Design and characterization of a sustainable food for people with anaemia

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Iron deficiency

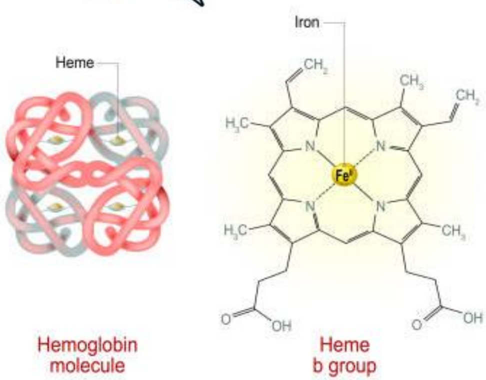
1st cause of anemia → 25 % of the world population affected (WHO, 2015)

26 55.845
Fe
Iron

Target populations/risk factors : Pregnant women, Young children, Sedentary lifestyle, Obesity, Developing countries

Dietary iron

Heme iron (HI)



Bioavailibility 40%

Non-heme iron (NHI)

Fe^{3+}

Fe^{2+}

Bioavailibility 2-10%

Combination of animal and plant based ingredients ("meat factor") (O'Flaherty et al., 2019)

Strategy

Development of fortification solutions to increase the bioavailability of iron rather than supplementation (Piskin, 2022)

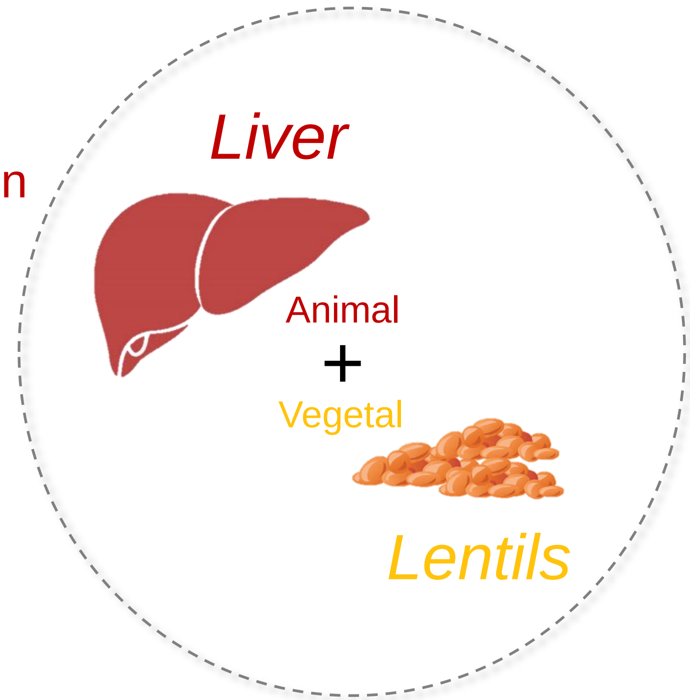
How to develop a sustainable and appetizing iron-rich food?

Nutritional, functional and organoleptic complementarity

Animal by-products valorization

High HI content

High protein content



High fiber content

Organoleptic qualities

Functional properties

Design by 3D-food printing

Foodini 3D-printer

by *Natural Machines*

An innovative and suitable tool:

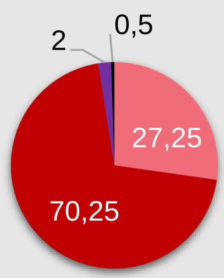
- Rapid prototyping
- Personalized nutrition
- By-products valorization
- Food design and texture
- Increase food acceptability

…

Printable recipes and printed shapes

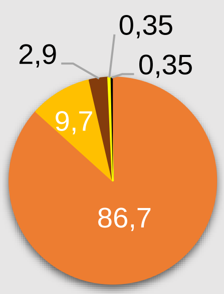
Printable recipes

Animal

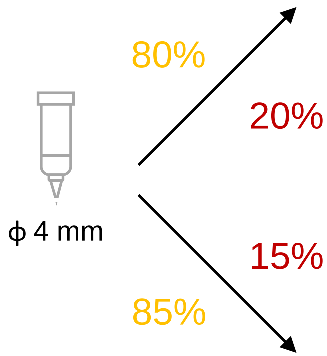


- Raw pork liver
- Raw chicken liver
- Rasperry vinegar
- Salt

Vegetal

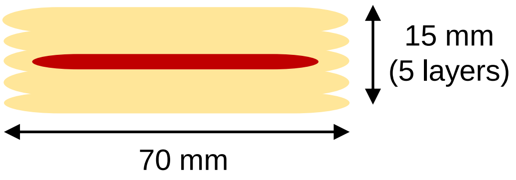


- Mashed coral lentils
- Lupine flour
- Peanut oil
- Curry powder
- Salt

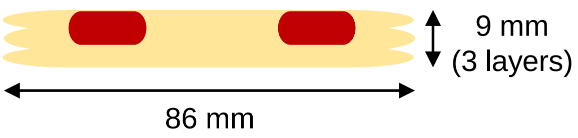


2 shapes selected

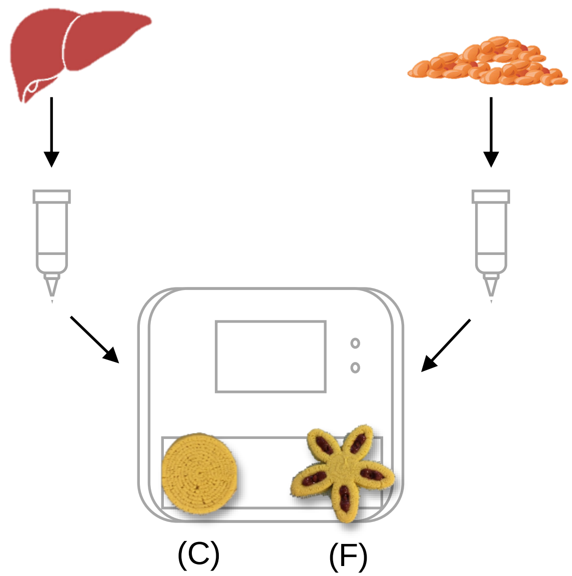
"Cookie" (C)



"Flower" (F)

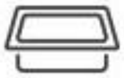


Experimental approach



$T_{product}$ = 72 °C

Baking conditions according to shape:
- (C): 180 °C / 5 min; 70% steam
- (F): 180 °C / 2 min 45 s; 70% steam



2 modified atmosphere packaging (MAP):
- **O_2-MAP: 70% O_2 / 30% CO_2**
- **N_2-MAP: 70% N_2 / 30% CO_2**

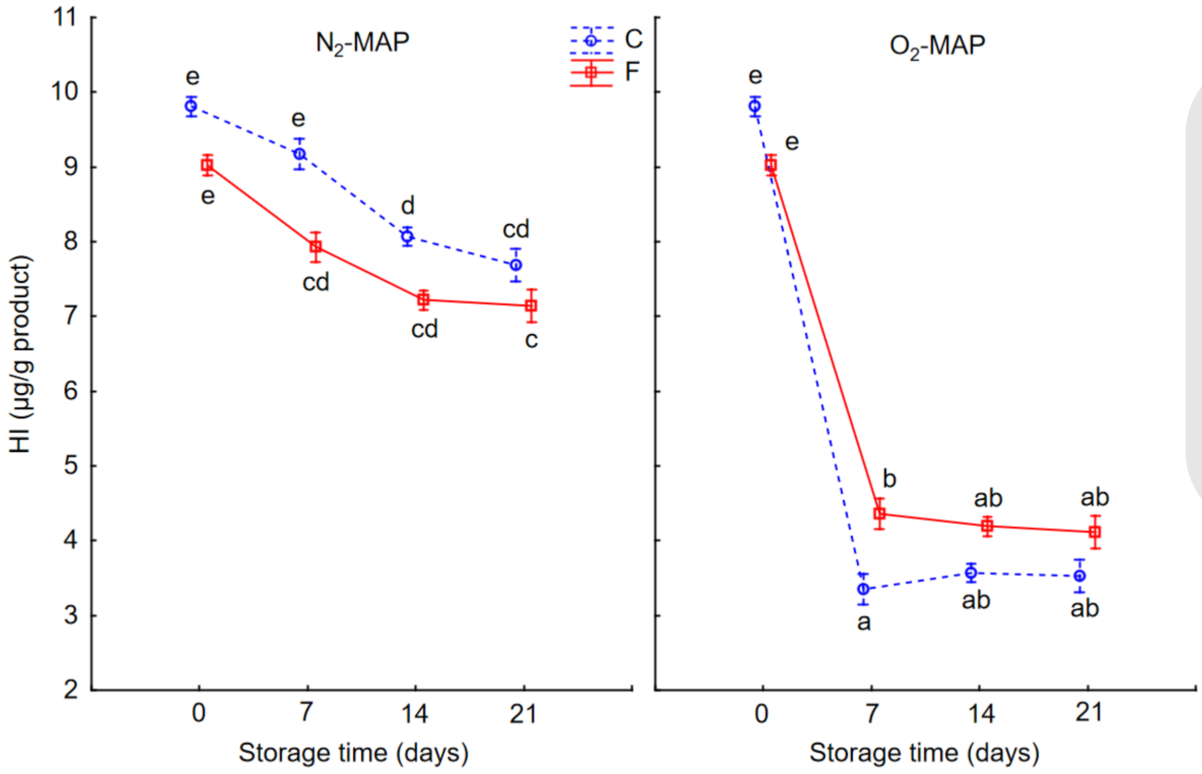
→ **Analyses on days 0, 7, 14 and 21 of storage at 4 °C**

Kinetic monitoring of 3D-printed products:

- Physico-chemistry:
  - pH
  - Water activity (a_w)
  - Water content
- Iron content:
  - Heme iron (HI)
  - Non-heme iron (NHI)
- Lipids oxidation:
  - ThioBarbituric Acid Reacting substances (TBARs)
- Texture Profile Analysis (TPA):
  - Hardness
  - Springiness
  - Cohesiveness
  - Gumminess
  - Chewiness

Heme iron (HI)

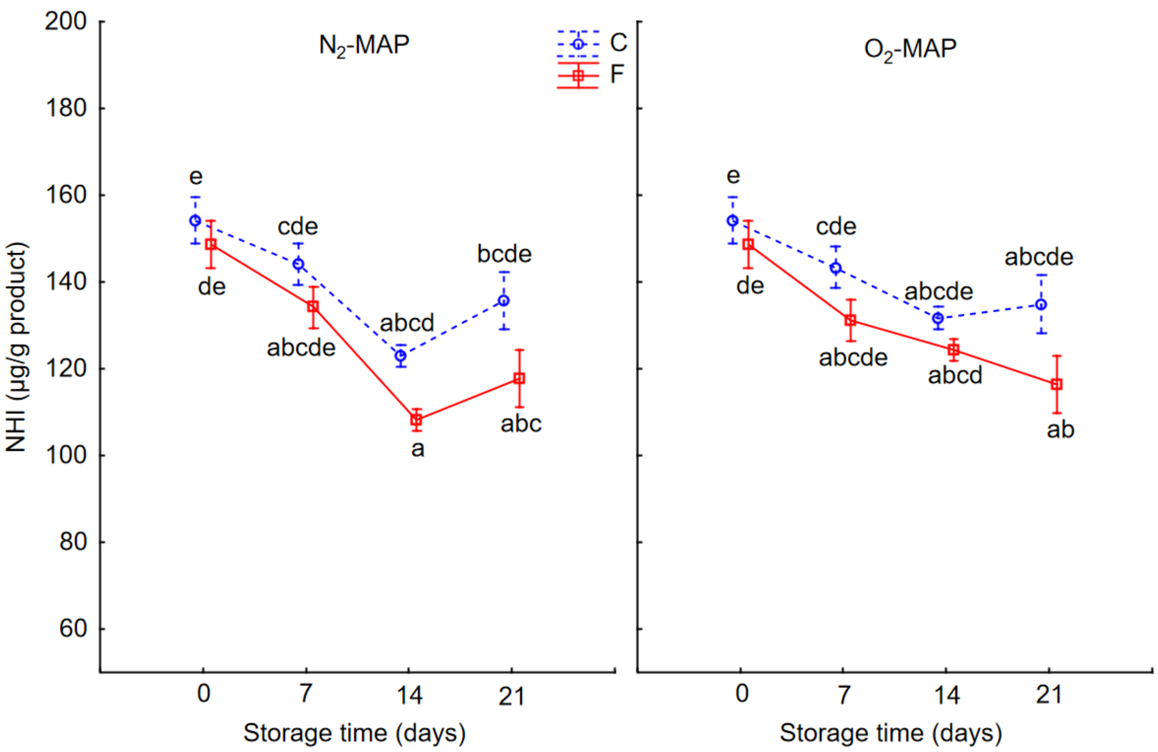
Effect of MAP, storage time and shape on HI content



- Sharp drop in HI from day 7 under O_2-MAP
- Degradation of heme molecule (oxidation)
- No difference between the two shapes

Non-heme iron (NHI)

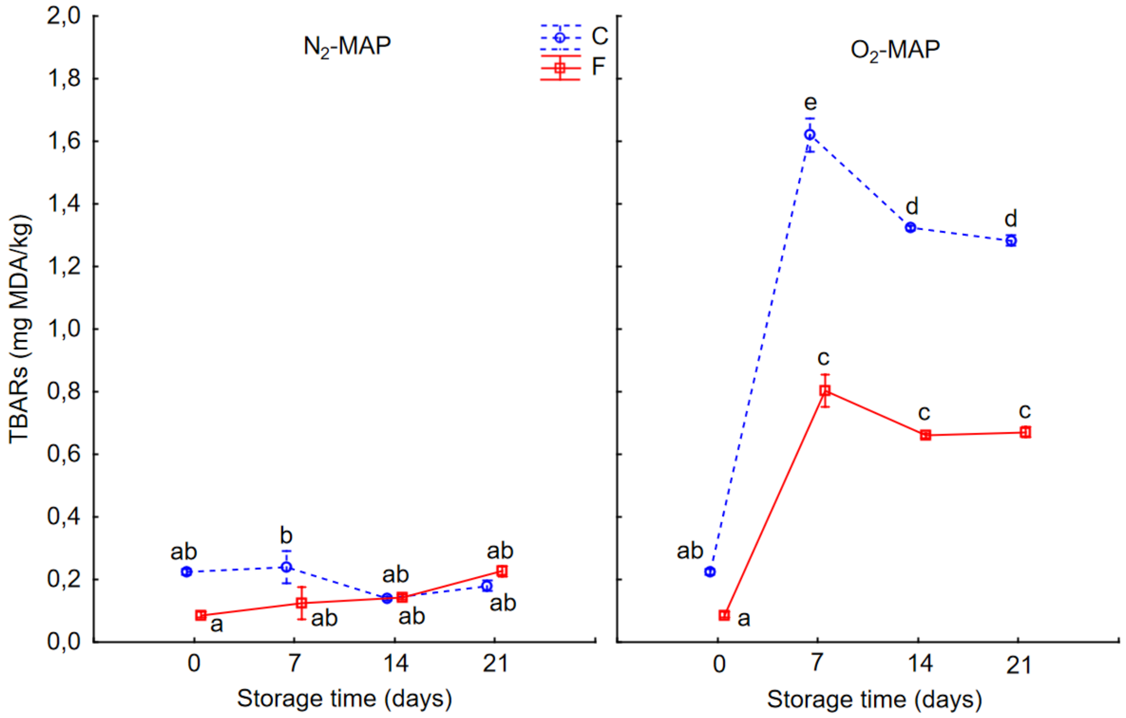
Effect of MAP, storage time and shape on NHI content



- No significant impact of packaging on NHI content
- HI/NHI conversion not seen at this stage
- No difference between the two shapes

Lipid oxidation

Effect of MAP, storage time and shape on lipid oxidation

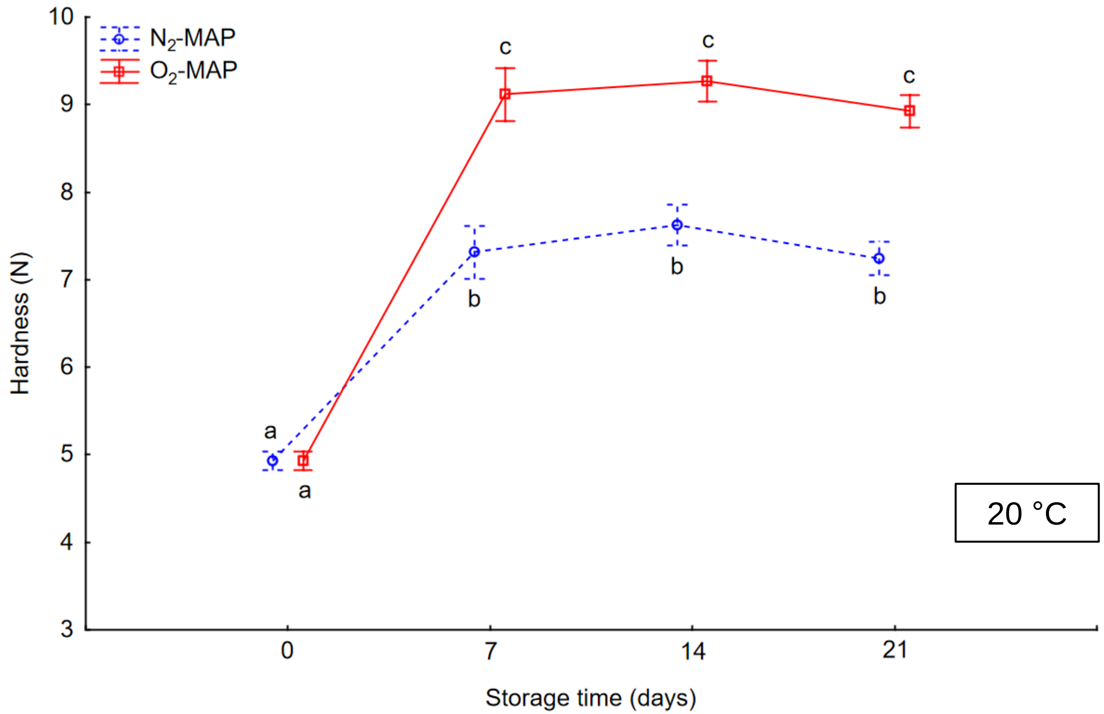


- High lipid oxidation from day 7 then plateau
- Difference between the two shapes due to their composition (O_2-MAP)

(More unsaturated fatty acids in poultry liver, antioxidant in lentils)

Texture Profil Analysis (TPA)

Effect of MAP and storage time on texture



Compact

Brittle

- Change in product structure/texture during storage
- Products significantly harder with O_2-MAP from day 7

Summary

- Demonstration of multi-layer manufacturing of hybrid liver/lentils product by 3D printing

- Storage under O_2-MAP caused oxidation of lipids, a drop in heme iron and product hardening.

→ **reactions of oxidation that occured** mainly between D0 and D7

foods MDPI

Article

Investigation into the Physicochemical and Textural Properties of an Iron-Rich 3D-Printed Hybrid Food

Coline Schiell [1,2], Stéphane Portanguen [2], Valérie Scislowski [1], Thierry Astruc [2] and Pierre-Sylvain Mirade [2,*]

Which effects on iron form and localization ?

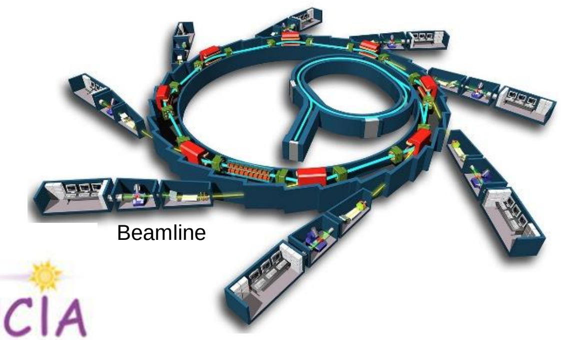
Synchrotron X-ray radiation

- X-ray fluorescence (XRF)

Elementary mapping (qualitative and quantitative information)

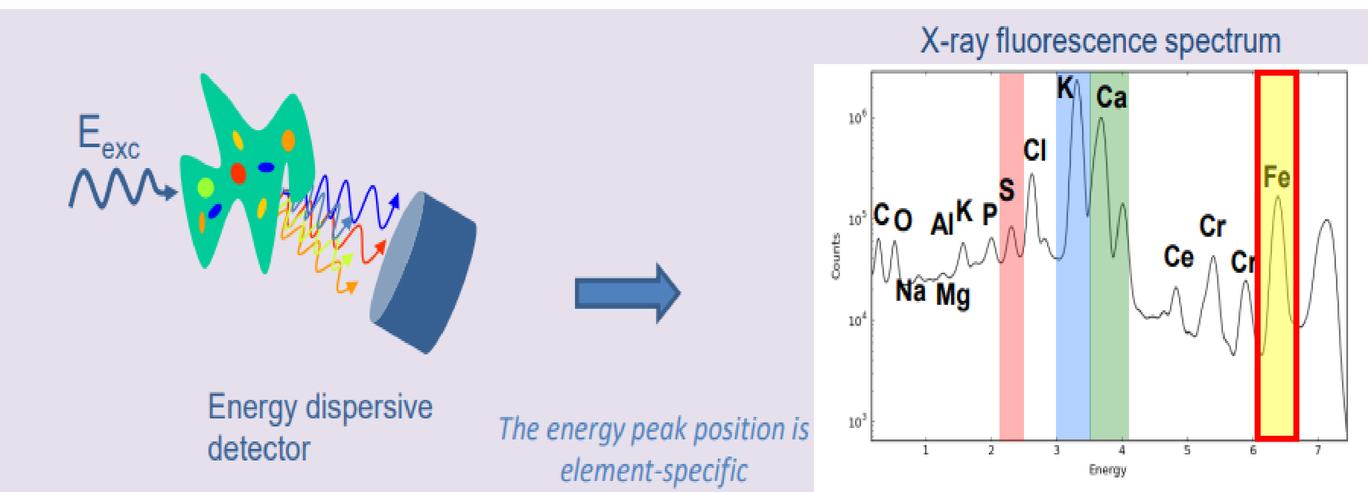
- X-ray absorption near edge structure (XANES)

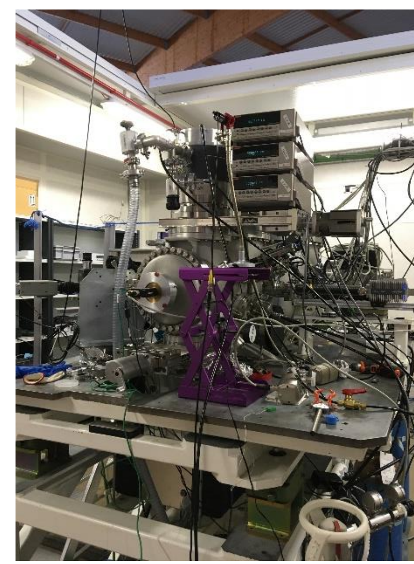
Oxidation state, mineral/compound signature



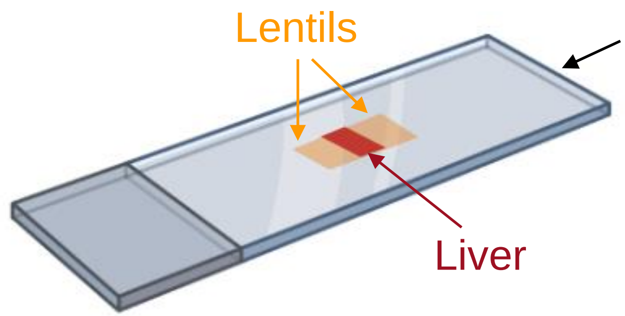
LUCIA

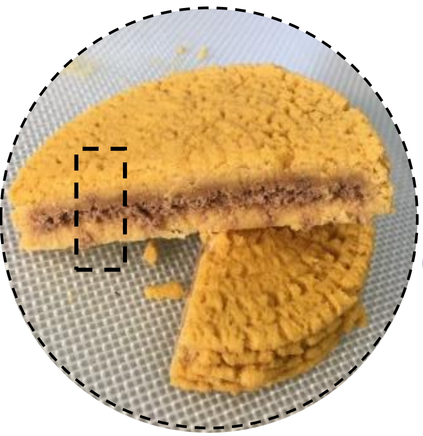
Soft and Hard X-rays (0.8-8 keV)





Experimental design



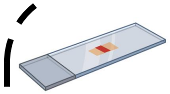


Oxygen-rich (O_2-MAP)

Nitrogen-rich (N_2-MAP)

Storage days (4 °C)

Timepoints for analysis:



Sections

- XRF
- µ-XANES
- Histological stains (HES and Lugol)

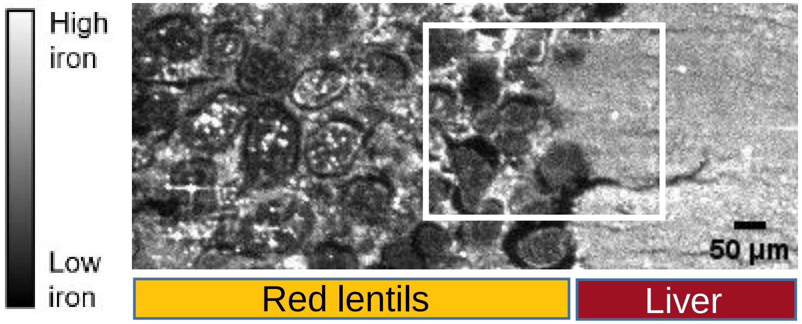
Powder

- XANES
- Raw materials and standards

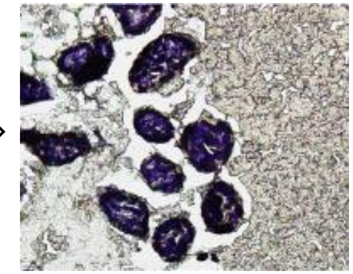
Results

µXRF maps of Iron

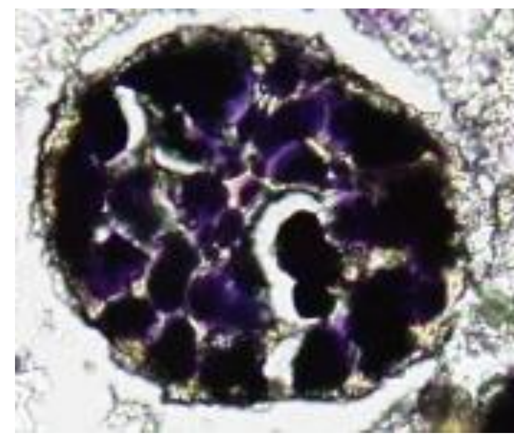
D0



Lugol staining



Amyloplasts with starch grains



N_2-MAP

O_2-MAP

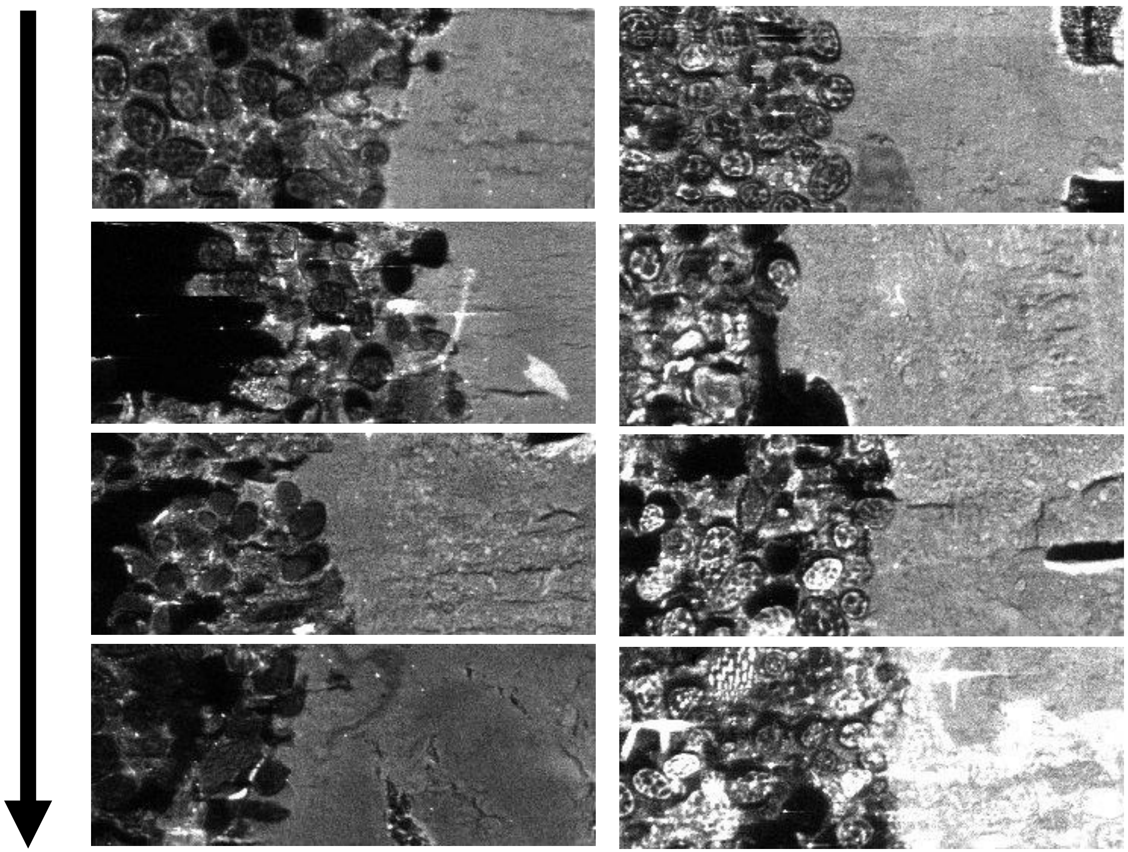
D5

D7

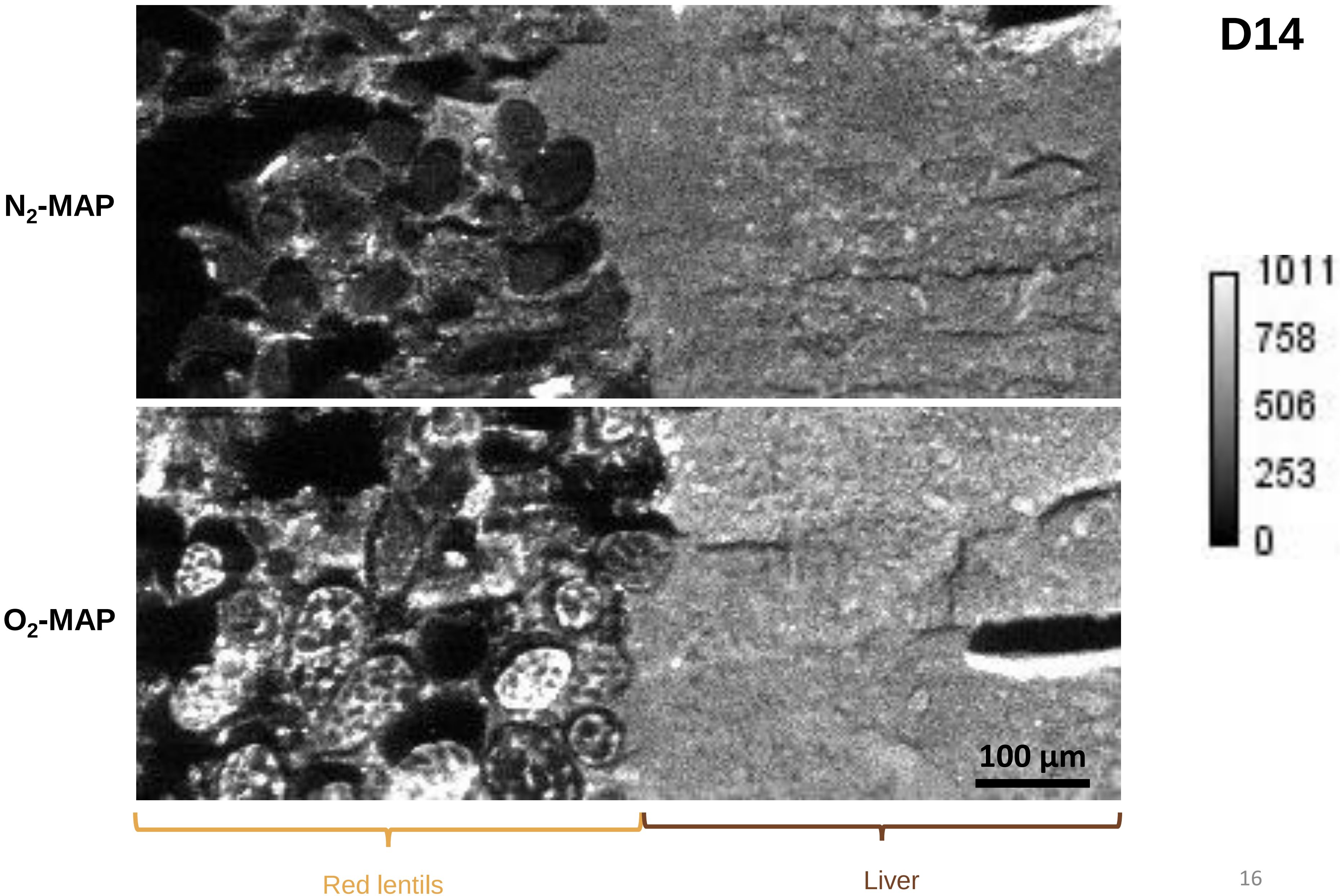
D14

D21

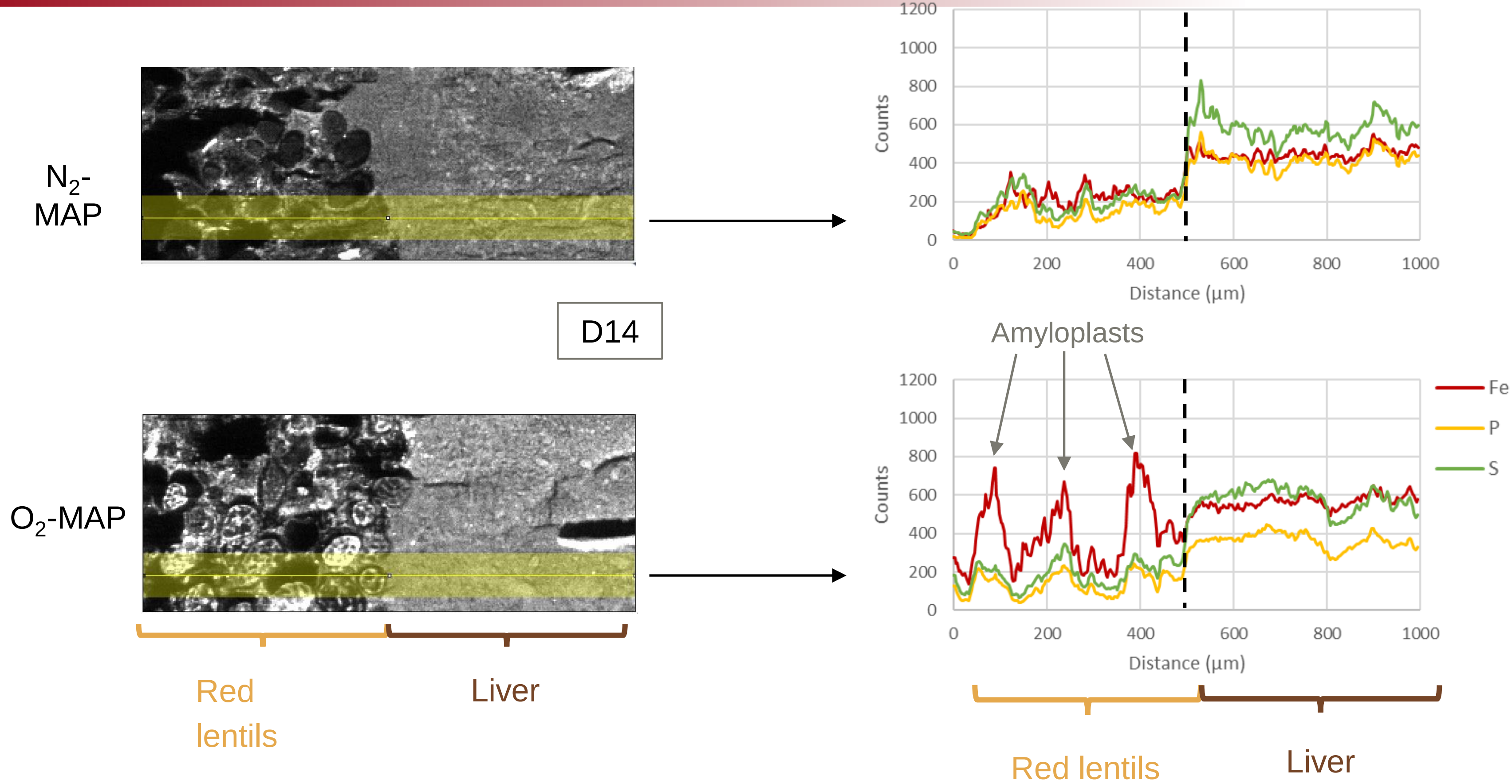
Time



Results



Iron distribution profiles



- heterogeneous iron distribution in the lentils due to iron concentration in amyloplasts as ferritin, according to Briat et al. (2010)
- Higher iron signal in samples under O_2-MAP suggesting a change in iron distribution

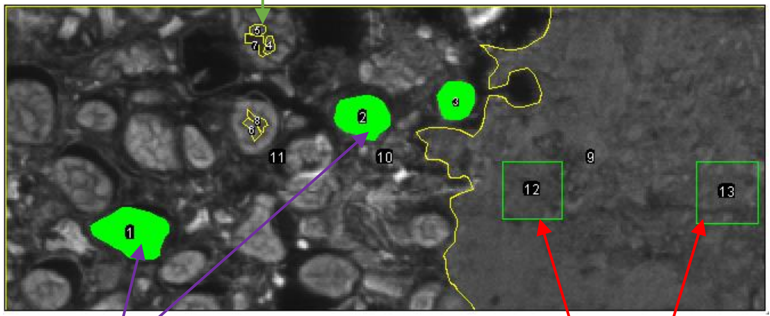
❖ Ferritin captures and induces the mineralization of iron in its cavity in the presence of oxygen (Zhao, 2010), likely increasing the iron concentration in amyloplasts under O2-MAP compared to N2-MAP

❖ Fe-P-S colocation linked to the presence of iron-complexing compounds (e.g. phytates, ferritin)

Correlations between iron and other elements

Selection of regions of interest (ROIs):

Starch grains



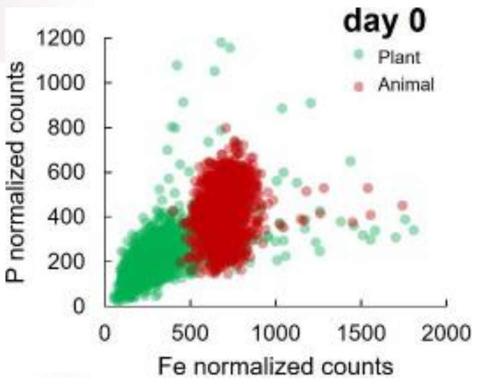
Amyloplasts

Animal zones at different distances from the interface

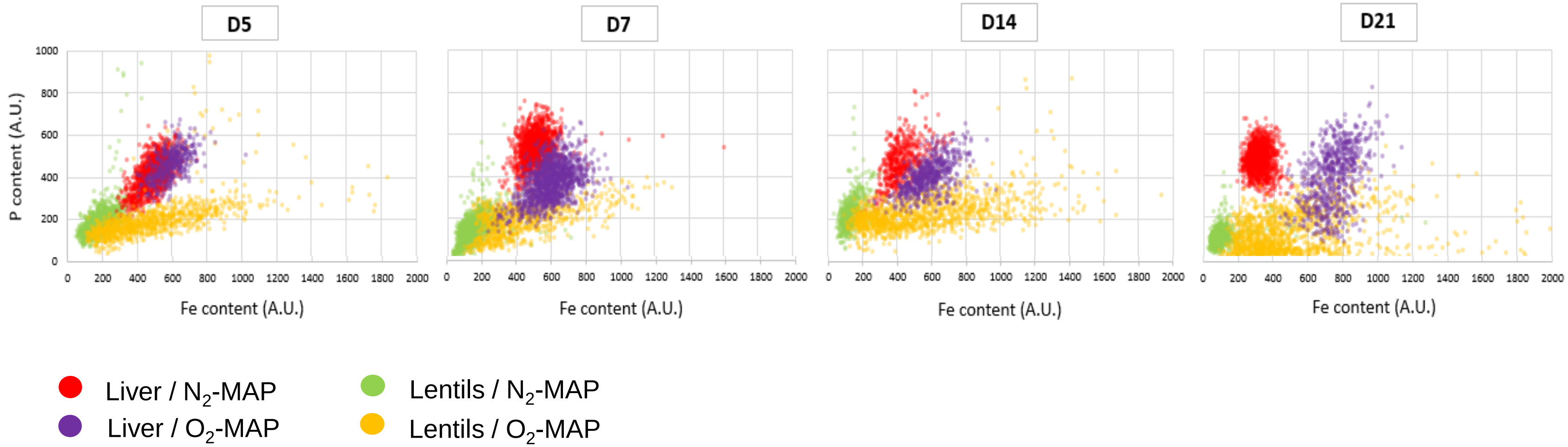
Extraction of data from elementary maps of Fe, S, and P (quantitative)

Objective: get information on potential bonds and the atomic environment of iron as a function of storage conditions

Correlations between iron and Phosphorus



Plot correlation between iron and other elements obtained from XRF maps:

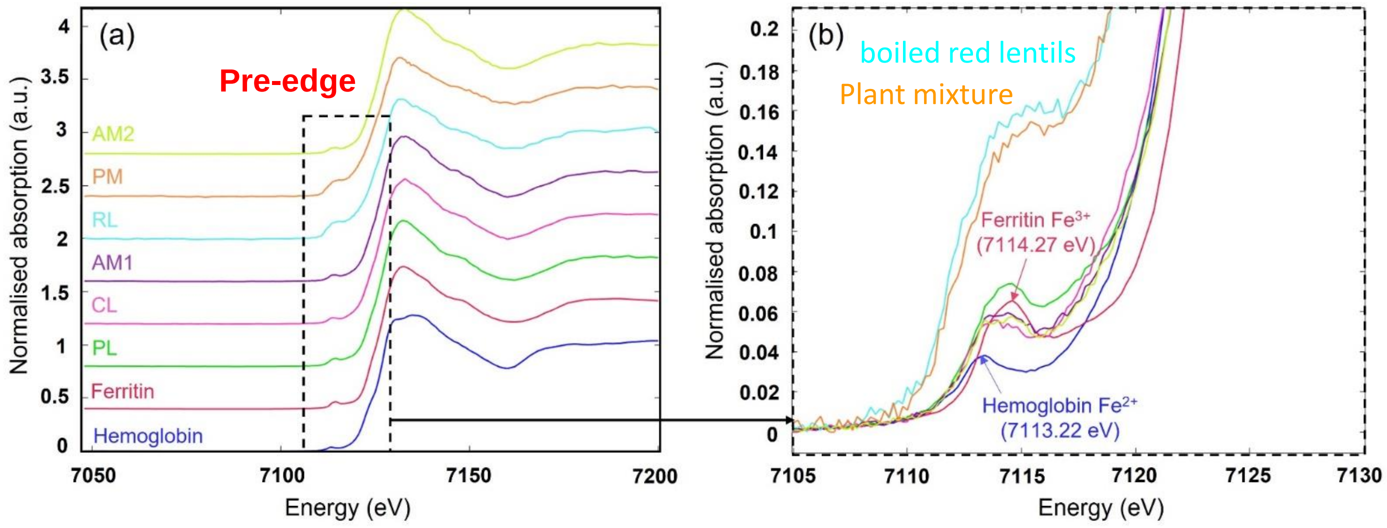


Positive correlations between Fe, P (and S) in the liver and lentil areas, and changes in these correlations during storage

→ Change in the atomic environment of iron depending on the storage conditions of the food

→ Link with the presence of iron chelating compounds (phytates, biological sulphate, ferritin, sulphur-containing proteins, etc.)

Identification of the oxidation state of iron from XANES spectra



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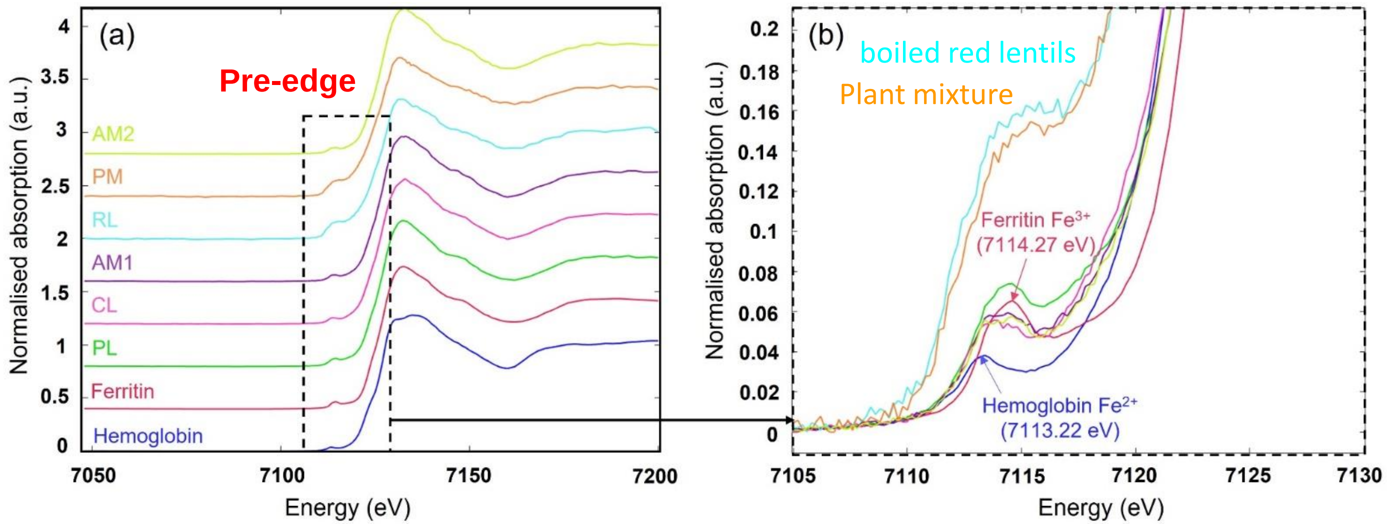

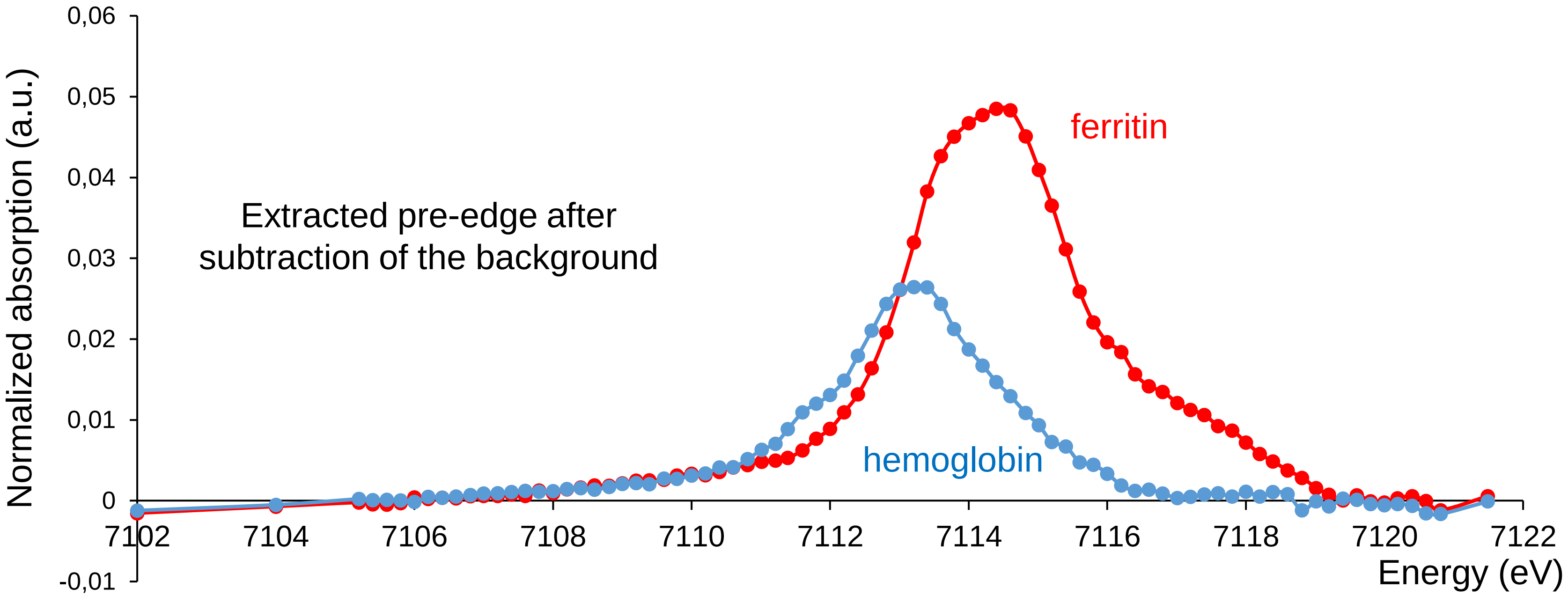

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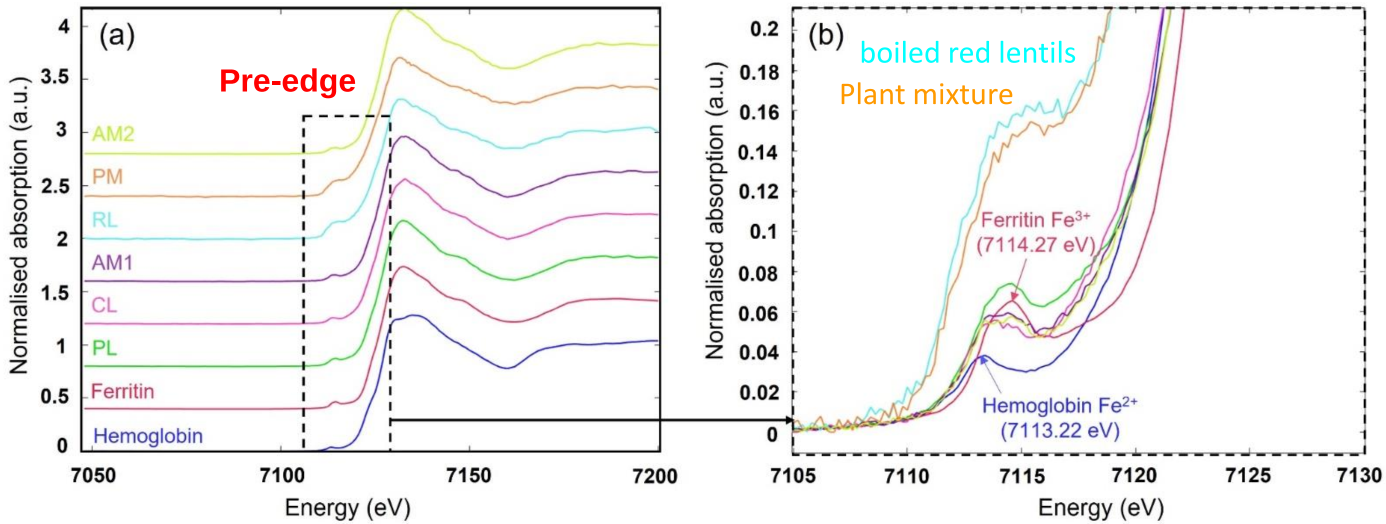

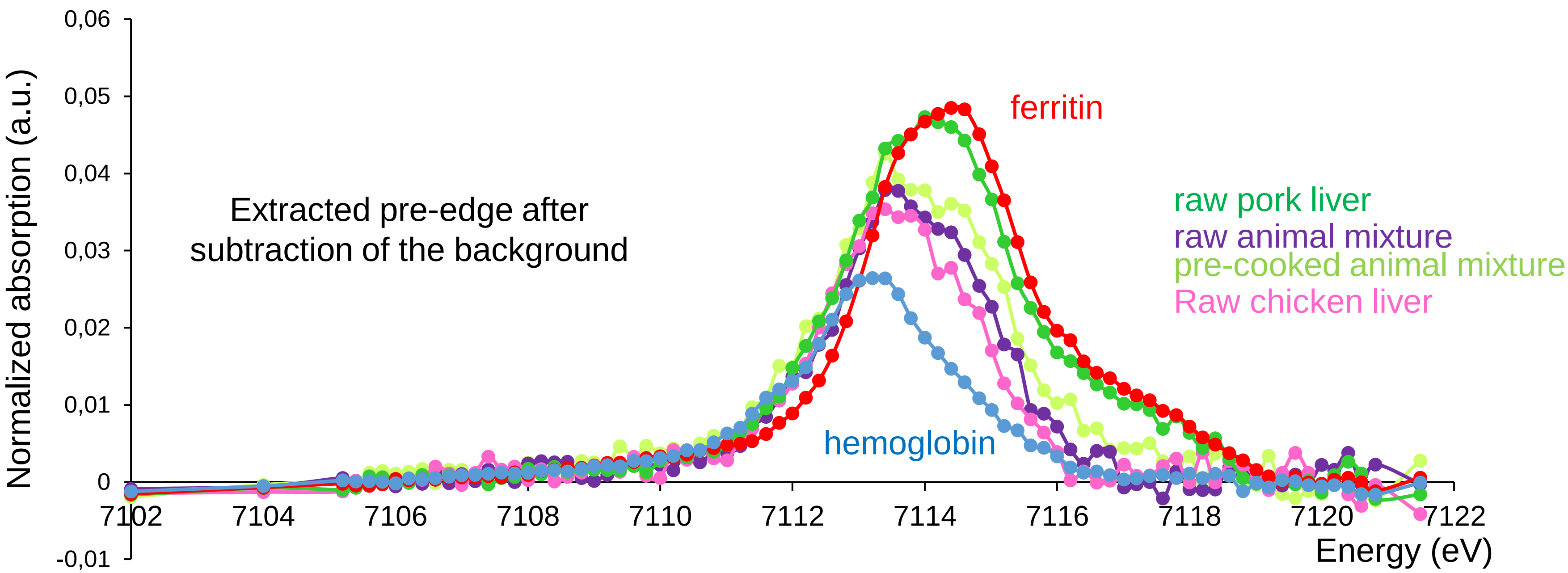

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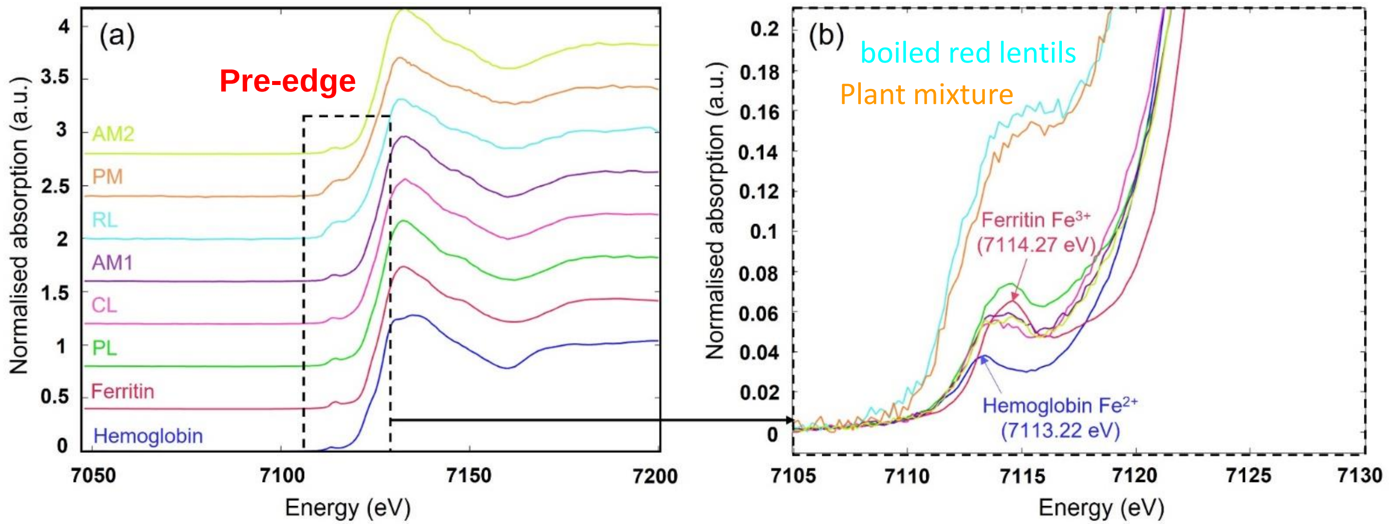
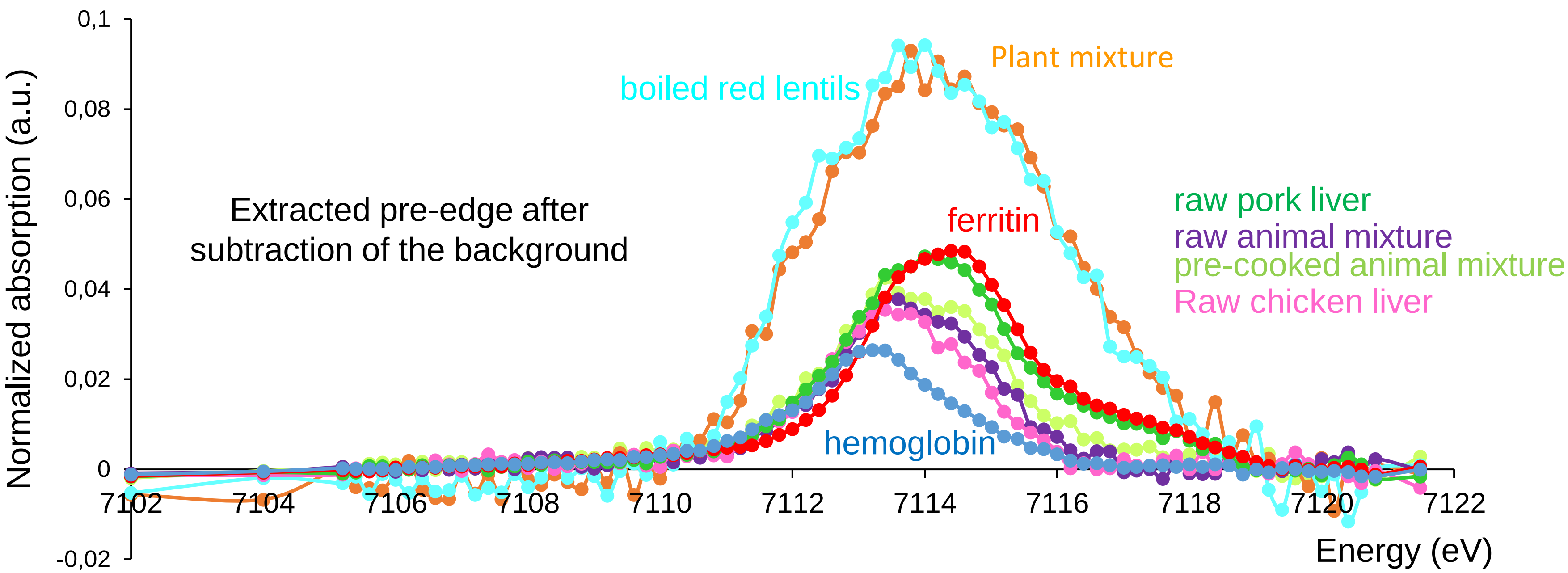
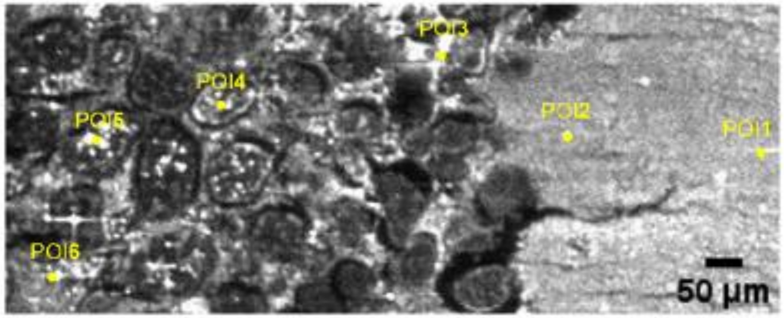


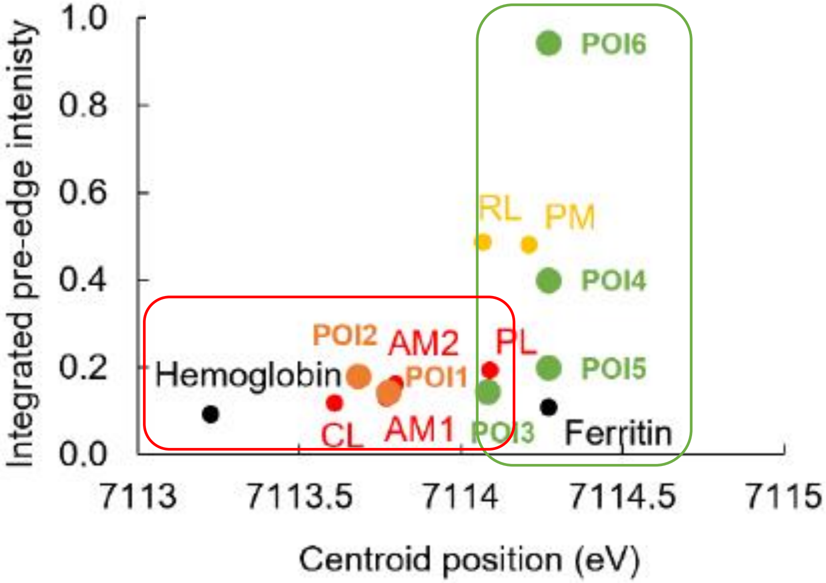


XANES showed spectral signatures specific to the animal and plant mixtures

µ-XANES acquisition around the animal/plant interface

Day 0

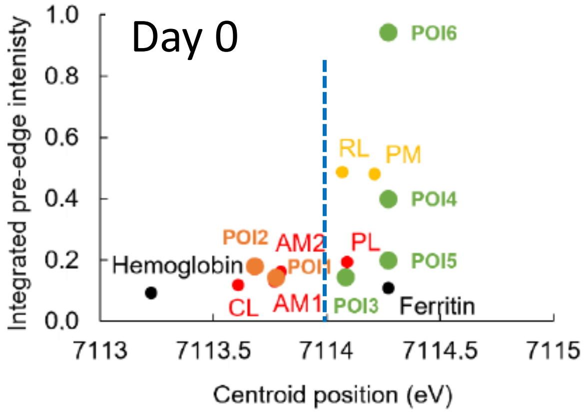




POI: Point of Interest	RL: Red Lentils PM: Plant Mixture	CL: Chicken Liver PL: Pork Liver	AM1: Raw Animal Mixture AM2: cooked Animal Mixture

µ-XANES discriminated iron from plant origin from iron from animal origin on hybrid food section

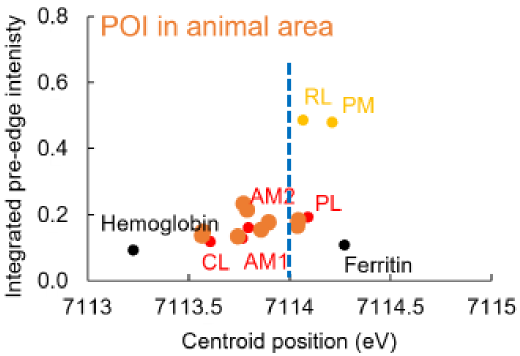
Results

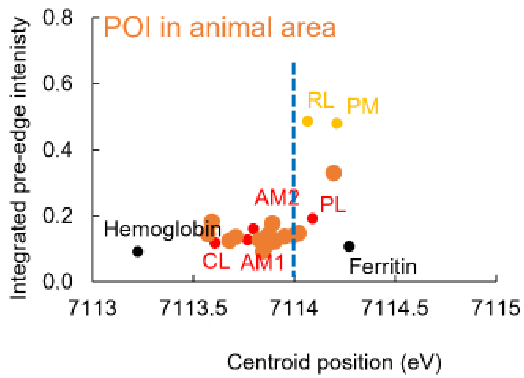


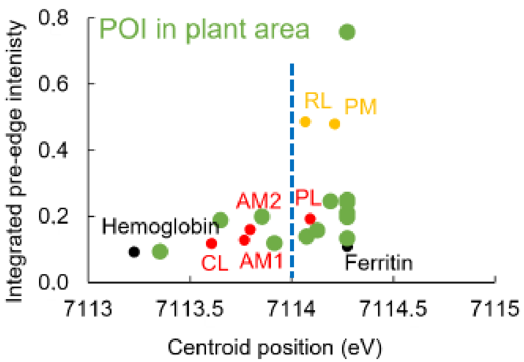
POI: Point of Interest
PM: Plant Mixture
RL: Red Lentils
CL: Chicken Liver
PL: Pork Liver
AM1: raw Animal Mixture
AM2: cooked Animal Mixture

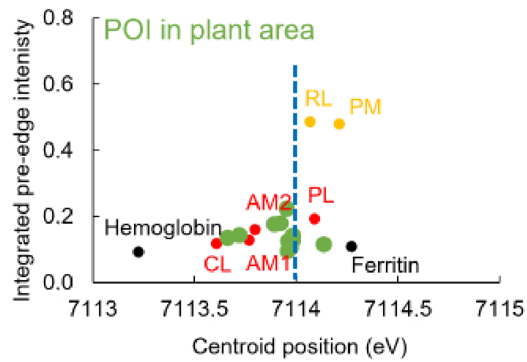
Effect of storage on µ-XANES spectra characteristics

N_2-MAP **Day 5 to day 21** O_2-MAP









Shift of the plant centroid position to the liver part espescially during storage under O2-MAP.

Transfer of iron from liver to lentils ?

Change in chemical form of lentils iron ?

Conclusions

3D printing of hybrid liver/lentil food achievable

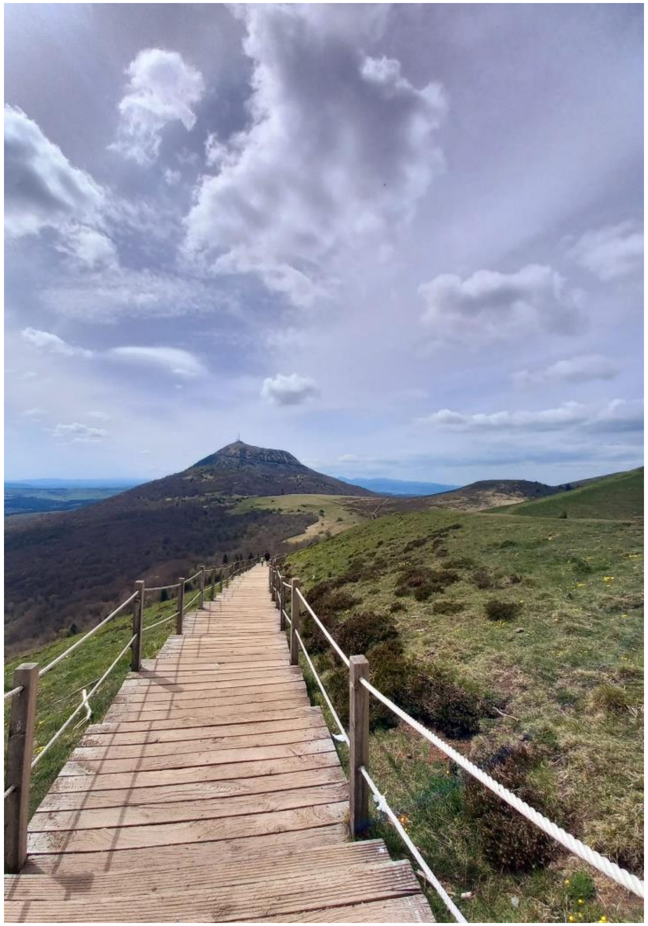
Pay particular attention to the method of storage to preserve quality , including iron speciation and bioavailibity

X-ray spectroscopy and XANES approaches to food matrices are relevant to better understand the mechanisms of iron transfer and its interactions with its environment.

The observed phenomena raise questions and further research is needed to verify the working hypotheses.

Schiell et al. Iron distribution and speciation in a 3D-printed hybrid food using synchrotron X-ray fluorescence and X-ray absorption spectroscopies. Submitted to Food Chemistry

Thank you for your attention!



« Imaging and Transfers » team
UR 0370 Qualité des Produits Animaux (QuaPA)

INRAE

SOLEIL SYNCHROTRON
LUCIA

?? Any questions ??

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