communication
www.cetic.be

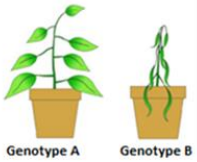
CASE STUDY 1: Heterogeneity of blends

- ❑ Food and pharmaceutical industries
- ❑ Uniform distribution of the mixture's properties
- ❑ Essential control to verify this homogeneity

CASE STUDY 2: Phenotyping

- ❑ Phenotyping is a key principle in varietal selection:
- ❑ Quantifying the observable characteristics of an organism to understand the interaction between its genes and its environment.
- ❑ Phenotype = Genotype + Environment





Use of AI combined to Hyperspectral Imaging

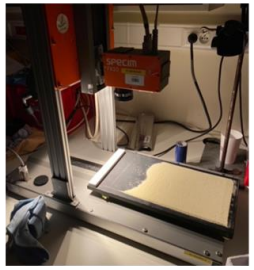
QUALISPECTRA project

CASE STUDY 1: Heterogeneity of blends

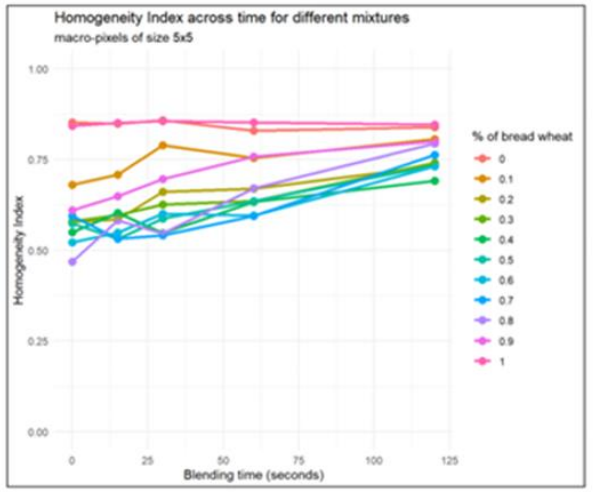
Wheat and durum blends

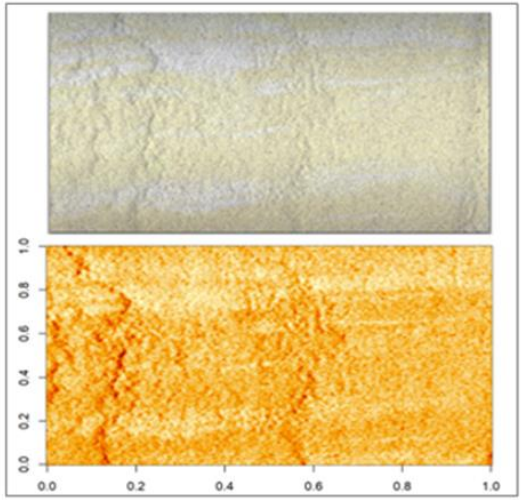
275 samples of hard wheat-wheat semolina mix

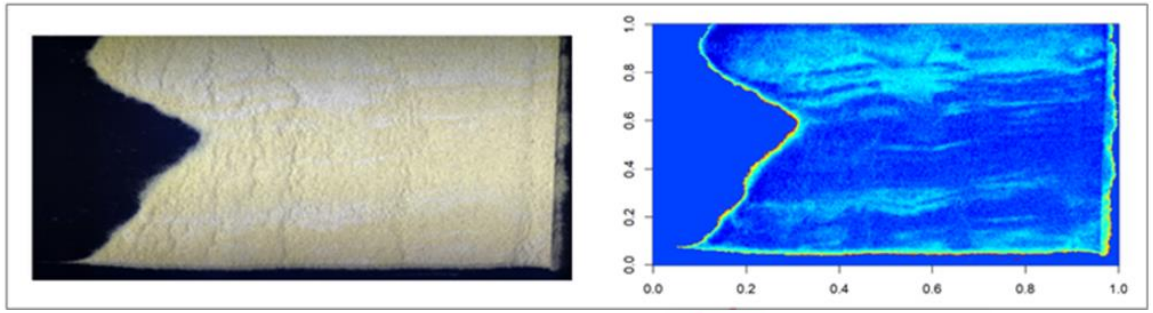
Blending with 5 mixing times



Specim FX10 system measurements (400-1000 nm)





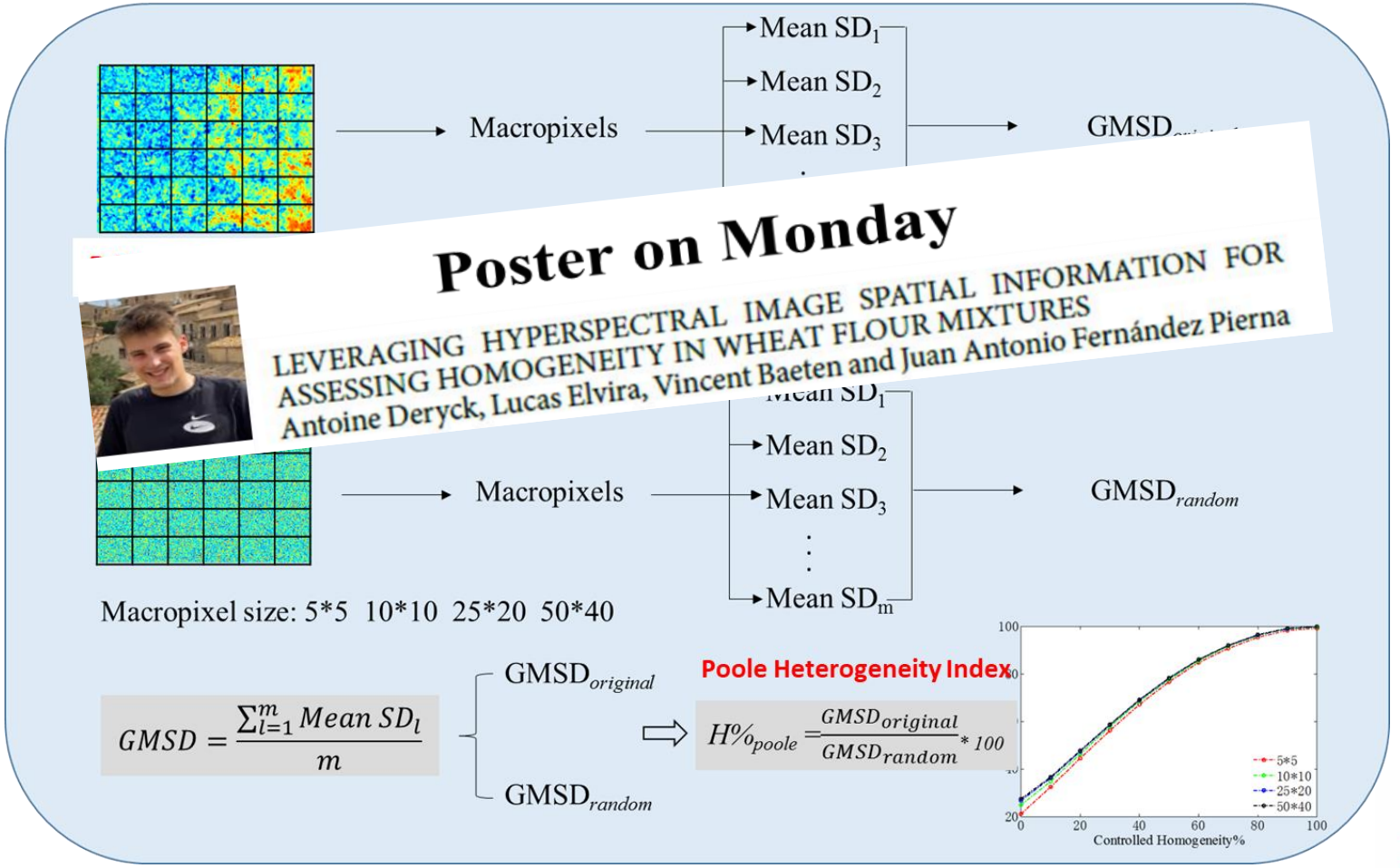


Ing Antoine Deryck

Use of AI combined to Hyperspectral Imaging

QUALISPECTRA project

CASE STUDY 1: Heterogeneity of blends



Dr. Guanghui Shen

Wallonie recherche CRA-W

Use of AI combined to Hyperspectral Imaging

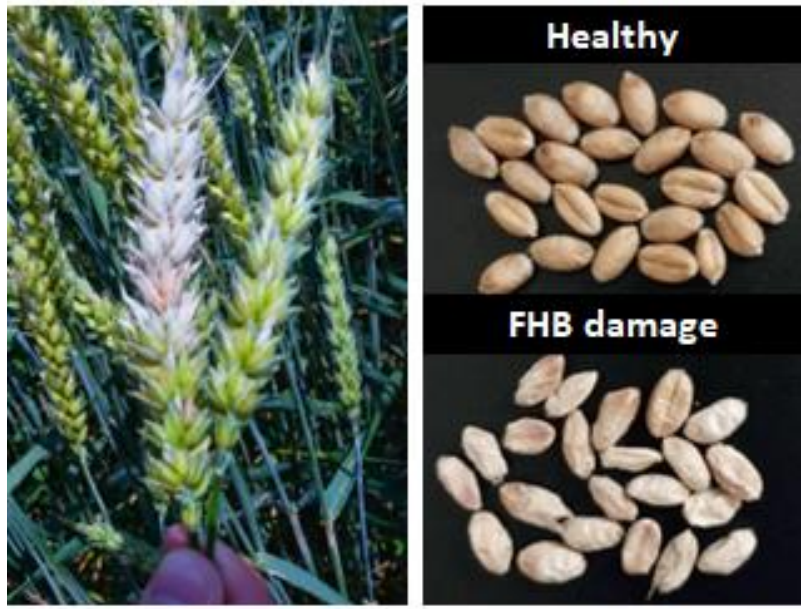
QUALISPECTRA project

CASE STUDY 2: Phenotyping

Application to fusariosis of wheat

- Fungal disease infecting wheat ears
- Causes damages to grain
  - Reduces yield and quality
- Can produce mycotoxins
  - Danger to human and animal health

Fungicide treatment only preventive and not totally effective



Source: Birr T. et al. (2020)

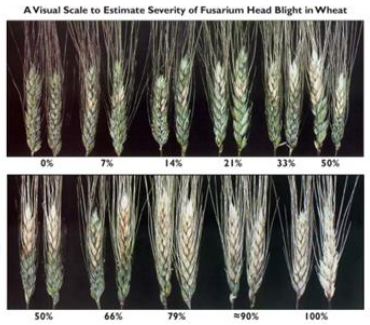
Dr Damien Vincke

Wallonie recherche CRA-W

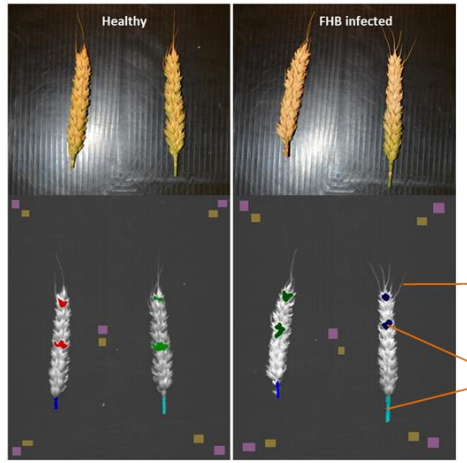
Use of AI combined to Hyperspectral Imaging

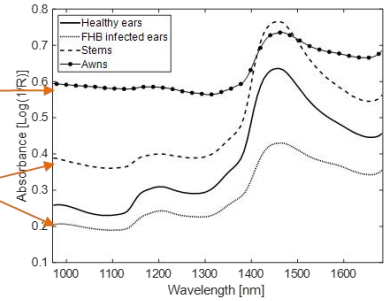
QUALISPECTRA project

CASE STUDY 2: Phenotyping



Source: Stack R.W. & McMullen M. (2011)



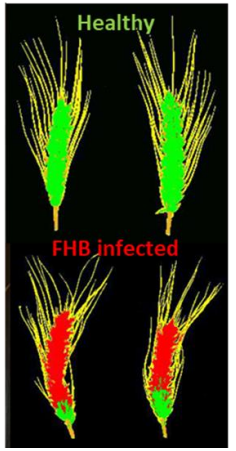


MODEL CALIBRATION

Classification models (PLS-DA)

NIR-HSI predicted image

MODEL VALIDATION



	Actual class: FHB-infected	Actual class: Healthy
Predicted as FHB-infected	152	13
Predicted as Healthy	2	141

Sensitivity: 98,7%

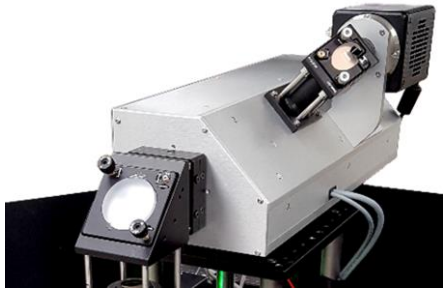
Specificity: 91,6 %

Ing Corentin Demoitié

Extension to other spectroscopic techniques

Raman Imaging

LAMBDA-X | MASTERS IN INNOVATION



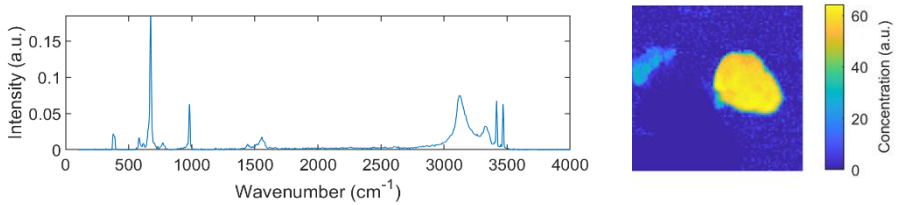
Journal of RAMAN SPECTROSCOPY

RESEARCH ARTICLE

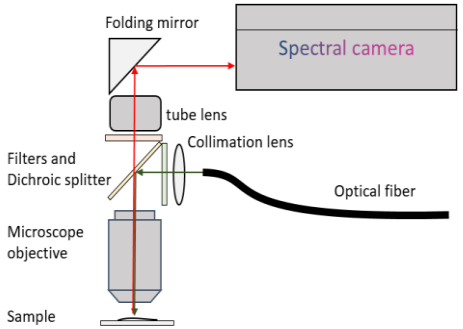
Raman Fourier transform imaging: application to melamine and melamine-milk powder mixtures analysis

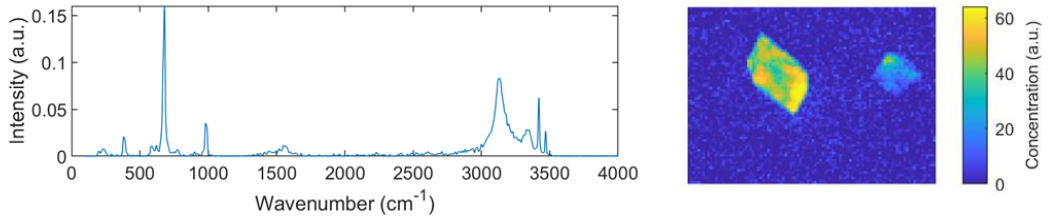
François Stevens, Didier Beghuin, Maxime Delgrange, Quentin Arnould, Vincent Baeten, Juan Antonio Fernández Pierna

First published: 30 June 2022 | https://doi.org/10.1002/jrs.6415



MCR-ALS analysis of a mixture of melamine and powder milk





MCR-ALS analysis of melamine diluted 100 times on SERS

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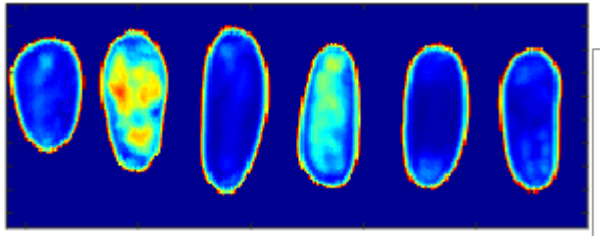
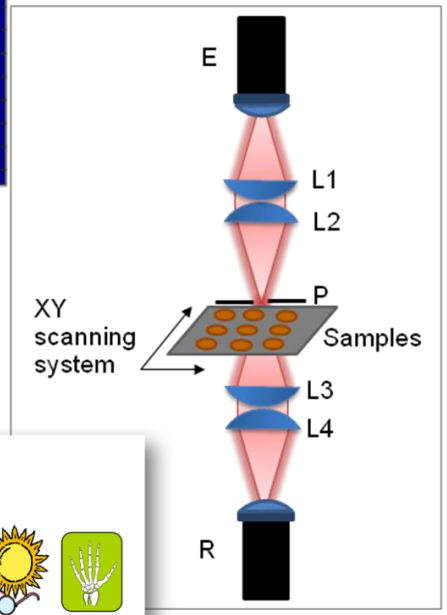
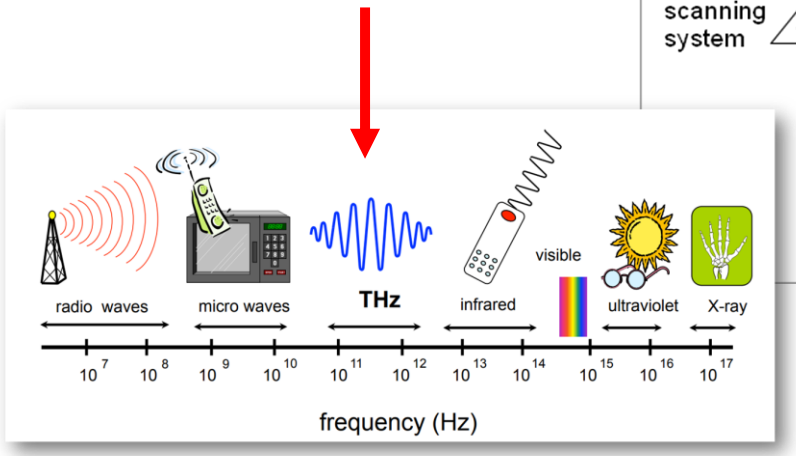
Extension to other spectroscopic techniques

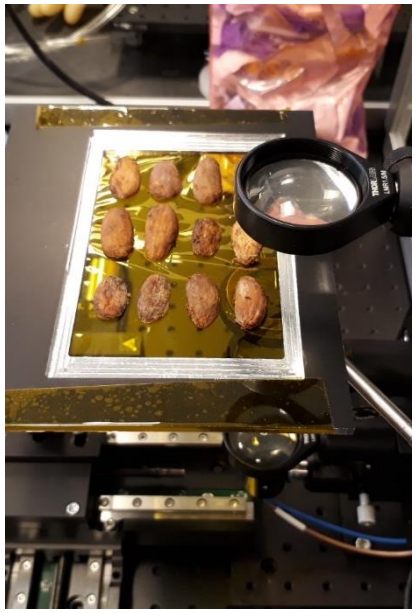
Terahertz Imaging

Multitel
INNOVATION CENTRE





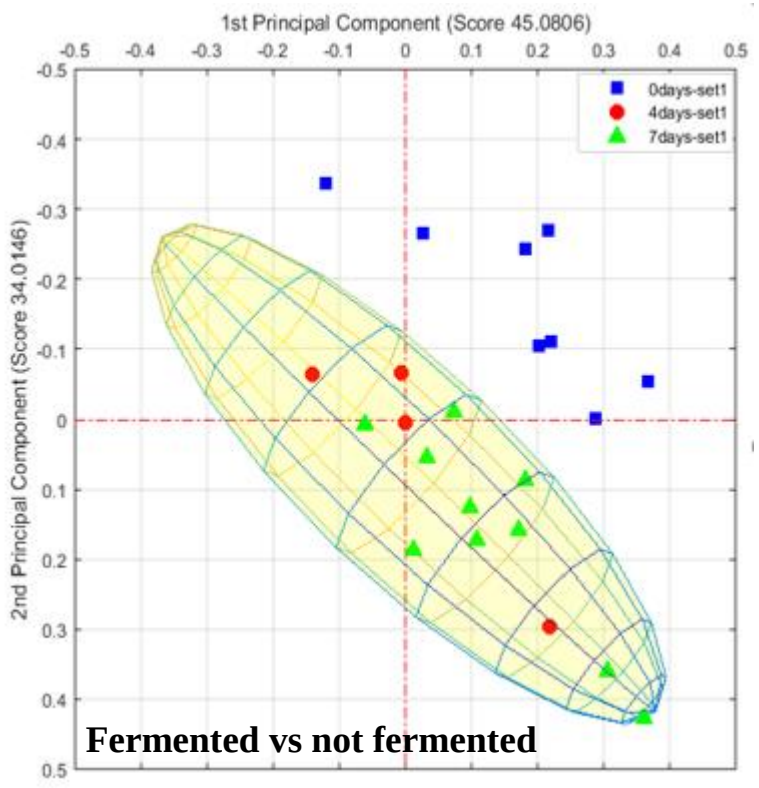




› Int J Food Microbiol. 2022 Mar 16;365:109537. doi: 10.1016/j.ijfoodmicro.2022.109537. Epub 2022 Jan 14.

A method for non-destructive determination of cocoa bean fermentation levels based on terahertz hyperspectral imaging

Dinh T Nguyen [1], Audrey Pissard [2], Juan Antonio Fernández Pierna [2], Hervé Rogez [3], Jesus Souza [3], Fabian Dortu [4], Saurav Goel [5], Yves Hernandez [4], Vincent Baeten [2]



R. Gente, N. Born, A. Rehn, M. Koch
CROP.SENSe.net Symposium, Bonn, 29.9.1014

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Conclusion - Challenges and opportunities

Initial Investment: High upfront costs for equipment and software

Data management: Find easy ways to manage images and spectra.

Innovation: Continuous R&D efforts to improve sensor technology, miniaturization and data processing capabilities.

Partnerships: Collaborations with academic institutions and industries to expand application areas.

Conclusion - Challenges and opportunities

Economic Benefits: Improved efficiency and productivity in various industries through precise monitoring and analysis.

Long-term Savings: Reduction in operational costs and wastage through accurate data insights

Integration with AI, IoT, and cloud computing to unlock new potential.

Transfer of data / models between systems for broader applications.

Conclusion - Challenges and opportunities

In the agri-food sector, monitoring crop quality, identifying diseases or pests, optimising harvesting and ensuring food quality throughout the agricultural supply chain

Fraud and counterfeit control; regulatory compliance

Technology transfer to other industries in the biochemical sector: pharmaceuticals, cosmetics, agrochemicals, etc

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