IRON DISTRIBUTION AND OXIDATION IN A 3D-PRINTED ANIMAL/PLANT HYBRID FOOD USING SYNCHROTRON X-RAY RADIATION

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I. INTRODUCTION

Iron deficiency is the leading cause of anaemia, which affects about 25% of the world's population [1]. Several approaches are being explored to address these deficiencies, including the development of new iron-rich foods in which iron would be provided naturally through the nutritional richness of the ingredients involved. However, iron absorption is related to complex mechanisms and depends on the form of iron, haem iron (HI) or non-haem iron (NHI), and on the other components of the food [1]. Moreover, the chemical and textural properties of the food may be affected by storage conditions and time [2]. In this context, this study investigated the time-course chemical changes at the microscopic scale in a hybrid food composed of liver and lentils, comprising several forms of iron.

II. MATERIALS AND METHODS

A commercial 3D food printer was used to design model foods consisting of alternating layers of animal and plant mixtures. The animal mixture was obtained by chopping raw pork liver (27.25% w/w) and raw poultry liver (70.25% w/w), then mixing with raspberry vinegar (2% w/w) and salt (0.5% w/w). To improve printability, the animal mixture was pre-cooked at 50 °C for 15 min. For the plant mixture, red lentils (approx. 86% w/w) were cooked for 15 min from boiling in unsalted water in the ratio of 1:5 (w/w) before being sieved and mixed with lupine flour (10% w/w), peanut oil (3% w/w), curry powder (0.4% w/w) and salt (0.4% w/w). After baking (5 min/180 °C with 70% steam) and before being stored at 4 °C, the 3D-printed foods were packed under two different modified atmospheres (MAP): oxygen-rich (O_2-MAP) or nitrogen-rich (N_2-MAP). A part of the foods was ground in liquid N_2 and on the other part cuts of 10 µm and 6 µm thickness were made after cryofixation in liquid N_2 cooled isopentane. The distribution and location of iron were studied at the interface of animal and plant parts at 0, 7, 5, 14 and 21 days of storage using synchrotron X-ray fluorescence (XRF). The oxidation state of the iron was also determined on the initial mixtures and on the hybrid foods by X-ray Absorption Near Edge spectroscopy (XANES) at Fe K-edge. In addition, HI and NHI contents were assayed in triplicates. Analysis of variance followed by the Tukey HSD post hoc test ($P < 0.05$) was performed on data.

III. RESULTS AND DISCUSSION

The results demonstrated a change in iron distribution in animal and plant parts and an overall higher iron concentration at the animal/plant interface in samples stored under an oxygen-rich atmosphere compared to those stored under N_2 (Figure 1). The animal part (on the right) was more homogeneous than the plant part (on the left) where we noticed a more heterogeneous distribution of iron which was mainly accumulated in the amyloplasts (spherical particles) around the starch grains as shown by the profiles. This trend was observed for all samples from D5 to D21. The impact of storage time was lower than the effect of storage conditions. This may be explained by the presence of oxygen

in the atmosphere promoting the oxidation of iron [2], which can then be stored in another form (e.g. accumulation in the nucleus of phytoferritin in amyloplasts [3]). In agreement with a previous study [4], iron assays showed a significant ($P < 0.05$) drop in HI content, while total iron content was not significantly impacted by storage conditions due to the predominance of NHI, in the form of ferritin.

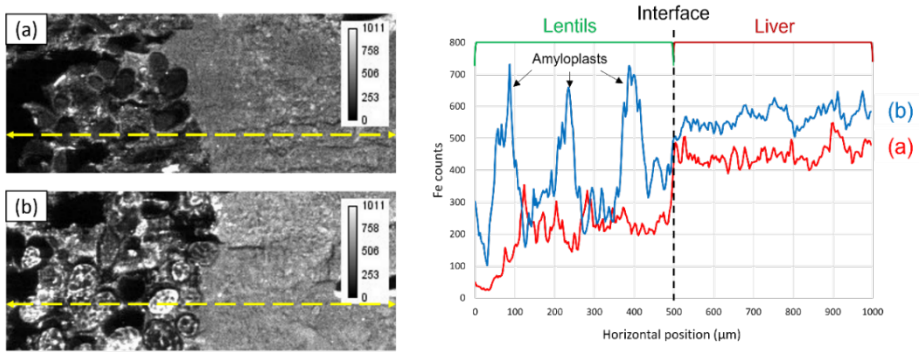

Figure 1. XRF maps (left) and corresponding iron profiles (right) of a sample stored 14 days under N_2-MAP (a) compared to a sample stored the same period under O_2-MAP (b). The yellow dotted line corresponds to the area where the profiles were calculated.

Furthermore, correlations between iron and other elements such as sulphur and phosphorus depending on the storage conditions and material were noticed. This can be linked to binding of iron to sulphur proteins [5] or colocalization of iron and phosphate in ferritin core [3]. Preliminary analysis of the XANES spectra revealed different pre-edge peak pattern and thus specific iron chemical forms for animal and plant initial mixtures. The animal mixture was closer to the animal ferritin reference, which is consistent with the fact that iron is mostly stored as ferritin in the liver. The pre-edge peak pattern of the plant mixture was closer to the FeS_2 reference although it is different and shows a shift to lower energies compared to the animal matrices which would indicate a more reduced iron form.

IV. CONCLUSION

The study highlighted the effect of time in storage and MAP composition on oxidation mechanisms in animal/plant hybrid food containing different iron forms. Most of the changes were observed from day 5 for foods stored under O_2-MAP, which resulted in a change in the distribution and forms of iron in animal and plant parts as indicated by the decrease in HI and the modification of the atomic environment of iron.

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