INRAE

Research and Innovation 2021
For Food, Bioproducts & Waste

Division of Science for Food, Bioproducts and Waste
TRANSFORM

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LEGAL MENTIONS

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Foreword

Our ambition: produce the science needed to underpin the bioeconomy transistion

In 2020, we launched TRANSFORM, a new INRAE division entirely devoted to science for food, non-food, bioproduct and waste engineering. Therefore, the last 18 months have been intense, building new internal relations, consolidating the Division's vision and mission and building its strategic roadmap for the next 4 years.

Fortunately, as this report reflects, TRANSFORM is built upon solid scientific foundations that provide substance for our ambitions. In this regard, this year's highlights fully reflect the Division's legitimacy as a major international contributor to the development of a circular bioeconomy, with activities covering all of its vital parts, including food science, biotechnology, biobased materials science and waste treatment technologies. Regarding the latter, this report puts a spotlight on how the Division's research laboratories are using cutting edge science and technology to innovate in fields such as wastewater treatment or plastic recycling, translating science into impact.

Of course, the year 2020 was marked by a major crisis that stressed the fragility of population health, the intricate interconnections between the socioeconomic, bio and geo-spheres and the transformative power of digital tools. It also brought into greater focus society's need to pay greater attention to the environment and the need to build more resilient, sustainable systems. These lessons are not lost on TRANSFORM. We are more than ever committed to supporting the development of a circular bioeconomy!

In conclusion, I thank all Division staff members for their dedication, especially during the deepest moments of the crisis, and wish you a pleasant read of TRANSFORM division's annual report.

Michael O'Donohue
Head of TRANSFORM Division

Characterization of biomass materials and process mechanisms

To characterize the components of biomass material from cell level up to the whole plant, our scientists use an array of advanced imaging techniques to unravel and track how proteins change structure in response to process mechanisms, and especially enzyme-driven processes. This work serves to design and discover new functionalities for valuable biomass material.

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Typical Stemphylium lucomagnoense spores.

Characterization of the enzymatic repertoire of marine fungi

Read more

Wissal B-A *et al.*

Characterization of the CAZy repertoire from the marine-derived fungus Stemphylium lucomagnoense in Relation to Saline Conditions

Marine Drugs . 2020 - https://doi.org/10.3390/md18090461

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Context

Several marine-derived fungi have conserved the ability to survive and thrive on land. Their enzymatic machinery, purpose-adapted to degrade plant biomass in environmental conditions like high salinity and neutral-to-alkaline pH that are very different from those found on land, remains largely unknown. However, the enzymes that these fungi produce could be constructively exploited by industries that work with high-salinity and high-alkaline conditions.

Results

Working in partnership with the University of Sfax–Tunisia, Bangalore Institute of Bioinformatics–India, and the CNRS, we screened twenty marine fungi isolated on the Tunisian coast. A combination of microbiology and proteomics approaches selected Stemphylium lucomagnoense for its ability to degrade plant biomass in the presence of sea salt, and identified 51 enzymes belonging to several known lignocellulolytic enzymes families.

The number of enzymes secreted by S. lucomagnoense under different culture conditions was found to shrink by 50%–66% in the presence of sea salt or when growing on seagrass rather than wheat straw. These observations show that sea salt exerts negative pressure on enzyme production and suggest that the S. lucomaganoense secretome is better equipped to degrade land-based plant material or that the set of enzymes required to degrade seagrass is less diversified, likely due to its composition.

In addition, proteomics analysis uncovered evidence pointing to an alginate lyase-type enzyme produced exclusively in the presence of sea salt and that may be used to degrade brown algae polysaccharides, thus supporting the hypothesis that this fungus has adapted to its marine environment. Proteomics analysis of this marine fungus is the crucial way forward to gain foundational understanding of microbial metabolism and adaptation to marine ecosystems.

Future outlook

Moving forward, the next step in this study will be to biochemically and structurally characterize several enzyme targets in order to study the key protein-driven determinants of saline adaptation. All these enzymes make promising targets for further investigation into their biochemical characteristics and their biotechnological potential as biocatalysts for industrial process applications. Looking at the bigger picture, the results of our study offer valuable insights for other fields of research, such as carbon cycling in marine habitats, as well as advancing foundational understanding of marine microbial communities.


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Protein structure as an actionable way to optimize infant formulas

Read more

Halabi A *et al.*

Modification of protein structures by altering the whey protein profile and heat treatment affects in vitro static digestion of model infant milk formulas.

Food & Function . 2020 - https://doi.org/10.1039/d0fo01362e

Halabi A *et al.*
Structural characterization of heat-induced protein aggregates in model infant milk formulas.

Food Hydrocolloids . 2020 - https://doi.org/10.1016/j.foodhyd.2020.105928

This research has been realized through the INRAE and Brittany Regional council-funded PhD thesis by Amira Halabi defended 20 October 2020.

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Context

Infant formula is a breast milk substitute that covers babies nutritional needs. Infant formula and breast milk share a similar composition in terms of macronutrients but a different fine composition and structure, especially on the protein front. Infant formulas are usually based on bovine milk protein ingredients, particularly whey protein. Substituting whey protein with α-lactalbumin and lactoferrin is an actionable way to bring infant formula closer to the protein profile of breast milk. However, the heat treatments applied in infant formula manufacture to guarantee microbiological safety modify the structure of the proteins and may affect their digestibility. Our objective was to study the impact of heat treatments combined with a compositional change in protein fraction on protein structure in model infant formulas and ultimately in simulated in vitro digestion.

Results

Three model infant formulas presenting differentiated protein profiles were heat-treated between 67.5 °C and 80 °C at two dry matter concentration levels. Each of these three parameters affected the kinetics of whey protein denaturation and the structure of heat-induced protein aggregates in the infant formulas. The infant formulas more closely profiled to human breast milk (i.e. with α-lactalbumin and lactoferrin) showed less heat-induced alteration than the infant formulas containing bovine whey protein (mainly β-lactoglobulin). At the same 65 % degree of whey protein denaturation, the structure of heat-induced protein aggregates was dependent on infant formula composition and process time–temperature combination.

In vitro digestion in conditions simulating infant gastrointestinal physiology showed that chyme (food mass partially digested in the stomach) microstructure was dependent on in-food protein structure, forming bigger-sized aggregates with the infant formula containing native casein micelles. These proteins tended to hydrolyze slowly, whereas denaturated lactoferrin was hydrolyzed faster, especially in the gastric phase. Peptide release over the course of digestion was modulated by structure and nature of the source proteins: greater numbers of more digestion-resistant bioactive peptides were released in the infant formula that was compositionally closer to human breast milk.

Future outlook

Using heat treatments and/or source-protein profile as a way to modulate protein structure could be actionable as a route to optimize infant formulas. It would be instructive to assess the physiological impacts (for digestive tract development, microbiota, and so on) of these heat and/or protein-driven modulations.

© https://ioc.eu.com/fr/fiches-produits/pour-le-collage/

Towards rationalising the use of tannins in wine-making

Read more

Watrelot AA, *et al.*
Multimethod approach for extensive characterization of gallnut tannin extracts.
Journal of Agricultural and Food Chermistry . 2020 - https://doi.org/10.1021/acs.jafc.9b08221

Mobilization and impact

A new oenological tannin brought to market by industry partner IOC.

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Context

Winemakers can use 'oenological tannins'–extracts from wine grapes but also from various woods and gallnuts–to improve the quality of their wines. Using tannins helps stabilize colour, prevent haze formation, build taste and improve mouthfeel, and are attracting interest as an alternative to sulfites for prevention of wine oxidation. These properties are shaped by the concentration but also the nature and proportions of the various families of compounds found in these extracts. The international code of winemaking practice defined by the OIV–International Organization of Vine and Wine (http://www.oiv.int/public/medias/6558/code-2019-en.pdf) rules a minimum 65 % polyphenol content, but the codex-endorsed assay methods lack specificity and fail to provide in-depth compositional profiling. New methods purpose-developed to characterize oenological tannins and connect their compositional profiles to use-value properties would be of huge benefit to suppliers of oenological tannins and the winemakers who use them, enabling them to improve the quality of the wines they bring to market.

Results

To address this challenge, we developed an analytical strategy that articulates advanced chromatographic techniques (HPLC-DAD-MS and HPSEC-DAD) working in complementarity with nuclear magnetic resonance spectroscopy. Applying this multi-method approach on three commercial gallnut tannin extracts revealed key differences in the structures, proportions and molecular weight distributions of their constituents (gallic acid, digallic acid, trigallic acid, and gallotannins containing1–17 galloyl residues per glucose molecule).

These compositional differences have little impact on the antioxidant properties of the tannins (which seem to be primarily connected to total tannins content) but they may have impacts on their other properties–crucially, their organoleptic properties (astringency, bitterness, colour, and more).

One of the extracts analyzed was shown to be a compellingly pure and powerful antioxidant, prompting our industry partner on this project to select and fast-track the extract to market.

Future outlook

Similar analyses are ongoing on tannins from other plant sources, notably oak wood, obtained through alternative extraction processes. Our industry partner is set to exploit these tannin composition–sensory properties linkages to rationalize the process of developing new products better geared to commodity-chain and end-consumer demand.

©Clélia Villemin

Chemical deamidation or enzymatic modification of gluten proteins influences their patterns of interaction with immune cells.

A cellular model sensitively responds to biochemical modifications of allergens

Read more

Villemin C, *et al.*

Deamidation and enzymatic hydrolysis of gliadins alter their processing by dendritic cells *in vitro*.

Journal of Agricultural and Food Chemistry . 2020 - https://doi.org/10.1021/acs.jafc.9b06075

Tranquet O, *et al.*

Allergic reactions to hydrolysed wheat proteins: clinical aspects and molecular structures of the allergens involved.

Critical Reviews in Food Science and Nutrition . 2020 - https://doi.org/10.1080/10408398.2018.1516622

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Context

Industrial processes enabling the diversification of food protein functionalities can modify their allergenicity. In animal models, enzymatic hydrolysis of gliadins, the major wheat allergens, reduces their allergenic potential or leaves it unchanged, whereas deamidation of gliadins was associated with severe allergic reactions.

We do not have enough hard science to link the biochemical characteristics of food proteins with their capacity to direct an immune response towards allergy or tolerance. Compounding the issue, there is still no validated *in vitro* test that could serve to assess the effect of food protein modifications on allergenicity and–ultimately–to assess the risk of new engineered ingredients triggering new allergies.

Dendritic cells are involved in capturing and presenting allergens to immune-system cells. Dendritic cell–food protein interaction is considered key as an early event that directs immune response towards tolerance or allergic sensitization.

Results

Working in collaboration with Dutch researchers on the COST (Cooperation in Science & Technology) Action ImpARAS (Improved Allergenicity Risk Assessment Strategy), we brought *in vitro* dendritic cells into contact with native, enzymatically-hydrolyzed or deamidated gliadins. Native gliadins have an immunostimulatory effect: they induce dendritic cell expression of several compounds involved in initiating immune responses–including compounds that help activate T-cells or help dendritic cells migrate towards the organs where allergic response will express.

Enzymatic hydrolysis and, to a lesser extent, deamidation lead to a decrease in the molecular weight of gliadins. In both cases, there is a loss of native gliadin epitopes, i.e. of antigenic sites in wheat allergy, but deamidation also generates new epitopes.

These modifications increase gliadin uptake and breakdown by dendritic cells, and mask the immunostimulatory effect of the gliadins. Therefore, both enzymatic hydrolysis and deamidation are found to heavily modify certain key properties of gliadins and gliadin–dendritic cell interactions.

Future outlook

This high-potential *in vitro* model needs however to be optimized to reproduce *in vivo* and clinical-practice observations and enable implementation of rapid and readily operable methods for a priori assessment of the allergenicity of functionally-modified ingredients. Progressing the model hinges on a validation phase with reference proteins known to be either highly or rarely allergenic.

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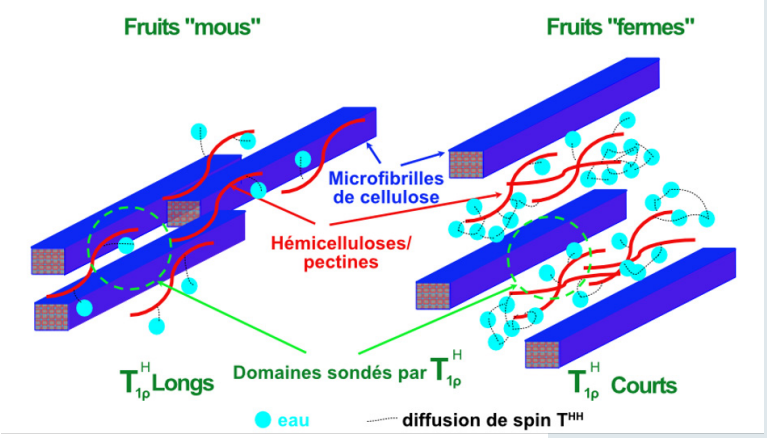
Polysaccharides play a role in firming up apples

Read more

Lahaye M, *et al.*

Cellulose, pectin and water in cell walls determine apple flesh viscoelastic mechanical properties.

Carbohydrate Polymers . 2020 - https://doi.org/10.1016/j.carbpol.2019.115768



©Marc Lahaye
Schematic illustration of the cellulose fibres and cell-wall polysaccharides (pectins, hemicelluloses) in soft and firm fruits based on dynamic parameters measured by solid-state NMR ($T_{1\rho}^H$, T_{HH}).

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Context

The NOVA2cidre joint technology unit and the IFPC (French Institute for Cidermaking) have been working to understand the root cause of variability in cider-apple pressability. The juice yield extracted by pressing depends on the firmness of the fruit at grating and at filtration when it goes through the press. These mechanical properties stem from the assembly and arrangement of the apple cell-wall polysaccharides but also from tissue-scale fluid flow in the gratings and from the pattern of cell-wall deformations occurring through the process. To understand the variability in apple batches, we need to first unravel the complex factors associated with the mechanical properties at work at these different scales.

Results

The firmness of six apple varieties was measured on fresh crop and after destructuring by freeze–thaw cycles, and the results showed distinct patterns of rheological behaviour between varieties. Analysis of cell-wall polysaccharide chemistry revealed fine structures of the pectins that add or subtract firmness.

Structural and dynamic parameters measured by NMR (degree of crystallinity in the cellulose, relaxation and diffusion in solid media) were also linked to firmness and showed that the crystalline organization of the cellulose plays no role in the firmness of the fruit. Furthermore, when the cellulose fibres were more loosely organized in the cell walls (faster relaxation), the pectins were more hydrated (slower diffusion) and the fruits proved firmer. These results clearly indicate that mechanical properties of the fruit are governed not only by fine-grained polysaccharide structure and polysaccharide group–polysaccharide group interactions, but also by how well these different polysaccharide groups (especially pectins and cellulose) are organized and hydrated.

Future outlook

The measurement of dynamic (interactional) structural parameters in various types of native or reconstructed complex plant macromolecules assemblies will be developed further through thesis work to consolidate the NMR-enabled insight.

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Divide and characterize: partial hydrolysis of a wheat protein

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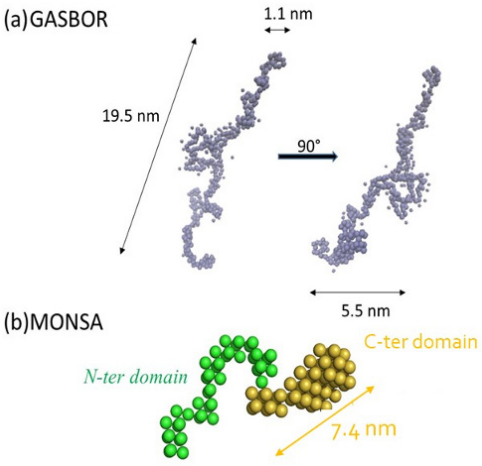
Sahli L *et al.*

New exploration of the γ-gliadin structure through its partial hydrolysis.

International Journal of Biological Macromolecules . 2020 - https://doi.org/10.1016/j.ijbiomac.2020.09.136



©Line Sahli

Low-resolution models of the γ-gliadin obtained from small-angle X-ray scattering curves and displayed by (a) GASBOR (2) and (b) MONSA (3) software.

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Context

In the grain, wheat storage proteins form assemblies in the grain called protein bodies. These assemblies are formed by interactions that depend on biological microenvironment but also on intrinsic structural characteristics of the proteins, whose structures have not been resolved yet. In an effort to probe these characteristics, we set out to study a wheat protein, γ-gliadin, and each of its N-terminal (N-ter) and C-terminal (C-ter) domains obtained after partial hydrolysis. These proteins are known to show broad structural and conformational flexibility, yet the roles played by N-ter and C-ter are unclear. The goal of this research was to mobilize advances in the field of intrinsically-disordered proteins to revisit the wheat gliadin structure.

Results

Biochemical and structural methods (dichroism spectra, small-angle X-ray scattering, ab initio computational modelling) were developed to determine whether or not γ-gliadin is intrinsically disordered. Based on our evidence, we learned that the wheat γ-gliadin is partially disordered–with a disordered N-ter domain and an ordered C-ter domain. We went on to propose a new three-dimensional model of γ-gliadin on the basis of *ab initio* computations and small-angle X-ray scattering curves (Figure 1). We also found that the disordered N-ter domain is resistant to enzymatic hydrolysis, for reasons that remain unknown. Chemically-engineered short peptides mimicking the repeated motifs of amino acids in the N-ter domain showed high structural similarity with the whole N-ter domain. These synthetic peptides could serve as models to make headway in understanding N-ter resistance to hydrolysis and its wider contribution to the wheat storage proteins assembly systems.

Future outlook

A better comprehension of gliadin structure may lead to greater insight into the way gliadins self-assemble during synthsis in wheat grain. This in turn could provide us with a deeper understanding of how the grains respond to cereal commodity processing.

Apple juice found to contain novel phenolics with surprising tanning properties

Read more

Castillo-Fraire CM *et al.*

Preparative fractionation of 5′-O-caffeoylquinic acid oxidation products using centrifugal partition chromatography and their investigation by mass spectrometry.

Journal of Chromatography A . 2019 - https://doi.org/10.1016/j.chroma.2019.01.071

Castillo-Fraire CM *et al.*

Interactions between polyphenol oxidation products and salivary proteins: Specific affinity of CQA dehydrodimers with cystatins and P-B peptide.

Food Chemistry . 2020 - https://doi.org/10.1016/j.foodchem.2020.128496

Partnerships

This study materialized through thesis work by C.M Castillo-Fraire and through a collaborative venture with the REQUIMTE/LAQV Laboratory at University of Porto in Portugal.

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Context

Cider apples contain high amounts of phenolic compounds, which are nutritionally significant substances. Using cider apples could prove a pertinent way forward for developing innovative high-nutritional-value apple juices, but not if it compromises organoleptic quality, such as excessive astringency due to the tanning properties of certain polyphenols complexing with specific salivary proteins like proline-rich proteins (PRPs).

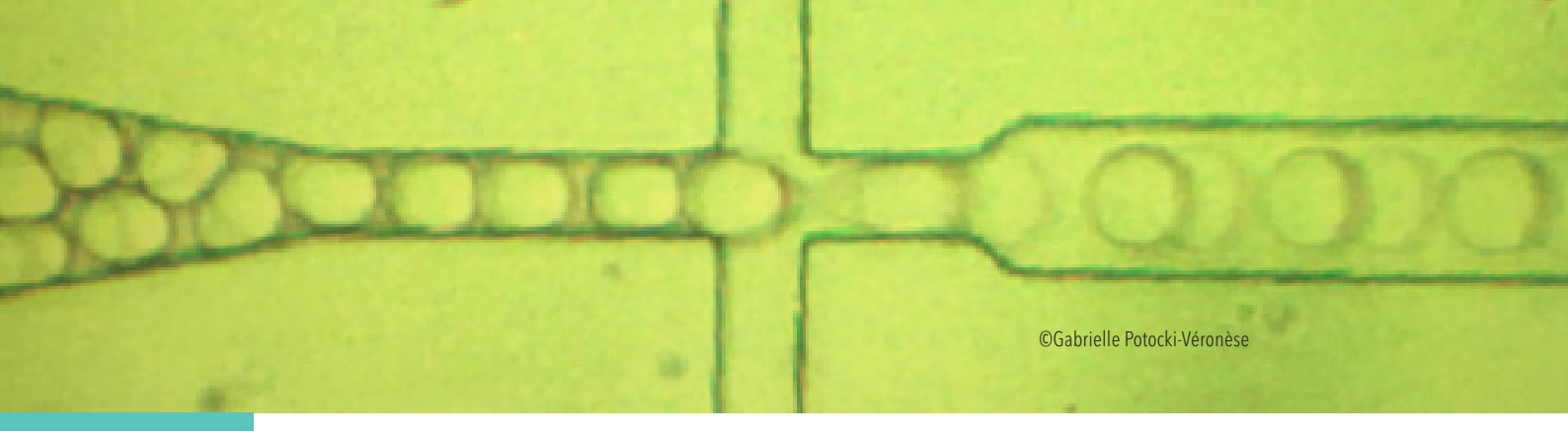
When apples are processed into juice, the enzymatic oxidation of polyphenols generates new polyphenolics ('oxidation products') with original structures, but little is known about their nutritional and organoleptic properties. To address this gap, we set out to characterize the structures and study the tanning properties of products resulting from the oxidative dimerization of chlorogenic acid, the main phenolic acid in apple juice.

Results

Precipitation of various salivary proteins by a mixture containing several chlorogenic acid oxidation products was measured, and we found that these oxidized phenolics significantly interacted with statherin/P-B peptide and cystatins whereas precipitation was significantly weaker for the PRPs. This original behaviour was subsequently confirmed by fluorescence quenching experiments performed with pure proteins and purpose-purified oxidized phenolics. To the best of our knowledge, the strong and specific affinity of phenolic compounds for these two families of salivary proteins (P-B peptide and cystatins) had never previously been observed, and their relatively low ability to precipitate PRPs was also unexpected. These results strongly suggest that the tanning effect of some polyphenols–in this case oxidation products–may more specifically concern other salivary proteins than PRPs.

Future outlook

Work ongoing and in the pipeline aims to explore the tanning properties of oxidation products from other polyphenolic families of polyphenolic compounds (catechins, procyanidins), and to press ahead with sensory analysis to investigate the material effects of these specific interactions on perceived in-mouth astringency.



©Gabrielle Potocki-Véronèse

Microfluidics to deliver ultra-high-throughput screening of microbial functions

Read more

Tauzin AS *et al.*

Investigating host-microbiome interactions by droplet based microfluidics.

Microbiome . 2020 - https://doi.org/10.1186/s40168-020-00911-z

Mobilization and impact

This droplet microfluidics technology is up and running and accessible to the wider scientific community via the Toulouse Biotechnology Institute-hosted PICT-ICEO platform, an IBISBA EU research infrastructure for translational biotech R&D&I

Context

Microbial ecosystems are a gold mine of opportunity for the prospecting of new functions with biotechnology value that can then be optimized by protein engineering to support industrial biotechnology applications. However, a majority of species that make up these complex communities are not yet cultivated, which makes them a black box system whose inner functions are difficult if not impossible to study. Indeed, today's automated microbiological screening strategies on solid media or microplates require large quantities of substrate and litres of culture media, which make them incompatible with investigations into certain functions that require the use of expensive reagents.

Within the framework of the H2020 Catsys and Metafluidics projects, researchers from TBI–Toulouse Biotechnology Institute working in tandem with the Hollfelder group at the University of Cambridge have pioneered novel droplet microfluidics approaches to miniaturize and speed up screening capacities and explore the limitless functional potential of microbial ecosystems. This new frontier marks a major opportunity for progress, especially for deciphering the human gut ecosystem, which is where microbiota–host interactions essentially shape and dictate our global health.

Results

The scientists have combined droplet-based microfluidics with metagenomics to develop ultra-high-throughput screening strategies that can probe the functional diversity of thousands of bacterial genomes in the space of just an hour of work– and all with less than a milligram of substrate sample. These miniaturized picolitre-scale techniques are generic enough to compatibly support the discovery and engineering of a huge variety of intracellular and extracellular enzymes and metabolic pathways that hold significant value as starting points for human and animal health, for bioremediation of polluted ecosystems, and countless other applications. This work has already led to the discovery of new pathways of human glycan degradation by intestinal bacteria.

Future outlook

Such developments offer wide-reaching perspectives for functional metagenomics, enzyme and strain engineering, microbial culturomics and holobiont research, and thus open up a new era of ultra-high-throughput discovery and optimization of microbial enzymes, metabolic pathways, species and even consortia. Results obtained on the human intestinal microbiota already offer new perspectives for understanding the mechanisms involved in chronic intestinal diseases and developing new preventive and curative strategies.

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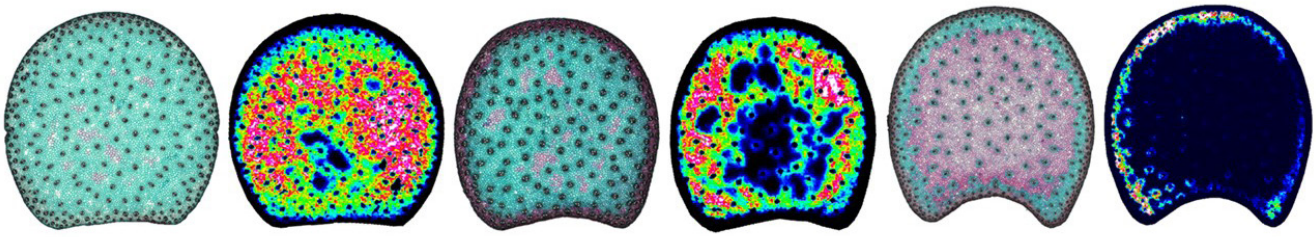

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A direct image of lignocellulosic cell walls degradability

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Arnaud B *et al.*

Imaging study by mass spectrometry of the spatial variation of cellulose and hemicellulose structures in corn stalks.

Journal of Agricultural and Food Chemistry . 2020 - https://doi.org/10.1021/acs.jafc.9b07579

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Context

Methodizing and improving lignocellulose transformation is a pivotal strategic challenge for efficient biorefineries. Our research attempts to better understand and prioritize the factors that shape recalcitrance to enzymatic degradation. The recalcitrance of a biomass stems from multiple interplaying factors: lignin content plays a key role, but heterogeneous degradation has been correlated to cell wall structure and composition and to the wider histological and biochemical heterogeneity of lignocellulosic substrate. Our work breaks new ground by employing a novel mass spectrometry imaging approach to directly observe the local-point hydrolyzability of the crop tissue. This approach goes beyond mapping of lignified tissue, as it measures the joint impact of lignin and polysaccharides in the tissue on accessibility to enzymes and efficiency of the enzymatic action.

Results

Mass spectrometry imaging is an emerging technique that provides dense information on localized structure and chemistry at micrometre scale. Our team has pioneered the route to coupling this technique with enzymatic treatment to gain *in situ* access to cell-wall-polysaccharide structures. Here, this approach was mobilized to give an image of cell wall degradation at whole-stem-section scale. At the same time, it captured the histological and biochemical heterogeneity of the lignocellulosic substrate and the resulting localized impacts on its biodegradability.

We studied two maize genotypes at four stages of maturity that presented contrasting characteristics in terms of bioconversion process and lignification pattern. Several enzymes were selected to target the major cell-wall polysaccharides. In both genotypes at every growth stage, enzymatic degradation occurred preferentially in weakly-lignified cell walls, and this pattern was reproduced in all the structural groups of the polysaccharides investigated. These results line up with previous studies to show that lignin acts as a major physical barrier preventing enzyme access to their substrate. They also revealed that certain non-cellulosic polysaccharides follow a heterogeneous distribution dictated by their class of structure. Finally, our findings suggest that these non-cellulosic polysaccharides are not all deposited in the cell walls at the same plant growth stages.

Future outlook

This research is set to press ahead with the same approach to investigate the role played by small phenolic acids bound to cell-wall components in lignocellulosic plant tissue recalcitrance to degradation.

©INRAE -Bertrand Nicolas

Plant-cell morphology mapped by greyscale-level granulometry

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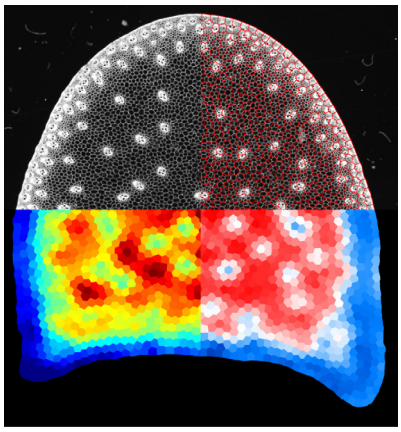
Legland D *et al.*

Parametric mapping of cellular morphology in plant tissue sections by gray level granulometry.

Plant Methods . 2020 - https://doi.org/10.1186/s13007-020-00603-7



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Global workflow-steps for parametric mapping computation. Original image in greyscale levels. Automated region-of-interest contouring. Curve plots of the geometric mean sizes of cells in each region (from blue to red). Mapped representation of the first explanatory axis in the principal component analysis (negative values in blue, positive values in red).

Contact

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Context

The cellular morphology of plant organs is strongly related to other physical properties such as the size, shape, mechanical properties or chemical composition of the plant or plant organ. Cellular morphology often varies depending on type of tissue or position in a specific tissue. A common challenge in quantitative plant histology is to quantify not only the cellular morphology but also how it varies within the image or the plant organ. Image texture analysis is a fundamental part of the image analysis toolbox that has proven invaluable for describing plant cell morphology when individual cells are hard to isolate. As a rule, it is applied at whole-image scale, which narrows the scope for analysis of spatial heterogeneity.

Results

We developed a method that generates a parametric map of cellular morphology in images of plant tissues by working up from macroscopy or microscopy images. The workflow starts by segmenting the image into a huge number of tessellated regions of interest using a centroidal Voronoi diagram, which produces a set of hexagonal regions contouring the plant organ, and then using grey-scale mathematical morphology to extract quantified image texture features from each region. The resulting granulometric curves can be interpreted either through multivariate data analysis (principal component analysis) or by computing descriptive-metric statistics such as the average size or localized heterogeneity of the cells. The parameters are computed for each region-of-interest, making it possible to graph a visual map of the variations in image texture. We have employed this methodized workflow to map cell morphology on macroscopy-scale image cross-sections of plant-stem internodes. The resulting parametric maps give a graphed picture of the in-stem variations in cellular morphology, making it possible to connect these variations in cellular morphology to the in-stem pattern of tissue distribution.

Future outlook

The results inform understanding how the cellular morphology is related to genotypic and/or environmental variations, and to clarify the relationships between cellular morphology and other key plant tissue descriptors, such as chemical composition of the cell walls. The method yields quantitative data, so results can readily be integrated to produce representative statistical models of a single plant tissue or organ. The workflow is essentially generic, so it can be applied to other types of images, including images from foods that present a clear visual texture.

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Constructed wetlands for wastewater management systems—revisited in depth

Read more

Martinez-Carvajal GD *et al.*

Assessment of X-Ray computed tomography to characterize filtering media from vertical flow treatment wetlands at the pore scale.

Science of the Total Environment . 2019 - https://doi.org/10.1016/j.scitotenv.2020.136510

Mobilization and impact

Publication–under MIT license–of the image analysis program developed by German Dario Martinez-Carvajal: https://gitlab.irstea.fr/reversaal/wetlands_xray_tomopgraphy

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Context

Constructed wetlands are the most widespread decentralized wastewater treatment technology used in rural France, with more than 5,000 facilities currently in operation (accounting for 20 % of small wastewater treatment plants). This treatment technology was introduced in France in the 1990s. Because it is relatively recent, it is difficult to predict the lifespan of these treatment systems. French constructed wetlands are composed of two treatment stages, each with several filters that are fed alternately in order to maintain rest periods. The filters are filled with gravel (1st stage) and sand (2nd stage) and planted common reed (*Phragmites australis*). The first-stage filters are fed with raw wastewater, and a deposit layer forms on the surface. This configuration greatly simplifies the task of sludge management, where removing of the surface deposit layer is only required once every ten to twenty years. In order to predict the life span of the treatment wetland, it is necessary to have a reliable method for observing and characterizing the deposit layer.

Results

Previous research conducted within REVERSAAL has revealed that a network of macropores inside the deposit layer is likely able to explain how the *biomantle* (combined depth of the deposit layer and the first few centimetres of filter material) maintains good aeration and good filter functioning.

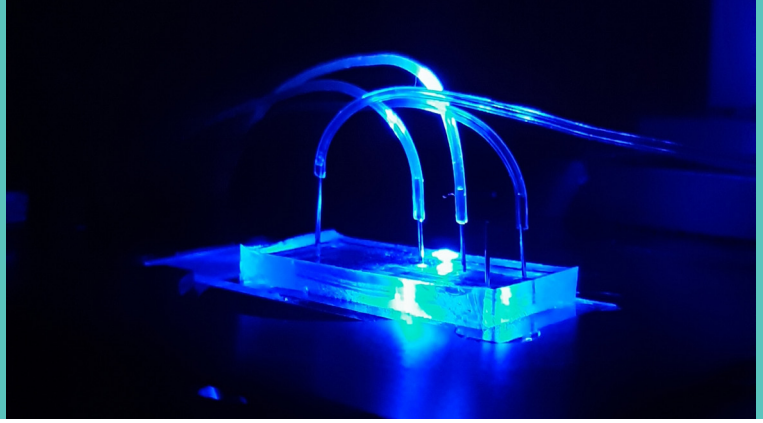
X-ray tomography made it possible to directly observe the macropores in the biomantle and quantify their size variations during different operational phases. Research has confirmed that a 7-day rest period is crucial as it restores the infiltration capacity of the deposit layer and brings air into the subsurface environment.

The combined use of X-ray tomography, a special data extraction protocol, and a new image processing algorithm adapted to the study of treatment wetlands marks a major step forwards in the observation and understanding of the formation of the biomantle in French vertical flow treatment wetlands.

The image processing algorithm is open-source and available to the greater scientific community under a MIT license

Future outlook

The method developed here has been recently implemented on the REFLET platform that hosts a semi-industrial scale pilot dedicated to the long-term study of deposit layer formation. It will serve as a benchmark measurement alongside other sensor technologies designed to give useful feedback to system operators. Future research activities will continue to improve the prediction of treatment wetland life span. Several research projects are available to a broad scientific community.



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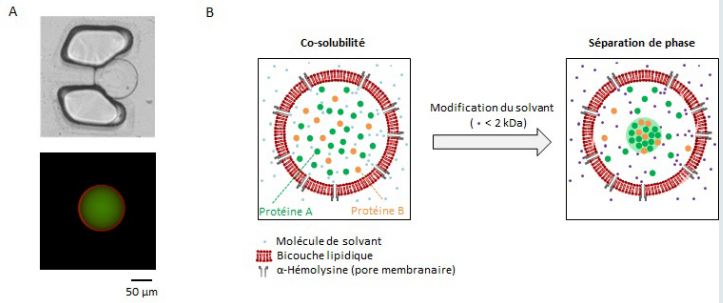
Biopolymer assembly mediated by biomimetic microreactors

Read more

Cochereau R *et al.*

Semi-permeable vesicles produced by microfluidics to tune the phase behaviour of encapsulated macromolecules.

Journal of Colloid and Interface Science . 2020 - https://doi.org/10.1016/j.jcis.2020.07.022



@Rémy Cochereau
Microreactors–Scheme

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Context

Biomass is a precious asset. Optimal upvaluing of biomass requires a firm grasp of the assembly mechanisms of the biopolymer scaffolds. These biopolymers can form a huge spectrum of different assemblies, from crystalline structures to amorphous aggregates and back to highly-ordered fibre architectures. These assemblies are formed by interactions that depend on the molecular properties of the biopolymers but also on the governing physical–chemical conditions (pH, temperature, ionic strength, and so on). The thermodynamic pathway adopted by the system can also play critical role in shaping its final structural state. In an effort to methodize this thermodynamic pathway and make it custom-tuneable, we purpose-developed a set of microreactors in a design inspired by living cells.

Results

The design process used microfluidics to produce and trap giant unilamellar vesicles (GUV) encapsulating macromolecules. The GUVs were generated from dual-compartment emulsions that are diameter-tuneable within a 20µm–110µm range. We demonstrated that their permeability to ions and small (< 2 kDa) molecules could be made tuneable using a pore-forming protein called α-hemolysin. These vesicles can be purposed to (i) encapsulate biopolymers in their ideal solubilization conditions, (ii) modify the quality of the solvent (pH, ionic strength, reducing agents, and more) through controlled exchanges across the lipid membrane, and (iii) probe phase transitions and their allied structural properties. We used these biomimetic microreactors to unlock evidence of a liquid–liquid phase separation process, dubbed coacervation, in wheat protein dispersions.

Future outlook

Now, they are ready to be mobilized to study the structure and dynamics of biopolymer complexes and start to construct a firm understanding of their underlying stucturational pathways. We anticipate this research as a starting point to innovate the use of controlled food-protein assemblies to encapsulate bioactive compounds or to texturize food products. The microreactors developed here could also be mobilized to serve research into the enzymatic hydrolysis of complex assemblies.

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Characterization of the structure and biosynthesis of mannans in wheat

Read more

Verhertbruggen Y *et al.*

The TaCslA12 gene expressed in the wheat grain endosperm synthesizes wheat-like mannan when expressed in yeast and Arabidopsis.

Plant Science . 2021 - https://doi.org/10.1016/j.plantsci.2020.110693

Verhertbruggen Y *et al.*

Challenging the putative structure of mannan in wheat (Triticum aestivum) endosperm.

Carbohydrate Polymers . 2019 - https://doi.org/10.1016/j.carbpol.2019.115063

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Context

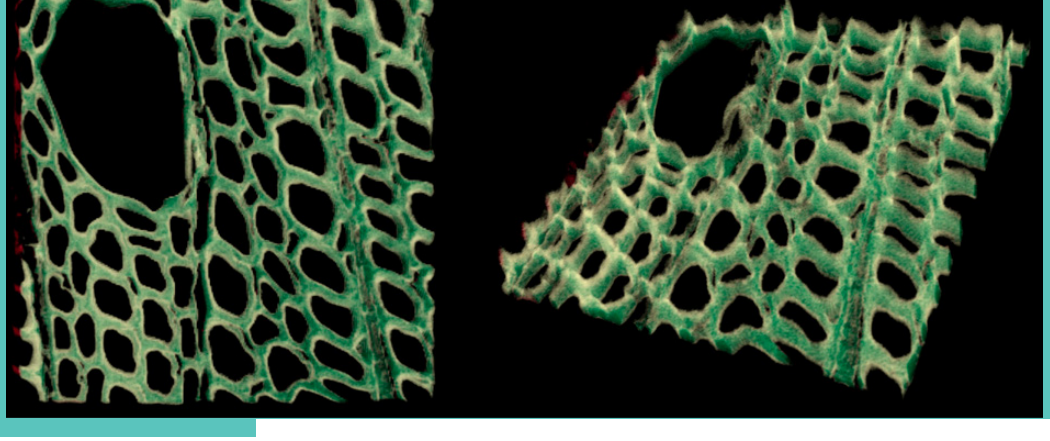
The cell wall polymers in cereal grains have attracted investigation on several fronts: for their nutritional benefits (dietary fibre), their adverse effects on the digestive health of certain livestock, and their effects on wheat grain workability. Mannans are polysaccharides (complex carbohydrates) found in plant cell walls, but they have been under-researched in wheat endosperm. In some plants, they accumulate in storage organs (an example is galactomannans in guar seeds). The structure of mannans influences their properties (solubility, water absorption, gelling). Mannan content and structure vary across different plant biomasses. The mannans found in cereal grains had never before been isolated or studied. The EU-funded MANAN project set out to elucidate the structure, and biosynthesis of mannan in wheat and its role in grain development.

Results

Wheat mannans were purified and characterized using a combination of biochemical and physical–chemical methods to determine their composition, their structure, and their molar mass. Challenging the previous literature, wheat mannans were found to consist of relatively short chains of β(1,4)-linked mannose with little acetylation. Immunolabelling showed that the wheat mannans predominantly localized to the walls of the endosperm (the storage tissue from which white flour is extracted), and that they emerged early during endosperm development but were absent from the first cells to form. Functional genetics methods identified a gene expressed specifically in the endosperm that, when introduced into an organism lacking mannan, led it to produce mannans that shared a similar structure to that of wheat mannan.

Future outlook

From a basic science perspective, this work set out to unravel the function played by mannans in plant organs. From a more applied science perspective, the aim is to determine the role played by mannans in the processing and end-use properties of cereal products, such as their (visibly negative) effects on digestive health in livestock.



©Yassin Refahi
Cell walls not modified by hydrolysis (green) are displayed together with the cell walls that were deconstructed during hydrolysis (yellow). Small segments of cell walls (red) visible on the left-hand side come from a slight movement of the sample in the x-y coordinate plane.

4D cellular imaging of the hydrolysis of lignocellulosic biomass

Read more

Zoghlami A *et al.*

Three-dimensional imaging of plant cell wall deconstruction using fluorescence confocal microscopy.

Sustainable Chemistry . 2020 -https://doi.org/10.3390/suschem1020007

Mobilization and impact

In line with our plan for open science, the scripts are available online *via* the FARE lab's GitLab repository.

This study was published in Sustainable Chemistry and the data analytics scripts can be found online at : https://gitlab.com/farelab/teamyr/publications/zoghlami_et_al_sus_chem_2020

Contacts

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Context

The conversion of lignocellulose biomass (LB) as a natural renewable resource into bioproducts can be a solution to concerns over effects of climate change and increasing demand for biobased chemicals and materials. However, LB is naturally recalcitrant to enzymatic conversion, which hinders economic and sustainable conversion of LB. Research conducted over the past decades allowed identification of a number of physical-chemical factors underlying LB recalcitrance. The identified parameters are specific to biomass species and pretreatment type. Moreover, little is known about structural factors at cellular and tissular scale, mainly due to the technical challenges to acquire three dimensional time series (4D datasets) and to develop computational tools to process 4D images in order to extract structural parameters from the data.

Results

To address this gap, we developed a 4D imaging protocol for tracking the enzymatic hydrolysis of LB samples. This protocol lays out instructions for setting up an incubation chamber in which the sample is immersed in an enzymatic cocktail held at a constant temperature of 50 °C. Fluorescence confocal microscopy is used to acquire images with parameters optimized to minimize photobleaching. Using the protocol, time-lapse images of the cell wall enzymatic hydrolysis can be acquired as a first starting-point for studying enzymatic deconstruction at cellular and tissular scale.
To illustrate the potential advantages of using this protocol to achieve a quantitative characterization of LB deconstruction, we implemented a segmentation and tracking method to show the possibility of extraction of the dynamics of tissular scale changes. This method allowed tracking individual voxels' intensity values in 4D image datasets and quantifying the evolution of their values during hydrolysis time with an unprecedented detail. The pipeline was used to quantify the tissular scale deconstruction on poplar samples showing over 50 % cell wall deconstruction on the collected datasets during 24 h enzymatic hydrolysis.

Future outlook

We developed an imaging protocol for acquiring time-lapse series of LB during enzymatic hydrolysis, and further research is being conducted to analyse the 3D data in order to quantify various structural parameters at cellular level and at tissue level. We ultimately aim to study the relationship between these parameters and biochemical data during hydrolysis in order to determine whether these parameters can be used to predict and model the bioconversion potential of LB.

Rationalized food and food-process engineering

Conscious of their mission to produce clean, healthy, tasty food, TRANSFORM scientists study ways to stabilize wine and wine aroma while cutting down the processing aids and additives typically used in conventional winemaking, or the ways that food-ingredient variability translates into the final quality of commodity products and processable foods like fruit juice and apple purée.

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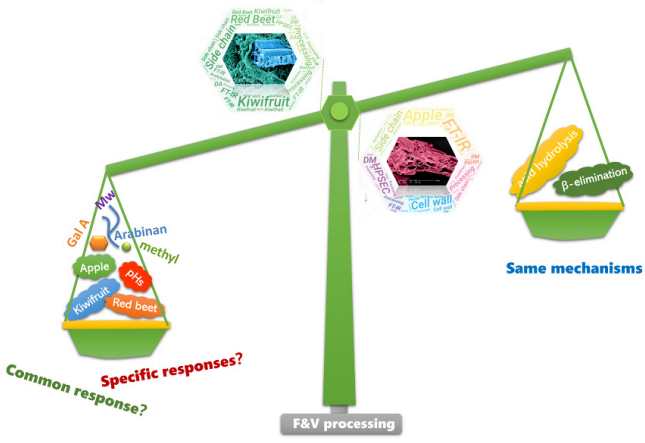
Plant cell-wall diversity explains the effects of cooking on fruit and vegetables

Read more

Liu X *et al.*

Modification of apple, beet and kiwifruit cell walls by boiling in acid conditions: Common and specific responses.

Food Hydrocolloids . 2021 - https://doi.org/10.1016/j.foodhyd.2020.106266



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Context

Why do some fruits and vegetables lose their texture when cooked while others retain their shape and crunch after simmering for over an hour? There are two interacting factors–the structure of the cell wall, and the micro-environmental tissue conditions, chiefly pH which is known to affect both the type and intensity of degradation. Heat treatment softens plant foods, due to the degradation of pectins, which are fragile cell wall polymers in acidic and neutral pH environments. Pectins undergo two major degradative mechanisms: acid hydrolysis, and β-elimination. To determine whether different degrees of softening in fruits and vegetables are due to their cell-wall structure or to the processing conditions–especially pH–employed, cell walls of apple, beetroot, and kiwi, which are known to show different behaviours in response to heat processing, were isolated and then exposed to boiling at pH2.0, pH3.5, and 6.0. The originality value added here is that cell-wall structure and pH were able to vary independently.

Results

All cell walls showed pectin loss whatever the treatment applied. Apple cell wall proved the most sensitive to degradation in both strongly acidic (pH2) and neutral (pH6) process environments, whereas beetroot cell wall proved the most sensitive to degradation in fairly acidic (pH3.5) conditions. Kiwi cell wall, which is relatively low in pectins, proved the least degradation-sensitive whatever the pH.

All cell walls showed less extensive depolymerization of pectins in the strongly acidic pH3.5 condition. Treatment in the neutral-condition pH6.0 medium degraded the pectin backbone by β-elimination, leading to the extraction of small molecules, especially in kiwi. Treatment in the strongly-acidic pH2.0 medium hydrolyzed the pectin sidechains but produced solubilized polysaccharides with a higher hydrodynamic volume, especially in apple.

Future outlook

This study revealed that different plant-food species show substantially different heat-processing behaviours. Considering each species with its own specificities will help to improve the quality of processed fruits and vegetables by adapting the processing conditions employed. The cooking process route can use pH to control and modulate the loss of texture–either to accelerate it or to slow it down.

We anticipate this research as a starting point to guide further study on interactions between cell-wall pectins and cooking conditions, and to raise prospects for refining the functional properties of plant-based foods.

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How fried foods 'drink oil—now explained

Read more

Touffet M *et al.*

Revisiting the mechanisms of oil uptake during deep-frying.

Food and Bioproducts Processing . 2020 - https://doi.org/10.1016/j.fbp.2020.06.007

Mobilization and impact

These results were part of the output from Fry'In 17, an FUI-funded [one-time cross-ministry funding package] collaborative research project involving industry partners Lesieur, Seb, Adventys and Ethera. Prototype batch fryers have been built that can prevent oil uptake or even withdraw the oil that has soaked the product.

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Context

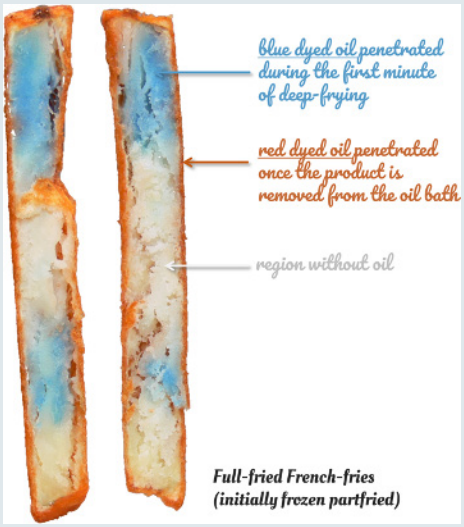
The popularity of French fries predates the French Revolution, but the consumption of deep-fried potatoes and other parfried-frozen products has only grown during the last years. It was long thought that the mechanisms of oil uptake in frozen French fries were similar to fresh-cut potatoes, but this is far from the truth– the oil penetration profiles are quite different, with a majority of the oil disappearing out of view into cavities below the crust reaching the core eventually.

Results

Frozen par-fried foods are typically characterized by advanced food-tissue damage. The cracks and fissures grow across length and width during deep-frying. In the first minute of deep-frying, the fry ends are well in advance of the middle so that steam can flow under the crust to both ends, where it escapes, and the frozen core, where it condensates. These processes have been imaged and modelled in 2D, and they are found to produce an uneven pressure field during deep-frying that can create powerful capillary suction over the first 40–60 seconds. It is easy to evidence how this mechanism can penetrate oil into all parts of the fries, even when wet, by half-immersing frozen French fry in a bath of colour-dyed oil. Oil penetration is observable at the core and up to several centimetres above the line of immersion.

Future outlook

Oil penetration in par-fried frozen fries can thus be driven by two kinds of control: an enthalpic control and an entropic control. With this insight, it is now possible to specifically adapt oil uptake reduction strategies to either par-fried frozen or fresh-cut fries.



Emerging the oil penetration mechanism in a par-fried and frozen French fry by immersion in a series of colour-dyed oil baths.
©Olivier Vitrac

©Vincent Farines - INRAE

SO_2 and yeasts in alcoholic fermentation and wine science

Read more

Ochando T *et al.*
Comprehensive study of the dynamic interaction between SO_2 and acetaldehyde during alcoholic fermentation.
Food Research International . 2020 - https://doi.org/10.1016/j.foodres.2020.109607

Aguera E *et al.*
Comprehensive study of the evolution of the gas–liquid partitioning of acetaldehyde during wine alcoholic fermentation.
Journal of Agricultural and Food Chemistry . 2018 - https://doi.org/10.1021/acs.jafc.8b01855

Mobilization and impact

This research has led to two published papers (see further down), an oral communication at the November 2018 International Congress on Grapevine and Wine Sciences in Logroño, Spain, and a presentation at SITEVI 2019 in Montpellier, France, and a recent write-up was recently submitted to the wine-and-vine trade journal *La Revue des Œnologues*.

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Context

SO_2 has long been used in winemaking as a barrier against oxidation and undesirable bacteria throughout the entire vinification process, from harvest through to bottling. However, producers and consumers are now moving towards wines with less or no SO_2 input (tagged 'natural' or no-SO_2 wines). There is little hard science on the effects of winemaking with reduced SO_2 doses, INRAE–SPO and the INRAE–Pech Rouge station devised a project to make headway in understanding the effects of SO_2 over the course of alcoholic fermentation.

Results

The project involved assessing the impact of SO_2 additions in grape must on fermentation kinetics and aroma production. We used an online monitoring system with hour-to-hour measurements to track fermentation kinetics and fermentative aroma production.

SO_2 input had little impact on fermentation kinetics when added at less than 25 mg/L but clearly increased the lag-phase period when added at more than 25 mg/L. This 25 mg/L threshold marks a significant shift in yeast metabolism: (i) when SO_2 is added at less than 25 mg/L, the yeast produces SO_2 in amounts that decrease with initial SO_2 content in the grape must, (ii) at 25 mg/L added SO_2, there is no variation in SO_2 in the fermenting juice and a greater accumulation of free acetaldehyde, and (iii) at above 25 mg/L added SO_2, final SO_2 concentration decreases.

Aroma production changes with SO_2 dose in the grape must. Synthesis of compounds directly related to sulphur metabolism increases with added SO_2, whereas synthesis of other volatiles related to central carbon metabolism and acetaldehyde (isoamyl alcohol, isobutyl alcohol and their esters) is maximal at 25 mg/L initial SO_2.

Future outlook

Developing SO_2-light vinification processes is one of the core-priority research themes to address in collaboration with the INRAE–Pech Rouge station, and the knowledge we have already acquired leaves us well equipped to engineer sharp and innovative solutions.

Research on the acetaldehyde factor is already pressing ahead through a PhD project in partnership with world-leading cognac producer Hennessy to develop strategies for minimizing acetaldehyde synthesis in cognac production.

© Eric Meistermann, IFV
Three bottles of white wine that formed protein haze around the cork at cellaring.

Haze formation in *rosé* and white wine: can we bring the bentonite doses down?

Read more

Vernhet A *et al.*

Wine thermosensitive proteins adsorb first and better on bentonite during fining: practical implications and proposition of alternative heat tests.

Journal of Agricultural and Food Chemistry . 2020 - https://doi.org/10.1021/acs.jafc.0c00094

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Context

Protein is a minor component but a major factor of colloidal stability and haziness in white wines and rosés. Haze and deposits that form in the bottled wines is a defect that consumers often find unacceptable. The most common strategy to counteract haze formation is fining with bentonite clay, where proteins that are positive-charged at normal wine pH adsorb onto negative-charged suspended clay particles.

However, this popular treatment demands doses that have steadily increased in the past two decades, and it also carries a number of drawbacks: it is non-selective (can also neuter aroma and eliminate the anthocyanidins that lend colour), causes loss of volumes (3–10 % down), and creates waste.

Various tests have been put forward to assess instability in wines, most based on using a heat program to precipitate out heat-unstable proteins. These tests read differently depending on *terroir*, grape varieties, and other factors, and in many cases lead to overestimate the treatment doses needed.

Here we led research to gain a foundational understanding of protein–bentonite interplays in order to rationalize the treatment options.

Results

Evidence from 7 different white wines (counting 1 vintage, 4 regions, 3 grape varieties) showed that proteins adsorb onto bentonite in a thermosensitivity-specific order: the most heat-unstable proteins, which cause haze formation, are also the proteins that most readily adsorb– which makes them the easiest to eliminate. Fluorescence spectroscopy on solutions carrying proteins adsorbed on bentonite showed that this pattern is explained by protein structure properties: the 'soft' proteins that can change conformation to adsorb are the proteins that undergo conformational change and unfold at lower temperatures, whereas the most heat-stable 'hard' proteins that cannot undergo conformational change are also the proteins that are harder to adsorb.

Future outlook

These results show that it is possible to stabilize wines without necessarily having to eliminate all the protein. Our findings open up opportunities to develop alternative sets of tests (using time–temperature curves) and ultimately to bring down bentonite doses.

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Do transition metals and phenolic compounds affect apple-juice yields?

Read more

Vidot K *et al.*

Metallic ions distribution in texture and phenolic content contrasted cider apples.

Postharvest Biology and Technology . 2020 - https://doi.org/10.1016/j.postharvbio.2019.111046

Vidot K *et al.*

Phenolic distribution in apple epidermal and outer cortex tissue by multispectral deep-UV autofluorescence cryo-imaging.

Plant Science . 2019 - https://doi.org/10.1016/j.plantsci.2019.02.003

Partnerships

This work was carried out in partnership with INRAe–Angers USC 1422 GRAPPE, INRAE–Angers School of Agricultural Engineering–SFR QUASAV, the SOLEIL Synchrotron facility in Gif-Sur-Yvette, GEPEA–Environmental Engineering UMR 6144 CNRS–University of Nantes in Saint-Nazaire, and led as part of PhD thesis work by Kevin Vidot.

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Context

The IONS project brief was to investigate the effect of variability in metal ion and phenolic content on oxidative degradation processes in the plant cell wall. The literature reports that oxidative degradation occurs when fruit ripens, prompting us to posit that oxidative degradation processes may affect the release and filtration of juice from the must. With that vision, we studied the content and distribution of transition metals and phenolic compounds in two cider-apple varieties of contrasting firmness over two years of harvest. We used model solutions to assess the impact of these variations on the degradation of pectin, a key cell-wall polysaccharide that shapes the texture of fruit.

Results

The in-sample ions and phenolic compounds were mapped at the SOLEIL synchrotron facility using fluorescence cryo-microscopy. Special-purpose low-temperature sample preparation and observation methods were developed to keep diffusion of these compounds contained. We exploited the deep-UV-region wavelengths to chart the distribution of different families of phenolic compounds typically found in apple. In parallel, we also localized the metal ions, which showed substantial variations in distribution within apple tissues and within varieties but even more significant variations between years of harvest. Pressing the fruit brings the phenolics and ions into contact. A study carried out with model solutions showed that a major phenolic compound in apples could drive or dampen the oxidative degradation of pectins depending on iron content.

Future outlook

In addition to the methods developed for localizing diffusible solutes that are transposable to other highly hydrated matrices, these results raise prospects for monitoring metal ions as oxidation-process markers involved in the development of palatability and processability properties in fruit musts and fruit juices.

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How is the quality of cooked apple purees predictable from infrared spectra of the initial raw apples?

Read more

Lan W *et al.*

A new application of NIR spectroscopy to describe and predict purees quality from the non-destructive apple measurements.

Food Chemistry . 2020 - https://doi.org/10.1016/j.foodchem.2019.125944

Context

Consumers of apple puree expect products that differentiate between brands yet consistent within the same label. The natural variability and heterogeneity of raw materials make it difficult to obtain trait-stable processed fruit formulations and to optimize the process routes to methodize constant controlled quality.

Near-infrared spectroscopy (NIRS) is widely used for quality control assessments in farmed food crops, as it delivers fast and non-destructive measurements. The challenge addressed here was to test the ability of NIRS to predict the properties of cooked apple purees based on spectral information captured from intact raw apples.

Results

The purees were prepared with sets of apples from varied cultivars, farm systems, and periods in 4°C storage and with two levels of post-cook mechanical refining. There were good apple-to-puree correlations on titratable acidity ($R^2 > 0.91$), soluble solids content ($R^2 > 0.79$), rheology ($R^2 > 0.79$) and dry matter content ($R^2 > 0.72$). NIRS proved able to confidently classify the apple purees according to variety (> 82%) and time-in-storage (> 88%). However, the real originality value added was that we predictively gauged the quality properties of the purees from spectra acquired non-destructively on the input-ingredient apples: the technique posted satisfactory predictive performances on viscosity of the puree ($R^2 > 0.82$) and on key compositional parameters such as cell wall (fibre) contents ($R^2 > 0.81$), dry matter content ($R^2 > 0.83$), soluble solids content ($R^2 > 0.80$) and titratable acidity ($R^2 > 0.80$).

Future outlook

Apple industry processors use their skilled experience to obtain a standard-quality puree by blending the apple varieties upstream of processing. The results reported here therefore open up routes for better valorising quality of fruit resources and optimizing the properties of the processed foods according to the raw materials.

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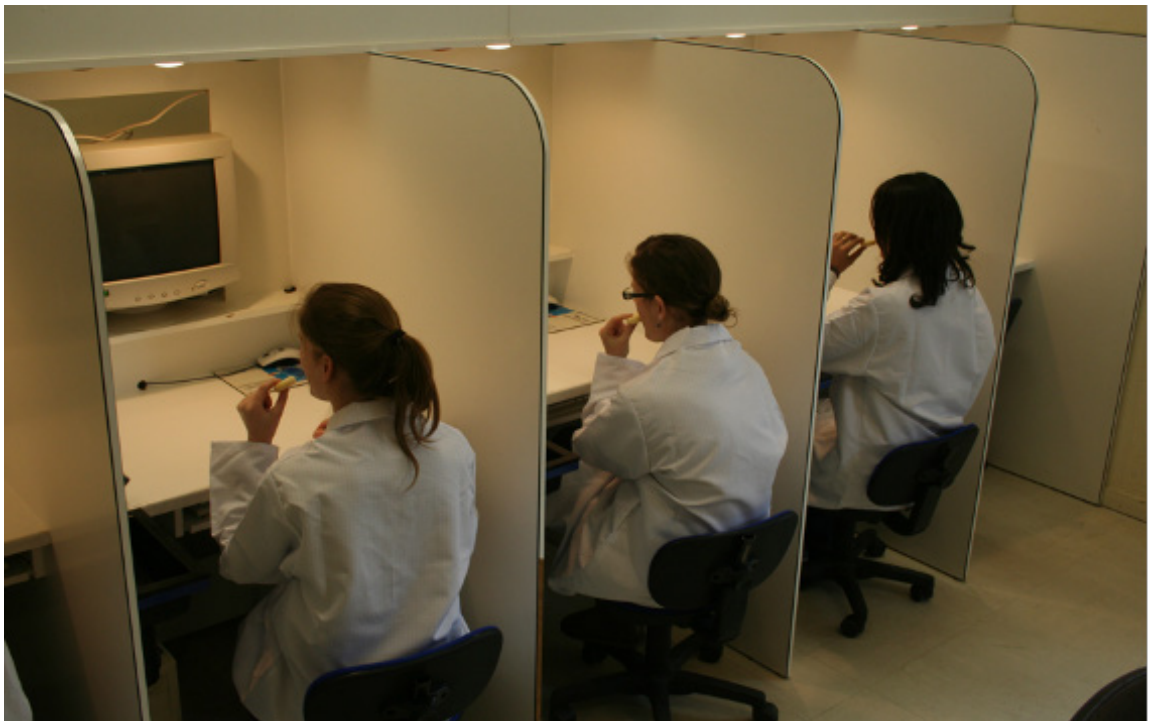
Sensory perception of foods and interplays with consumer science



TRANSFORM scientists aim to understand the dynamics of food flavour and aroma perception by studying saliva and oral mucosa as well as their interplays with the mechanisms underlying multisensory perception. This science provides an invaluable foundation for understanding the sensory perception of plant protein-fortified foods and using that understanding to improve their acceptability for consumers.

Numerical model simulates chewing cereal-based foods fortified with pea protein

Read more

Assad-Bustillos M *et al.*
Impact of protein reinforcement on the deformation of soft cereal foods under chewing conditions studied by X-ray Tomography and Finite Element Modelling.
Journal of Food Engineering . 2020 - https://doi.org/10.1016/j.jfoodeng.2020.110108

Assad-Bustillos M *et al.*
Oral processing and comfort perception of soft cereal foods fortified with pulse proteins in the elderly with different oral health status.
Food & Function . 2020 - https://doi.org/10.1039/C9FO02993A

Mobilization and impact

This research was framed under the ANR-funded AlimaSSenS project (ANR-14-CE20-0003) and led to a PhD thesis by Mélissa Assad-Bustillos via a CIFRE agreement arranged with Cerelab. In addition to academic and cognitive impacts, this research was mobilized by the industry partner to make and test a set of real foods.

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Context

It is vital to understand how chewing affects ease of eating and enjoyment in order to properly formulate foods that cater to over-65s, especially in terms of valuable protein content. With that vision, we chose two classic widely-retailed cereal products known to offer a soft-textured crumb– brioche and sponge cake – and versions fortified with pea protein. For each of these four foods, i.e. the standard brioche and sponge and the pea protein-fortified versions, the mechanisms leading to deformation and fragmentation into a bolus were tracked using X-ray microtomography (µCT, ESRF Grenoble), modelled using the finite element method (FEM), and studied on 20 different volunteers aged 65 years or over presenting contrasting combinations of oral and salivary health.

Results

Analysis of the 3D µCT images showed that the crumb pore walls were thicker in the brioches than the sponge cakes, and fortification with pea proteins led to even thicker pore walls. Dynamic analysis of pore cell structure during compression showed that the sponge cake pore walls are easier to fracture whereas the brioche pore walls readily undergo deformation with little compression force and no fracture. Each 3D µCT image of the foods was digitized for integration into numerical FEM model to simulate its mechanical behaviour under compressive stress and determine the distribution of internal strains and stresses in the food matrix and the zones exposed to most damage. Computations showed less efficient stress transfer in the brioches, and especially the pea protein-fortified brioche, than in the two sponge cakes. In addition, size of the food bolus particles in sponge cakes eaten by all 20 subjects decreased rapidly during chewing, which points to a fragmentation mechanism, whereas chewed brioche particles showed a combination of fragmentation and agglomeration mechanisms. These differences in breakdown patterns lead to different chewing behaviours evidenced by the variations in bolus viscosity. Once we take physiological inter-individual differences into account, these different breakdown patterns may be assigned to the difference in pore cell structure between these cereal-product foods.

Future outlook

These results open up opportunities to move forward into studies on cereal food–saliva interplays and validate the numerical model of chewing, which has so far remained limited to brittle (crispy) foods. This model can serve to reverse-engineer targeted crumb pore structures and design new cereal-based foods high in added plant protein formulated especially for seniors.

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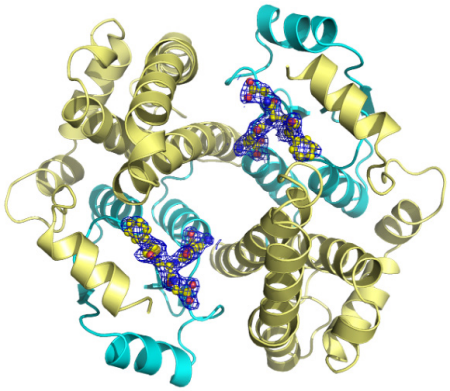
The metabolism of aromas deciphered by X-rays

Read more

Schwartz M *et al.*

Interactions between odorants and glutathione transferases in the human olfactory cleft.

Chemical Senses . 2020 - https://doi.org/10.1093/chemse/bjaa055



X-ray structure of the GSTA1 dimer complexed with the glutathione conjugate of cinnamaldehyde (@Mathieu Schwartz)

Contact

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Context

We all have smells we love and smells we hate. These reactions come from the aroma compounds that stimulate the olfactory receptors in the nasal cavity. Our nasal cavity is also equipped with a huge number of enzymes that can metabolize any odor-active compounds that get inside. Recent research shows evidence that this metabolic activity likely influences the way we perceive odors, especially during food consumption. These enzymes engaged in nasal metabolism include glutathione S-transferases (GST), which are enzymes that can conjugate the glutathione group to various reactive molecules–including those found in food. Here we focused on this family of enzymes. The aim was to precisely localize the GSTs in the nasal cavity and show how aroma-active compounds get structurally modified.

Results

Two GST-family enzymes (GSTA1 and GSTP1) were localized in the nasal epithelium: GSTA1 was found in the ciliated cells directly in contact with the air entering the nasal cavity, whereas GSTP1 was found deeper in the basal cells. We showed that both these GSTs are able to metabolize various odorant molecules and form metabolites carrying a glutathione moiety. X-ray diffraction data acquired at the SOLEIL synchrotron facility on crystals of GSTA1–aroma-compound complexes demonstrated that the 3D structure of GSTA1 enables it to bind various aroma-active compounds–including cinnamaldehyde–in a protein binding pocket. The results argue that nasal metabolism affects flavour perceptions by directly modifying the odorant molecules reaching the olfactory receptors.

Future outlook

A previous study has shown that odorant metabolization modifies odorant perception in humans. The next step now is to show how the GST family specifically contributes to odor perception. Moreover, GST expression profiles vary between individuals, which could lead to inter-individual differences in capacity to metabolize odorant molecules, and ultimately affect food preferences. Work is already underway to explore this hypothesis.

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The saliva metabolome: a reflection of early childhood

Read more

Neyraud E *et al.*

Longitudinal analysis of the salivary metabolome of breast-fed and formula-fed infants over the first year of life.

Metabolomics . 2020 - https://doi.org/10.1007/s11306-020-01661-7

Partnerships

Axiom Platform, MetaToul-MetaboHub ; Toulouse

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Context

Saliva is a biological fluid that plays multiple roles. First and foremost, it protects the oral cavity against pathogens and protects the teeth from decay, and plays a role in food perception and digestion. Saliva contains mainly proteins and metabolites. Metabolites are small molecules that reflect an organism's metabolism, i.e. the set of chemical reactions that it plays host to. Metabolism can be modified by diseases but also by natural processes like ageing, exercise, diet, and more. The entire set of metabolites found in a given biological fluid or tissue is called the 'metabolome'. CSGA researchers have been studying the saliva metabolome for several years now, and particularly its relationships with taste perception and diet, but they have recently turned to focus on how the salivary metabolome evolves during the first few months of life.

Results

They collected saliva samples from 32 infants with different milk feeding experiences (breast milk vs. infant formula) at 3, 5, 11 and 15 months of life. The results showed no significant breast-vs-formula differences in saliva metabolome. However, there was an age effect on several metabolites–including propionic acid, an end-product of bacterial metabolism, and 5-aminopentanoic acid, which both increased with age. 5-aminopentanoic acid is thought to be a degradation product of salivary proteins by enzymes called proteases, potentially from bacterial origin. Another two metabolites that also increased with age are ketone bodies, which newborns produce when fasted. The increased concentrations of these ketone bodies found here runs in parallel to the decreases in 3 sugars: lactose, glucose, and maltose. These patterns likely reflect a dietary transition that operates when the infants start to diversify to solid foods, marking a decrease in lactose intake. Taken together, these changes are thought to reflect two major events: a change in diet with the gradual introduction of foods other than milk, and a change in oral–including microbial–metabolism. This research brings firm evidence that saliva composition can serve as a marker of physiological diet-related events occurring during early childhood.

Future outlook

This presence of metabolites reflecting bacterial metabolism opens a number of fresh perspectives on the role of the oral microbiota, particularly in shaping food perception and food preferences.

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Characterizing dynamic flavour perception of nutritional supplements

Read more

Delompré T *et al.*

Characterizing the dynamic taste and retro-nasal aroma properties of oral nutritional supplements using Temporal Dominance of Sensation and Temporal Check-All-That-Apply methods.

Foods . 2020 , 9, 1456 - https://doi.org/10.3390/foods9101456

Mobilization and impact

These results can translate directly into pharmaceutical industry practice for better patient liking of food supplements.

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Context

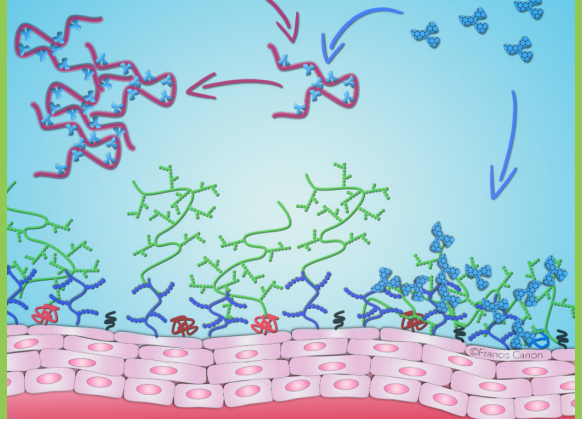
Orally-disintegrating nutritional supplements designed to dissolve in saliva are used to improve nutritional status, typically in people who experience difficulty swallowing. This dosage form is the most popular and preferred option for nutritional supplement tablets, but many of the high-nutrient-value vitamins, minerals and amino acids they contain are known to have unpleasant tastes such as bitterness or astringency. These negative off-notes come as the active compounds in the tablets gradually get released as the tablet dissolves, creating bitterness and leaving an unpleasant aftertaste. Effective masking strategies, such as adding flavourings or sweeteners, would provide manufacturers with an opportunity to improve consumer appreciation of their nutritional supplements.

Results

We achieved a deep and broad sensory characterization of these orally-disintegrating nutritional supplements by employing bespoke temporal dominance of sensations (TDS) and temporal check-all-that-apply (TCATA) methods. These methods made it possible to characterize the temporal perceptions of four products spanning various galenic and aromatized forms as they dissolved. These nutritional supplements were found to share common sensory properties but also individual sensory properties that were mainly related to galenic form and active ingredients. In all cases, aroma had little or no impact on taste, and the perceived bitterness essentially arose from the ingredient minerals. Bitterness could potentially emerge throughout in-mouth oral processing but was masked by sweet and acid notes in the first and second third of oral processing time. The TDS and TCATA tests developed here can capably complement information on the dynamic sensory properties of the products under test. TDS emerged a larger number of differences in flavour perception whereas TCATA had more discriminant power across all sensory attributes. These methods together helped to unravel the time–course pattern of sensory perception when taking these tablets.

Future outlook

A more optimized formulation of these orally-disintegrating nutritional supplement tablets would make it possible to stifle and suppress the unpleasant tastes and better cater to patient demand. Crucially, choosing more functionally-effective aromants and modifying the kinetics of release of these flavourings in the mouth would ensure that negative tastes are effectively masked while reducing the use of sweeteners.



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Mechanism of astringency: aggregation of the pellicle film by tannins, and protective role of salivary proline-rich proteins

New insight on the role of oral mucosa in flavour perception

Read more

Canon F *et al.*

Perspectives on astringency sensation: an alternative hypothesis on the molecular origin of astringency.

Journal of Agricultural and Food Chemistry . 2021 - https://doi.org/10.1021/acs.jafc.0c07474

Ployon S *et al.*

Understanding retention and metabolization of aroma compounds using an in vitro model of oral mucosa.

Food Chemistry . 2020 - https://doi.org/10.1016/j.foodchem.2020.126468

Mobilization and impact

The ANR-funded MUFFIN project produced 12 scientific papers and led to 1 INRAE press release.

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Context

The pleasure of eating comes largely from the flavour of the food we eat. Flavour comes from the brain integrating our perception of aromas and tastes, but also trigeminal perceptions, such as the freshness of mint. Many of the molecular mechanisms underpinning these different sensations remain unknown–the sensation of astringency, for example, or aroma persistence. Astringency, which can sometimes prove unpleasant, is mainly perceived when eating plant-source food, and it is thought to be one of the barriers to a dietary transition to a more vegetarian diet. Aroma persistence, or 'length' or 'finish', comes from a prolonged release of the aroma compounds–even after the food has been swallowed. Here again, the molecular mechanisms behind whether a food will have a longer or shorter in-mouth release of aroma compounds are sketchy at best. However, in both these sets of molecular mechanisms–astringency and persistence–the oral mucosa appears to play a major role.

Results

Through research framed under the ANR [French national research agency]-funded MUFFIN project, we developed an oral mucosa model that has brought compelling evidence that the surface properties of the oral mucosa are modified by one of its transmembrane proteins, MUC1, which is involved in forming the mucosal pellicle, a thin layer of proteins lining the surface of the oral mucosa.

Applied to the study of astringency, this oral mucosa model showed that tannins–the compounds that trigger astringency–aggregate the mucosal pellicle and increase the frictional forces at its surface, whereas a ground of salivary proteins called 'proline-rich proteins' work to protect the mucosal pellicle against tannins.

This model also showed that the oral mucosa is involved in lasting aroma persistence by modifying the kinetics of tastant aroma-compound release. The oral mucosa was also found to harbour the capacity to metabolize the aroma compounds molecules and even generate new metabolites that are potentially odour-active too. Our insight thus finds that the oral mucosa may modulate both the quantity and quality of odourant molecules perceived when eating.

Future outlook

Results obtained through the ANR [French national research agency]-funded MUFFIN project on the role of MUC1 in the properties and functions of the mucosal film provided the frame for a new mechanistic hypothesis on molecular foundations of astringency, which we intend to explore in further ANR-backed work (MACARON project).

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Configural perception of complex odours

Read more

Tromelin A *et al.*

Exploring the characteristics of an aroma-blending mixture by investigating the network of shared odors and the molecular features of their related odorants.

Molecules . 2020 - https://doi.org/10.3390/molecules25133032

Wycke MA *et al.*

Configural perception of a binary olfactory mixture in honey bees, as in humans, rodents and newborn rabbits.

Journal of experimental Biology . 2020 - https://doi.org/10.1242/jeb.227611

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Context

A better understanding of olfactory function is critically-needed foundation for learning how individuals interact with their food, ecological or social environment. However, the bulk of the science on odour perception is grounded in studies that use simple basic odour stimuli, which fails to reflect how the sense of smell actually works in real life–and particularly in its analytical/configural duality. Like sight or hearing, smell can effectively operate in a configural mode that enables the brain to mentally represent a highly complex mixture of odourants as a simple unique 'object' or 'configuration', like for instance the *smell of coffee*.

Results

Our unique transdisciplinary approach at the nexus of psychophysics, chemistry, neurobiology, ethology and modelling, was able to show that configural odour processing is a trait shared by several animal species. We found that a mixture of ethyl isobutyrate (strawberry) and ethyl maltol (caramel), known to evoke pineapple odour in humans, is also processed configurally by bees. This finding further confirms our previous observations on newborn rabbits and mice and validates configural processing of odours as shared across species. Our work also highlighted the importance of learning/training in configural perception of odours in newborn rabbits, as we had previously shown in humans. Given that the olfactory system architecture is relatively well conserved between species, we postulated that configural processing may rely on specific early coding at olfactory receptors. Preliminary results surfaced the structural properties of 293 substances carrying odours of strawberry, caramel or pineapple identified using social network analysis and further assessed via a pharmacophore model. The innovative approach revealed potential complementarities between the molecular structures, which points to interactions at olfactory receptors.

Future outlook

There are perspectives leading out of this work on two fronts. In the ANR [French national research agency]-funded MULTIMIX project, we are in the process of testing out our hypotheses on olfactory receptors through a combination of neurobiology approaches and advanced modelling. In research framed by an international transdisciplinary collaboration involving INRAE–CSGA, two CNRS laboratories (CRNL and EGCE) and the NYU School of Medicine (USA), we are exploring the integrative neurobiological processes that support the processing of configural odour information in the brain.

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Sensory analysis booths with a trained panellists evaluating pea-based products for perceived taste intensity.

Cracking the flavour of peas

Read more

Cosson A *et al.*

Using a mixture design and fraction-based formulation to better understand perceptions of plant-protein-based solutions.

Food research International . 2021 - https://doi.org/10.1016/j.foodres.2021.110151

Cosson A *et al.*

Using multiple sensory profiling methods to gain insight into temporal perceptions of pea protein-based formulated foods.

Foods . 2020 - https://doi.org/10.3390/foods9080969

Partnerships

- Société Roquette Frères
- UMR SayFood (Audrey Cosson thesis)
- PAPSSO Platform
- Polyphenols platform, UMR SPO
- UMR SQPOV

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Context

Eating more pulses would help move towards more sustainable food systems–but there are barriers. Pulses as yellow peas are a legume crop with high potential agronomic, environmental, processability and nutritional value, but they have struggled to find a way into new food formulations due to their flavour (taste and aroma). Efforts to deliver a more plant protein-dense food offer hinge on cracking the root cause of the 'off-flavour' notes associated with pea proteins in order to come up with ways to mitigate or mask them.

Results

To tackle this challenge, we employed an original approach combining physical–chemical and sensory analysis with modelling on a set of products produced by fractionation of pea protein isolates and on a series of more complex formulated products, such as plant based protein beverages.

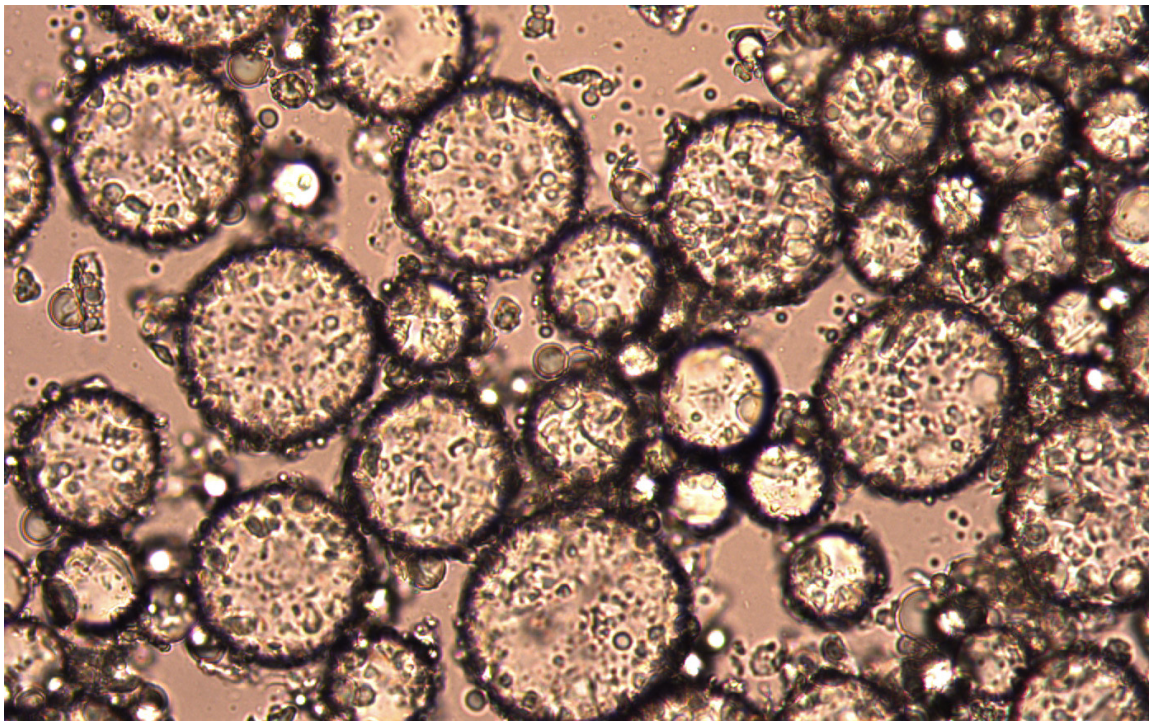
This work first made it possible to develop a sensory profiling method for clustering the sensory attributes by blocks, which then served to increase the discrimination between products with strong persistence. Then, we worked towards a fine-grained characterization of these products, including compositional analysis on their aroma compounds, proteins, peptides, phenolics, and saponins.

The combined analysis of this rich set of experimental data allowed to establish first-look explanatory relationships in order to determine the target compounds to explain the sensory perceptions. Through this approach, 34 (out of 79) aroma compounds, 14 (out of 3561) peptides and 11 phenolic compounds were identified as key compounds explaining the 'beany' (mixture of green, earthy, dusty and nutty notes), bitter and astringent notes of pea protein isolates.

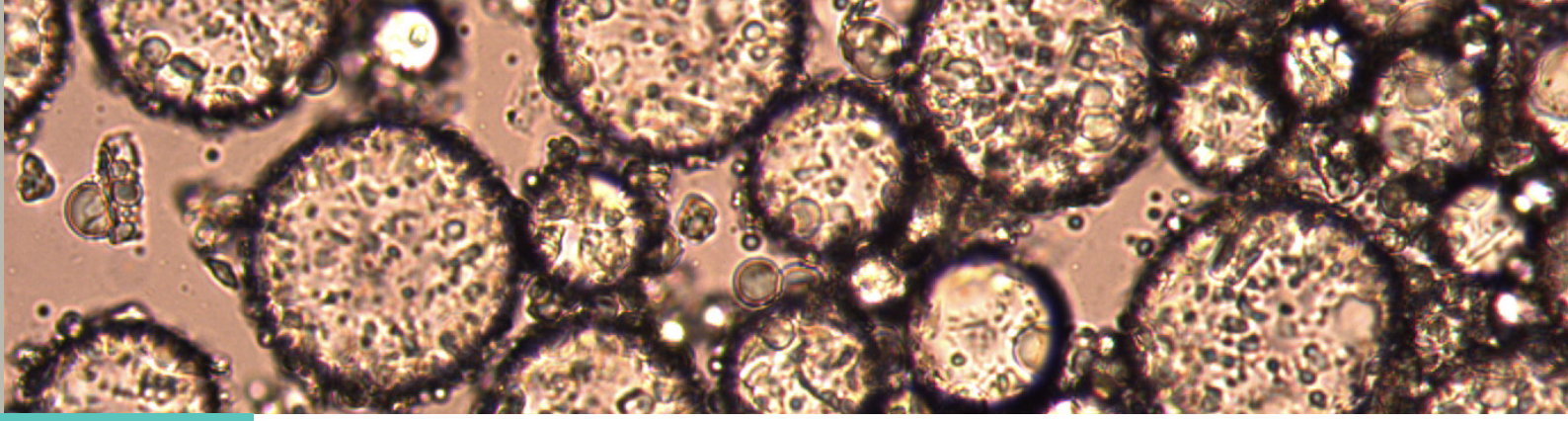
Finally, a wide range of plant-based beverages was developed and formulated with different protein ingredients from the blended fractions. The objective was to better understand how product composition (sunflower oil, gellan gum and salt) affects sensory perceptions of the beverages using temporal sensory analysis on consumption of one sip of beverage and of a full portion. We were thus able to quantify the temporal pattern of astringency and bitterness in relation to formulation.

The science acquired has brought key insights into the relationship between pea isolate composition (peptides, polyphenols, aroma compounds), food formulations, and perceptions. This work will allow us to propose ways to revisit the legume fractionation processes to downplay the off-notes in plant protein fractions.

Processing biomass resources for non-food value



To meet the growing demand for biomaterials to support sustainable systems, TRANSFORM research scientists work to enhance biomaterial performances by multifunctionalizing their architectures. These new functionally-engineered biomaterials run from nanoparticle thin films up to fibreboard panels, creating value streams that exploit key molecules and even whole plants.



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Stabilizing clean-label emulsions with crop-coproduct powders

Read more

Huc-Mathis D *et al.*

Pickering emulsions based on food byproducts: A comprehensive study of soluble and insoluble contents.

Journal of Colloid and Interface Science . 2021 - https://doi.org/10.1016/j.jcis.2020.07.078

Huc-Mathis D *et al.*

Valorizing apple by-products as emulsion stabilizers: Experimental design for modeling the structure-texture relationships.

Journal of Food Engineering . 2020 - https://doi.org/10.1016/j.jfoodeng.2020.110115

Mobilization and impact

3 scientific articles, 5 participations at conferences (Food Colloid Conference, EFFoST) and forums (Cosmetic 360, In'Cosmetics, FIE), 1 webinar (U Cosmetic), and 1 award for the VITACEL CS 5® coproduct ingredient (apple pomace) based on this research (Cosmebio award for best ingredient).

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Context

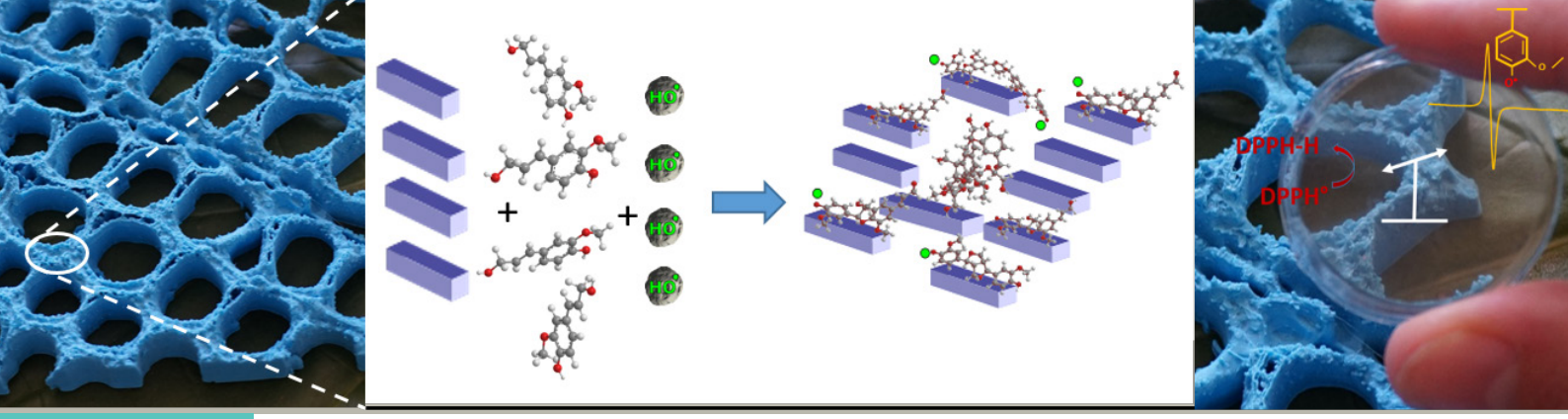
Reducing food loss and food waste is one of the major paths to more sustainable food–farming commodity chains. A new process route that restreams and upvalues plant-crop coproducts without having to go through countless processing steps and without using solvents would also meet consumer demand for more natural and less ingredient-packed everyday commodities, typically foods and cosmetics. This elegant strategy capitalizes on the complementarity between fractions naturally present in plants.

Results

We managed to stabilize oil-in-water emulsions using only powdered food coproducts (apple or orange pomace, oat bran, or beet pulp) without any added surfactants. All these coproduct-stabilized emulsions were coalescence-stable (average droplet diameter does not change over time) and the apple/orange pomace-stabilized emulsions were creaming-stable. An experimental test design mobilizing various formulation factors made it possible to build a working toolbox that formulators can use in practice to obtain a given texture. Accelerated ageing and scale-up tests have demonstrated the potential of this emulsifier innovation for operable process industrialization. Advanced analysis of the specific properties of the in-emulsion solutes and the characteristics of this new set of emulsifier powders led us to posit the kind of stabilizing mechanisms involved. The solid particles were observed at the phase interface by confocal microscopy, thus bringing confirmation that the emulsions are Pickering-type. However, the phase interfaces remain hybrid, as the soluble fraction works in complementarity with the insoluble fraction to stabilize the emulsion.

Future outlook

We need to press ahead with understanding and ranking these mechanisms. This generic approach could well be further extended and expanded to encompass other potential crop-coproduct commodities, which would be facilitated by finding indicators that can serve to predict the potential of a co-product for emulsion stabilization without having to systematically go back through in-lab tests. Finally, the sensory profiles obtained are different from 'conventional' emulsions and thus warrant deeper descriptive analysis and study to test how they translate to consumer perceptions. These are the objectives of the ANR-sponsored 'CLEVER' project for young research associates coordinated by the SayFood unit (D. Huc-Mathis) for the next 4 years, starting February 2021.



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Reactive oxygen species-driven oxidation of lignocellulose and pathways to nanostructured multifunctional materials

Read more

Gerbin E *et al.*

Dual Antioxidant Properties and Organic Radical Stabilization in Cellulose Nanocomposite Films Functionalized by In Situ Polymerization of Coniferyl Alcohol.

Biomacromolecules . 2020 - https://doi.org/10/1021/acs.biomac.0c00583

Mobilization and impact

This research has been co-funded by inter-Carnot Institute 3BCAR/Qualiment projects Lignoxyl 1&2, INRAE, and CNRS Condorcet research federation, and is set to continue through the EU-backed H2020-program BBI-JU project Zelcor (#72030) and the ANR-backed FuncLIPRO project (ANR-19-CE43-0007).

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Context

There is rising worldwide demand for innovative, high-performance biobased materials to support sustainable systems. Lignocellulosic polymers can adopt a huge spectrum of functional structures, like cellulose nanocrystals (CNCs) and lignins, which are relatively cheap biorefinery by-products. These structures can be purpose-combined into nanocomposites to synergistically exploit the mechanical strength, gas barrier and transparency properties afforded by the cellulosic matrix and the specific adhesion, water resistance and multifunctionality (anti-UV, antioxidant, antimicrobial, adhesive) properties of the lignin polymers. However, the performance of the materials remains highly dependent on the initial platform structures and assembly process used.

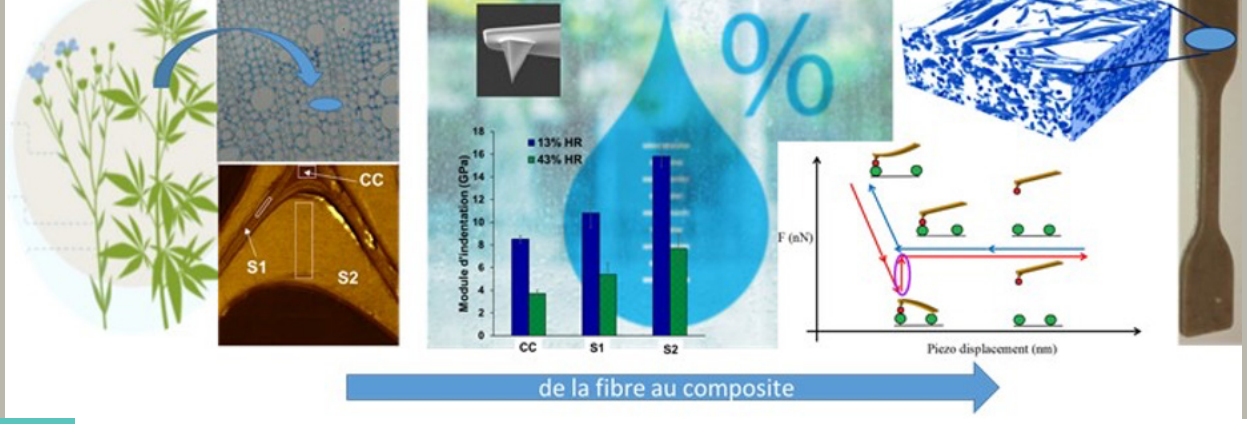
Results

These advanced CNC-based materials were developed by polymerizing a lignin monomer called coniferyl alcohol (CA) *in situ via* Fenton-process chemistry. The main challenge was to control the formation of hydroxyl radicals transforming phenols into phenoxyl radicals and thus catalyzing radical coupling reactions between the CA units in the cellulose matrix. The results show that the Fenton's reagent can isomerize the β–(1,4) bond to an α–(1,4) bond on the cellulose and oligomerize the CA with β-O-4, β–β and β-5 bonds derived from autooxidation and radical coupling reactions.

We then performed an advanced investigation of their physical–chemical and morphological properties using a battery of methods–electron spin resonance spectroscopy (ESR), infrared spectroscopy, dynamic vapour sorption and atomic force microscopy–and discovered that the final material is dual-functionalized depending on the degree of CA oligomerization: either a material with antioxidant properties comparable to those of BHT, or a material that stabilizes phenoxyl radicals. This intensive characterization effort on a gradient of scales from µm down to nm showed that these properties were related to the structure and morphology adopted by the oligomer inside the composite and ultimately, therefore, to the accessibility of free phenols trapped in the film. In contrast, the organic phenoxyl radicals formed by the Fenton reaction remain persistent and stable in the material. We also learned that the amplitude of the ESR signal is proportional to the degree of CA polymerization

Future outlook

The multidisciplinary methodological approaches developed through this research provide fresh foundations for understanding the oxidation reactions in lignocellulosic polymers. Functionalized CNC films hold promise for potential applications in electrochemically-active materials such as sensors and batteries.



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Water influences the nanomechanical properties of plant fibres

Read more

Coste R *et al.*

Effect of the interplay of composition and environmental humidity on the nanomechanical properties of hemp fibers.

ACS Sustainable Chemistry and Engineering . 2020 - https://doi.org/10.1021/acssuschemeng.0c00566

Marcuello C *et al.*

Atomic force microscopy reveals how relative humidity impacts the Young's modulus of lignocellulosic polymers and their adhesion with cellulose nanocrystals at the nanoscale.

International Journal of Biological Macromolecules . 2020 - https://doi.org/10.1016/j.ijbiomac.2019.10.074

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Context

Thermoplastic matrix composites reinforced with lignocellulosic fibres are a growing market because of the renewable nature of these fibres, their low density and their strength. However, the valued properties of fibres and composites depend on several factors related to fibre and matrix properties beyond the process implemented. These macroscopic behaviours are based on morphological and structural characteristics of the fibres and their interaction with water. Assessment of the role of water at subcellular and molecular scales is a key issue that needs to be addressed to exploit the potential mobilization of natural fibres in the design of smart and sustainable biobased materials.

Results

The spectroscopic, physical–chemical and interfacial properties of lignocellulosic feedstocks for biobased materials were mapped using atomic force microscopy (AFM). We then devised a unique set-up to enable continuous nanoscale monitoring of mechanical properties in response to a gradient of relative humidity. We managed to differentiate the properties of the different cell wall layers of the fibre, and we showed, for the first time, that this variation is associated with a difference in nanoscale hygromechanical behaviour. This result is explained by the differences in hygromechanical characteristics of each of the lignocellulosic polymers tested–characteristics that could also be tuned by their degree of interaction within the cell-wall layers. New methodologies based on the functionalization of AFM cantilevers with crystalline cellulose enabled us to complete a nanoscale quantification of the adhesion forces between the cellulose and other fibre components, and demonstrate that these interactions evolve as a function of ambient humidity.
Looking at the bigger picture, methodological advancements in AFM and force spectroscopy can be mobilized to help unravel how the fibres behave through the process of lignocellulosic fibre-based composite manufacture and gauge their stability to water.

Future outlook

The conclusions reached and approaches developed through this raise fresh prospects for understanding and predictive modelling the properties of biobased fibres and composites–for example, studying thermoset resin penetration the cell walls of wood material, modelling of the hygromechanical behaviour of lignocelluloses (ANR PRCI INTOS2), multiscale analysis of composite using different types of fibre and matrix materials.

Ovalie Innovation ©Stéphane Ballas / LCA @ Philippe Evon

Biorefining the whole coriander plant

Read more

Uitterhaegen E *et al.*

Performance, durability and recycling of thermoplastic biocomposites reinforced with coriander straw.

International Journal of Biological Composites Part A: Applied Science and Manufacturing . 2018 - https://doi.org/10.1016/j.compositesa.2018.07.038

Uitterhaegen E *et al.*

Impact of a thermomechanical fiber pre-treatment using twin-screw extrusion on the production and properties of renewable binderless coriander fiberboards.

International Journal of Molecular Sciences . 2017 - https://doi.org/10.3390/ijms18071539

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Context

Dwindling fossil fuel supplies have put farmed-crop biomass high on the agenda as a valuable renewable feedstock for producing low-carbon-footprint commodity biocompounds and bioproducts. To play a part in delivering ecologically sustainable solutions, LCA–Laboratory of Agro-Industrial Chemistry joined forces with Ovalie Innovation to develop a clean, green, no-waste process for biorefining the whole coriander plant. Biorefining whole plants makes it possible to value-stream the entire biomass resource—including the crop coproducts. Coriander makes a particularly attractive asset here, as its seeds are used as a spice and it gives an extract that makes a valuable essential oil. It is readily cultivatable in south-western France and can work to help diversify local crop rotation and fallowing systems. The coriander seed has a novel composition: 25 % edible oil and a 0.6 % fraction of essential oil. The edible oil contains 75 % petroselinic acid, a rare fatty acid that makes it a valuable building block for oils and fats industry. Fractionation of the seed to control the amount of essential oil co-extracted with the vegetable oil would prove a compelling asset for industry value streams.

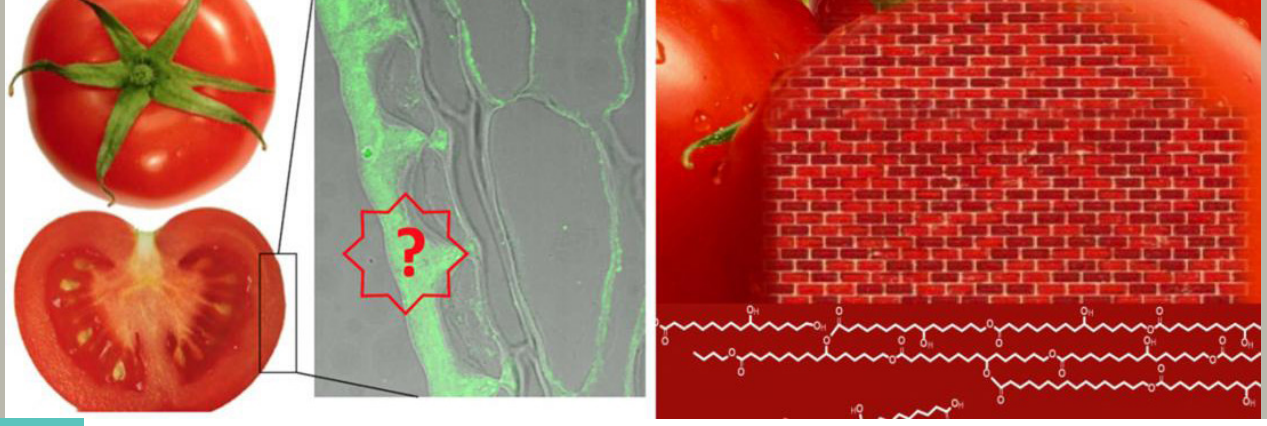
Results

We developed a solvent-free process for co-extracting the edible oil and essential oil from the coriander seed to afford an aromatic vegetable oil. The extraction conditions can be optimized to attune the aromatic power of the oil produced.

In order to value-stream the whole plant, the biorefinery set-up also produces biobased materials from the oilseed press cake left behind after the co-extraction process and straw chaff pulp. Pushing further, we have also developed 100 %-coriander fibreboard panels that emit zero formaldehyde, making them a clean green alternative to plywood for home and office partition walls, furniture, and many other end-use applications. These process routes also serve to yield plant pulp-based plastic composites that will be used in cars to make passenger compartments, in housing to make outdoor decking, and more.

Future outlook

This novel biorefinery concept could ultimately be expanded to other plant feedstocks. These results have enabled Ovalie Innovation to deliver steady revenues to its membership and to market its aromatic vegetable oil to the cosmetics and nutraceuticals industries while maintaining full end-to-end traceability from seed to sale-ready commodity. This oil is currently used for its pro-health benefits.



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A new piece in the structural puzzle of plant cuticle

Read more

Philippe G *et al.*

Assembly of tomato fruit cuticles: a cross-talk between the cutin polyester and cell wall polysaccharides.

New Phytologist . 2018 - https://doi.org/10.1111/nph.16402

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Context

The plant cuticle covers the surface of all aerial organs and performs multiple crucial functions (resistance to water loss, adaptation to climatic and biological stress). These properties are determined by the structural organization of the cuticle, a natural composite comprising lipids (cutin polyester) and cell walls (polysaccharides). However, this structural organization is still not fully resolved. In particular, investigations have struggled to get to the cell walls embedded in the cutin lipid polymer, and so their nature has remained unknown.

Results

Using tomato fruit as a model, we developed a multimodal approach mobilizing chemical and enzymatic pretreatments combined with a battery of complementary investigative methods (Raman and NMR spectroscopy, biochemical analysis, immunocytochemistry, infrared mapping). We managed to establish, for the first time, the fine structure of the cell walls entangled in the cutin polymer: the cutin-embedded polysaccharides (CEPs).

These CEPs share very different features to non-cutinized polysaccharide areas. In particular, the CEPs show a high degree of esterification (methylation, acetylation), and a low rhamnogalacturonan branching, and they also concentrate crystalline cellulose. This structural specificity of the CEPs embedded in cutin is a crucial new clue to deciphering the architecture of this natural composite and its structure–function relationships in the plant.

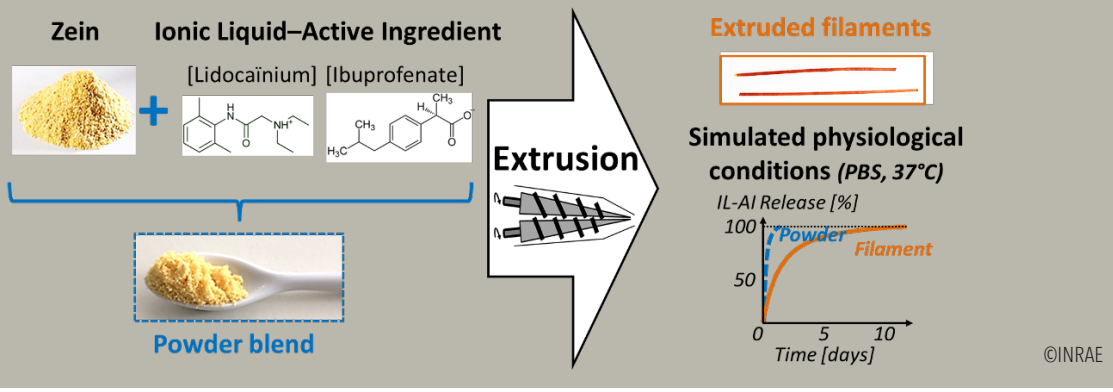
Future outlook

In addition, this research went on to demonstrate that modifying the degree of polymerization of cutin polyester (cutin polymerase-deficient fruit) leads to specific modifications in the CEPs but without modifying non-cutinized polysaccharides. This result provides the first evidence of lipid–cell wall cross-talk in cuticle architecture in planta.

This important work opens up new avenues to progress at the intersection of several research fronts:

i) for controlling cuticle formation for plant resistance properties (agronomics and plant improvement)

ii) and for the design of new bio-inspired materials (biobased materials, biomass streaming and waste-to-value, bioeconomy).



An extrudate to deliver a dual-active pharmaceutical ionic liquid

Read more

Chaunier L *et al.*

A drug delivery system obtained by hot-melt processing of zein plasticized by a pharmaceutically active ionic liquid.

Journal of Materials Chemistry-B . 2020 - https://doi.org/10.1039/D0TB00326C

Partnerships

This study was conducted in partnership with Lydie Viau from the UTINAM Institute (CNRS 6213 in Besançon) and Eric Leroy of GEPEA–Environmental Engineering (CNRS 6144 in Saint-Nazaire).

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Context

Biopolymers are gaining increasing attraction as an avenue for developing absorbable oral matrices for pharmaceuticals. Zein, the main storage protein in corn, has huge potential, particularly because it is hot-melt-processable and can interact with therapeutically-active compounds. In parallel, dual active pharmaceutical ingredient–ionic liquids (API-IL) hold huge promise for future drugs, as they can be easily dosed and processed to prepare stable pharmaceuticals that can quickly cross through cell walls. Including an API-IL in a biopolymer matrix, such as plasticized zein, not only facilitates shaping into form but also helps ensure targeted delivery and controlled release. The [Lidocaine][Ibuprofenate] API-IL–called LidIbu–even has a triple action: (i) a plasticizing effect on biopolymers, and dual-active therapeutic roles, with (ii) the cation, Lidocaine, as local anaesthetic and (iii) the anion, Ibuprofenate, as an anti-inflammatory drug.
The purpose of this study was to engineer a resorbable material from zein and assess its ability to release LidIbu as a dual API-IL.

Results

Intensive characterization of thermomechanical properties demonstrated that LidIbu makes an effective plasticizer. We then managed to obtain calibrated filaments that remain rigid at ambient temperature by extruding the zein + 20 % LidIbu blend at 130 °C.
The integrity of the pharmaceutically active ingredient was verified by thermogravimetric analysis together with in-depth structural characterization by NMR and X-ray scattering analysis. API-IL release was time–coursed under simulated physiological conditions and assayed by UV-spectroscopy. Under these conditions, it tool one week in immersion to release 85 % of the initial amount of LidIbu. This result is explained by a high affinity between the zein matrix and the pharmaceutically active ingredient, as evidenced by solid-state NMR. This tight affinity is promoted by the extrusion process and delivers a slow progressive release of this type of pharmaceutically active ingredient. Our study confirms that this new drug delivery-system material is ideally geared to target applications in the pharmaceutical or biomedical science.

Future outlook

Moving forward, future research will focus on engineering 3D-printable dosage forms to support targeted personalized drug delivery.

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Bending in the asymmetric films in response to an increase in pH.

Controlled assembly of nanocelluloses to develop macroscopic movement

Read more

Chemin M *et al.*

pH-responsive properties of asymmetric nanopapers of nanofibrillated cellulose.

Nanomaterials . 2020 - https://doi.org/10.3390/nano10071380

Contact

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Context

Actuators are materials that change their shape in response to an external stimulus. The change is usually an increase or decrease in the material's dimensions, and the stimulus is typically temperature, humidity, light, or pH. Most actuators today are made from synthetic polymers or semiconductors, and they have good stability and reversibility properties, but their life cycle typically equates to energy-intensive and/or toxic processes.

Our focus is on the use of biopolymers to fabricate actuators in a way that restreams lignocellulosic biomass as a feedstock for the bioeconomy. With that vision, we are channelling our research into cellulose nanofibres, which we obtain by mechanical delamination of the cellulose fibre, producing objects that present microns in length and just nanometres in cross-section. Cellulose nanofibres have hugely attractive mechanical, optical and barrier properties, and are widely used in composites, packagings, and coatings.

Results

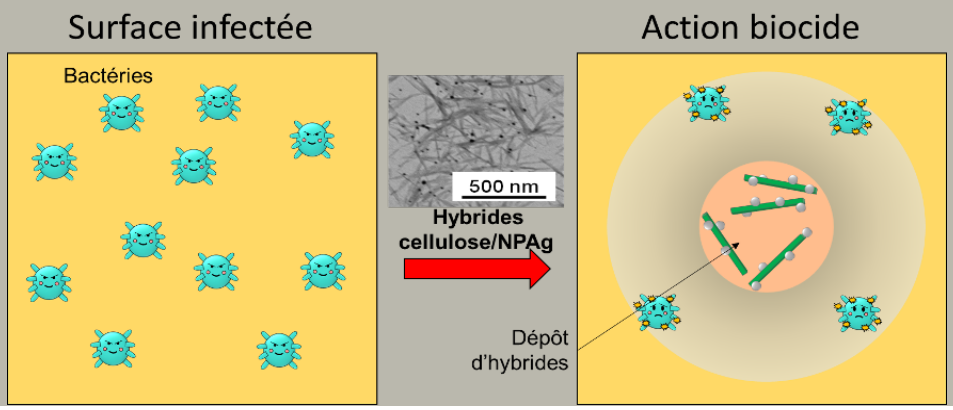
Our study breaks new ground as we manage to fabricate films made of asymmetrically-arranged cellulose nanofibres that have been oxidized in order to introduce charged groups ($COOH/COO^-$). The films are fashioned to present a concentration gradient of responsive groups along thickness. This is achieved by the successive deposition of functionalized and non-functionalized nanofibrillated cellulose layers, thus affording graded films where the concentration of COOH groups increases throughout the thickness.

When the nanopaper is exposed to the stimulus (pH increase), the functionalized layer becomes more charged than the non-functionalized layer. Electrostatic repulsion between the charges then separates the nanofibres, which prompts water uptake and volume swell. As the functionalized and non-functionalized nanofibre layers have different responses, the swelling is asymmetrical, and this asymmetrical response creates stresses within the film that ultimately translate into a macroscopic-scale bending.

This purposed asymmetric structural response is expected to find applications in robotics (clamps and levers for manipulation, artificial muscle and tissue, etc.).

Future outlook

The next step is to investigate how structural changes in response to several stimuli can be harnessed together to fashion programmable materials. The idea is to design new cellulose architectures to study stimuli–responsive conditioning as a step towards the ultimate goal of functionalizing the material with 'memory' functions.



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Cellulose nanocrystals go antibacterial

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Musino D *et al.*
Tuning of Ag nanoparticle properties in cellulose nanocrystals/Ag nanoparticle hybrid suspensions by H2O2 redox post-treatment: the role of the H2O2/AgNP ratio. nanomaterials . 2020 - https://doi.org/10.3390/nano10081559

Musino D *et al.*
Hydroxyl Groups on Cellulose Nanocrystal Surface Form Nucleation Points for Silver Nanoparticles of Varying Shapes and Sizes. Journal of Colloid and Interface Science . 2020 - https://doi.org/10.1016/j.jcis.2020.09.082

Mobilization and impact

Ongoing translational R&D is focused on applications in paints to coat the walls in medical facilities and applications in food packaging. However, the use of these hybrids does still need to secure clearance from the authorities.

European patent 16/06/2020 (n° EP20305658.5): Method for preparing a hybrid material based on unmodified polysaccharide nanocrystals and silver nanoparticles abstract
Authors: I. Capron, D. Musino, T. Rabilloud, C. Lelong, S. Luche

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Context

Over decades of research, silver nanoparticles (NPAgs) have emerged as one of the most potently effective biocidal agents, limiting or preventing microbial growth and proliferation. NPAgs find a broad spectrum of applications (in paints, cosmetics, dental materials, water treatment) due to their high surface-to-volume ratio and relatively low toxicity to human health. However, once they reach the end of their lifecycle, these biocides become environmental toxins.

Since biomolecules fail to deliver a viable solution as effective biocidal activity, the idea here is to combine biomolecules and silver particles to form a largely inert biocidal hybrid.

Results

Cellulose nanocrystals (CNCs) offer an ideal biobased substrate that can be readily surface-modified. In this protocol, we directed anchor NPAgs to the CNC surface to form a stable NPAg–CNC hybrid that can readily disperse in aqueous media. This suspension, prepared simply in water, enables controlled homogeneous distribution of the NPAgs, their size (from 10 nm to 300 nm), shape (spheres or prisms) and oxidation state (Ag+ vs. Ag0), and the amount of Ag grafted to the CNC surfaces. Moreover, this simple synthesis requires no prior chemical modification and no additional stabilizing agent.

Analysis of how these NPAg–CNC hybrids perform on B. subtilis shows potent effective short-term and long-term antibacterial properties. The optimal properties are achieved with a 20 % Ag content and with spherical 10 nm-diameter silver particles. These measurements give a minimum inhibitory concentration (MIC) of 0.048 µg Ag to achieve visible biocidal effect, which is the lowest concentration reported to date in the literature.

Future outlook

Our results on these cellulose–silver hybrids, which are hugely effective yet easy to synthesize with an inexpensive readily-available biobased template, open up all kinds of product opportunities for small and large-scale applications that revolve around biocidal agents. On top using a tiny amount of silver required, it is mostly the cellulose that will ultimately get released back into the environment.

Biomass sources used in this study: a) corn stalks ; b) *Miscanthus giganteus* (M. floridulus); c) wheat bran.
Prototype dual-jacketed glass reactor system custom-developed as part of this study - © Diana GARCIA-BERNET (LBE)

Insights into how microwaves improve the deconstruction of lignocellulosic biomass

Read more

Bichot A *et al.*

Evaluation of chemical-free microwave pretreatment on methane yield of two grass biomass with contrasted parietal content.

Energy Conversion and Management . 2021 - https://doi.org/10.1016/j.enconman.2020.113746

Bichot A *et al.*

Decoupling thermal and non-thermal effects of the microwaves for lignocellulosic biomass pretreatment.

Energy Conversion and Management . 2020 - https://doi.org/10.1016/j.enconman.2019.112220

Partnerships

This work was performed in the frame of Aurélie Bichot's PhD thesis (under a GAIA doctoral school contract) and the Valéoris project (financed by the Carnot 3BCAR network).

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Context

Pretreatment of lignocellulosic biomass is a key strategic challenge to support the development of sustainable and competitively cost-effective biorefinery processes. The pretreatments applied need to effectively and efficiently reduce biomass recalcitrance to deconstruction with low chemicals and energy consumption and low residue production. Various candidate technologies are available, but microwave treatment has started to emerge as a competitive and interesting option due to clear energy efficiency advantages, as the energy input delivered is used entirely by the substrate and the heat rise imparted is even and rapid (no inertia). However, we still know little about the mechanism of action of microwaves on biomass, and few of the studies on microwave-assisted pretreatment address the issue. Our study concerns the understanding of the mode of action of microwaves on biomass, focusing on the effect of the microwaves, on energy absorption by the biomass and on energy balance.

Results

A custom-developed dual-jacketed reactor system enabled us to test out different sets of microwave-process treatment conditions (duration, power density, quantity and type of solvent: water, ethanol, alkaline water, acidic water) while firmly controlling the temperature rise so as to decouple microwave heat effect from microwave radiation effect. The results showed that, under the conditions tested, the effect of the microwave treatment was exclusively due to the heat induced by the motion of molecules in electromagnetic fields. None of the biomass samples tested (corn stalks, *Miscanthus* stalks and wheat bran) were shown to more readily absorb microwaves. Pressurized microwave-assisted pretreatment at 4 bars with water as solvent brought the biomass to temperatures above 100 °C, which had the effect of destructuring the biomass, mainly by hemicelluloses solubilization (up to 33 %).

Future outlook

This research investigating the effect of microwaves on the deconstruction of lignocellulosic biomass is set to press ahead via the inter-Carnot (3BCAR/ Qualiment) project COLORANTH starting up in March 2021 in collaboration with INRAE–FARE and INRAE–SQPOV. The project mission is to drill down on microwave/enzyme pairings to improve anthocyanidin extraction from grape pomace.

It would also be instructive to assess the effects of high-temperature microwave heating on a wider variety of substrates and to set up a model to predict feed-material behaviour in response to dry-process microwave pretreatment.

Innovative processes to fuel the bioeconomy

TRANSFORM researcher scientists drive innovation by designing for cascading bioeconomy concepts and principles: by upvaluing farm, industry and/or urban waste into optimized waste-to-value streams built around new process route technologies and by creating products to grow the bioeconomy, such as biofertilizers, biohydrogen, or clean green alternatives to fossil-fuelled commodity compounds.

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A sustainable solution for protecting food against insect pests

Read more

Vachon J *et al.*

Use of lignin as additive in polyethylene for food protection: Insect repelling effect of an ethyl acetate phenolic extract.

Composites Part C: Open Access . 2020 - https://doi.org/10.1016/j.jcomc.2020.100044

Majira A *et al.*

Enhancing the antioxidant activity of technical lignins by combining solvent fractionation and ionic liquid treatment.

ChemSusChem . 2019 - https://doi.org/10.1002/cssc.201901916

Mobilization and impact

Translating these results to industry applications for insecticides and food packaging is a viable way forward, provided that the lignin extract scales up.

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Context

Dry-store foods are a favourite target for 'pantry pests'—insects that can get into packages and infest and contaminate the product, causing irreparable damage. Insect infestations can eat away almost 40 % of a food and severely compromise nutritional value, palatability, and food safety. Despite worldwide demand for insect-repellent food packaging, solutions remain rare and the technologies they employ are derailed by a number of drawbacks, from volatility and low thermal stability to prohibitive cost or toxicity of the additives. Zelcor, an EU-backed H2020-program project ['Bio-Based Industries Joint Undertaking'] coordinated by INRAE to give impetus to solutions for upvaluing recalcitrant biorefinery side streams, served as a space for the partners to address this challenge. Indeed, it offered to possibility to test the feasibility of using lignins as biobased insect-repellent agents for food-contact packaging. Led by consortium partner Sabic's petrochemicals division, the study focused on designing an active insect-repellent packaging material based on polyethylene and lignin phenolic compounds. Lignins are components of wood and straw and various side streams, and they offer a spectrum of functional properties that makes them good candidates as workable alternatives to natural or synthetic additives.

Results

This R&D effort brought the world-first demonstration of the anti-insect effect of technical lignin fractions matrixed into a plastic packaging. A plastics engineering technology made it possible to blend up to 5 % lignin fraction into high-density polyethylene without altering the mechanical and thermal properties of the films formed. The extrusion process is flexible enough to adaptively accommodate a lignocellulosic residue recovered from bioethanol production, a paper pulping process lignin, and even an organic extract of this pulping lignin. Due to its lower average molar mass and higher phenol content, the organic extract combines several advantages: miscibility in the polyethylene matrix, better antioxidant and antimicrobial properties, effective insect repellent activity. This organic extract, used as an additive blended at only 2 % in the polyethylene films, offers a whole new solution for the protection of dry-store foodstuffs.

Future outlook

These results pave the way for further anti-insect applications for this high-added-value lignin fraction, and for a more advanced study into the mechanisms governing its repellent properties.

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Super-enzymes to turn plastic waste into valuable resource

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Tournier V *et al.*

An engineered PET depolymerase to break down and recycle plastic bottles.

Nature . 2020 - https://doi.org/10.1038/s41586-020-2149-4

Mobilization and impact

Patents:

WO 2018/011284 et WO 2018/011281 "Novel esterases and uses thereof"

WO 2017/198786 "A process for degrading plastic products"

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Context

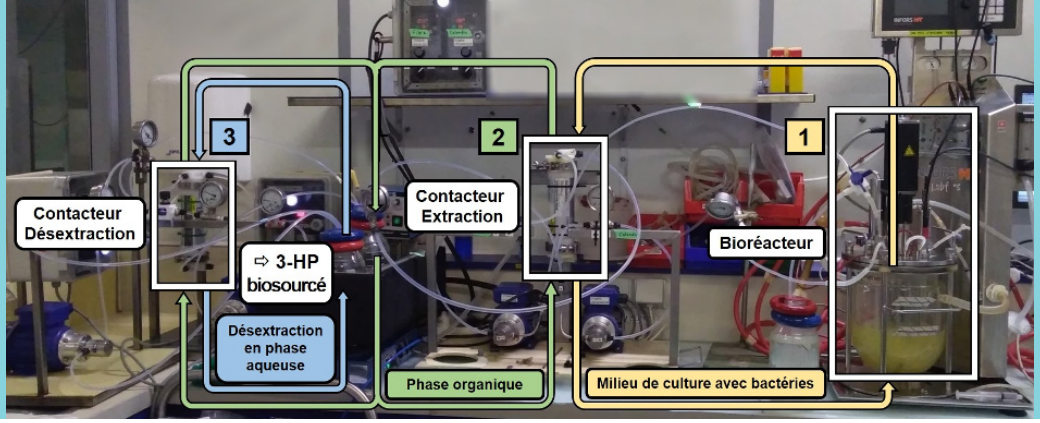
Plastics emerged only recently but have already become ingrained in the world around us. They have undeniably brought value to our everyday lives through the sheer diversity of their applications, but not without also bringing substantial impacts on our natural environment. Polyethylene terephthalate (PET) is the most common polyester on the market (annual production reached 70 million tonnes in 2018), where it is used to make bottles, textiles, and packaging containers. Only around 10 % of PET currently gets recycled. The recycling route is by thermomechanical means, but is actually an open loop: recycled PET loses much of its physical–chemical properties, to the point that PET recyclate cannot be reincorporated in new bottles at any more than 25 %. It gets also re-streamed into textiles, which again are hugely under-recycled. Ultimately, PET plastic ends up as pure waste. To date, the enzymes described as capable of depolymerizing PET into its component monomers (ethylene glycol and terephthalic acid)–and thus of using 100 % of this waste as a resource–are still a long way from true industrial-scale recycling. Effective post-consumer management of plastics waste with closed-loop waste-to-value re-steaming is therefore pivotal to delivering social and environmental sustainability.

Results

The CIMEs team at the Toulouse Biotechnology Institute joined forces with French company Carbios to optimize a long-forgotten PET depolymerase called 'leaf compost cutinase' (LCC) ready to drive development of an enzymatic biorecycling process. A compelling combination of advanced structural biology and molecular modelling enabled to identify the key molecular determinants involved in the PET depolymerization reaction, which were then targeted to generate a library of enzyme variants. Work was completed in parallel to improve the enzyme's thermal stability. This highly efficient, optimized enzyme achieves 90 % PET depolymerization in the space of just 10 hours, enlightening much higher productivity performance than all biological PET recycling processes reported so far. Carbios and CRITT Bio-Industries (INSA Toulouse) have developed monomer purification processes from which 100% recycled and 100% recyclable bottles were then produced. Their properties are identical to those manufactured by polymerizing brown-economy monomers, which is progress that cements the circularity of the process. L'Oréal, Nestlé Waters, PepsiCo, Suntory Beverage & Food Europe, recently validated this technology by each producing a bottle.

Future outlook

This world-first breakthrough illustrates the capacity of French public–private partnership collaboration to drive basic and applied research to the highest international level, and raises prospects for transitioning to circular economy technology that can deal with all PET waste. This is a game-changingly disruptive solution to address environmental problems caused by mass use of plastics. This enzyme is set to be used at the close of 2021 on the industrial readiness demonstrator currently being built by Carbios.



Extractive bioconversion for 3-hydroxypropionic acid production
© F. de Fouchécour, AK Sánchez-Castañeda

Using acetic acid bacteria to fuel the bioeconomy

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De Fouchécour F *et al.*

Process engineering for microbial production of 3-hydroxypropionic acid.

Biotechnology Advances . 2018 - https://doi.org/10.1016/j.biotechadv.2018.03.020

Mobilization and impact

This research has led to the filing of a patent (#EP20305396.2, De Fouchecour F, Castaneda A-K, Saulou-Bérion C, Moussa M, Athes-Dutour V, Spinnler H-E, Tréléa C) and a scientific article published in 2020 (doi:10.1002/jctb.6284), with three more papers prepared ready to be submitted(De Fouchecour F, Castaneda A-K, Saulou-Bérion C, Moussa M, Athes-Dutour V, Spinnler H-E, Tréléa C)

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Context

Looking ahead at solutions to serve the circular bioeconomy, polyfunctional organic acids are a major target for markets ranging from commodity feedstocks to speciality products like aroma compounds. One of today's big challenges is to develop a microbially-driven biorenewable production chain for these platform feedstocks. Among the candidate microorganisms, acetic acid bacteria present a particularly attractive functionality: the ability to oxidize alcohols into organic acids.

Results

The ProBioSSep team at the SAYFOOD joint research centre works on the integration of microbially-driven production and in-stream extraction processes. The team mobilized this approach to produce 3-hydroxypropionic acid (3-HP), an industrial precursor of acrylic acid, as a model platform molecule. Our precursor is 1,3-propanediol (1,3-PDO), for which organically-driven production is at industrial scale-up. We demonstrated that after growth on glycerol as substrate, the bacterium *Acetobacter* CIP 58.66 has the ability to produce 3-HP at high concentration (70 g L-1) with near-100 % molar yield and in excess of 1 $g.L^{-1}.h^{-1}$ productivity under aerobic culture conditions progressively fed in-stream with 1,3-PDO.

The 3-HP is recovered by reactive extraction using amine solvents that can selectively interact with the acid, in a process coupled with bioconversion. The reactive extraction process uses a first membrane contactor with downstream recovery of 3-HP from the aqueous phase in a second membrane contactor. This integrated extractive–bioconversion process enables full recovery of all product. We modelled the bioprocess kinetics involved in order to better describe the bacterial phenomena observed and gain a sharper understanding of the transfer mechanisms at work in the extraction process.
Other *Acetobacter*-driven bioconversion routes have been trialled and validated for producing other potentially valuable organic acids from higher alcohols for higher-value-added applications, ready to benefit from generic knowledge through our 3-HP model in tandem with the process integration approach.

Future outlook

The kinetic models developed in this work will be validated and further tuned in order to define an effective strategy for scaling, running and methodizing the integrated in-stream process. Research on extending and expanding the use of acetic acid bacteria to produce speciality compounds is currently ongoing through PhD thesis work.

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An integrated approach to minimize water consumption in the food –farming industry

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Garnier C *et al.*

Towards reduction of water consumption in vegetable processing industry through membrane technology. Case study of a carrot processing plant.

Environmental Science and Pollution Research . 2020 - https://doi.org/10.1007/s11356-020-10160-0

Romdhana H *et al.*

Exemple de stratégie de réduction de l'eau par l'analyse du pincement dans la conservation des légumes : présentation d'un cas d'étude issu du projet ANR Minimeau.

Industries alimentaires et agricoles . 2020

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Context

The MINIMEAU project aims to enable food–farming industries to minimize their water consumption in an effort to address today's urgent problems surrounding the availability, quality and cost of water. With that vision, MINIMEAU aims to facilitate wastewater reuse in food-commodity processes by developing a set of decision support and decision analysis and technological solutions enabling industries to reorganize their water networks without affecting the quality and safety of their food output.

The process re-engineering tools proposed here are based on the pinch analysis method that was originally designed to minimize energy consumption in industrial process plants. Transposition of the method to aqueous flows theoretically makes it possible to calculate minimum water network consumption, but practical implementation is complicated by the presence of other criteria ('pollutants') within the feedwater flows.

Results

A simplified pinch analysis (reorganization of water flows without re-treatment, only factoring a single pollutant) applied at ten pilot companies has shown a potential 30 %–45 % reduction in feedwater. In parallel, we pieced together a generic tool coupling pinch analysis with multicriteria optimization. The validity and effectiveness of the approach have been demonstrated on a case study from the literature and it is currently being field-deployed at a frozen vegetable packing facility and an edible oil refinery. At both these sites, the effluents identified as opportunities for reduction are going through water re-treatment trials. Membrane processes (reverse osmosis/nanofiltration) installed on rinsing or blanching-line (carrots, cauliflower) effluents can recover a water of satisfactory quality that is potentially reusable.

Future outlook

To ensure that the process re-engineering solutions do not simply divert the environmental impacts, their 'water footprint' will get assessed using a method developed at the IRSTEA–ITAP joint research centre. At project completion, a user-friendly 'toolbox' will be made available to all stakeholders involved. These results should also inform how government authorities set about recasting regulation related to water recycling and reuse, which is currently a limiting factor.

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Progress towards a new participatory multi-criteria decision analysis method

Read more

Sohn J *et al.*

Argumentation corrected context weighting-life cycle assessment: a practical method of including stakeholder perspectives in multi-criteria decision support for LCA.

Sustainability . 2020 - https://doi.org/10.3390/su12062170

Mobilization and impact

ArgCW-LCA has been trialled on vine-and-wine-sector constituencies to support a NoAw project decision on polyphenol extraction processes. The methodology is generic by design, making it perfectly transferable to other settings that require support on decisions involving a broad community of agents advancing a broad spectrum of narratives.

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Context

Life cycle assessment (LCA) is a process methodology for assessing the environmental impact of a product through various impact categories (burden on ecosystems, burden on human health, and so on). Impact scores for these criteria can be aggregated into a single composite score characterizing the all-round net impact of a product that can then serve as an indicator for comparing products on environmental performance. However, the scores for the impact categories need to be weighted, and weighting remains a tricky issue, as it brings a degree of subjectivity that can expose decisions to practitioner bias, produce environmental inequities, and ultimately undermine public acceptance for LCA-supported policy and planning. LCA practitioners would benefit from a process that transparently integrates multiple stakeholder perspectives and positions, which would help them reduce biasing and present the public with clearly-presented results, spelling out the rationales behind any particular weighting decisions.

Results

The INRAE–IATE knowledge engineering team ('ICO'), working in collaboration with international research-community, developed a methodology called 'Argumentation-Corrected Context Weighting for LCA' (ArgCW-LCA) that facilitates a more inclusive LCA process by transparently integrating and accommodating the multiple perspectives held by different constituencies. ArgCW-LCA equips an LCA practitioner to (1) factor in the full set of LCA environmental impacts, (2) include non-environmental impacts, (3) provide a transparent picture of the weightings used based on participant preferences, and (4) integrate stakeholder-constituency perspectives through a process of argument justification assessment. The method has been put into practice in the Horizon 2020 NoAW project where a community of researchers and industry constituencies is tasked with selecting a polyphenol extraction process technology for transition up to pilot scale.
ArgCW-LCA essentially advances a constituency consensus-based approach to interpret environmental assessments by including social and economic variables, which offers a pathway to LCAs that can better internalize all dimensions of sustainability.

Future outlook

The participatory component of ArgCW-LCA warrants deeper enquiry in its current model, the methodology enables decisionmakers to adaptively configure context-relevant decision support variables. The growing development of digital democracy-enabling technologies can be expected to further facilitate the integration of stakeholder-constituency perspectives, which would mark a precious step toward public participatory design for unbiased and consensus-built decision practice.

INRAE–LBE pilot-scale two-step organic-route hydrogen and methane production unit. ©INRAE

Turning municipal waste into valuable biohydrogen

Read more

Paillet F *et al.*

Inhibition by the ionic strength of hydrogen production from the organic fraction of municipal solid waste.

International Journal of Hydrogen Energy . 2020 - https://doi.org/10.1016/j.ijhydene.2019.08.019

Mobilization and impact

This research led to an INRAE–TRIFYL patent. In addition, this research:

– was awarded by the 'Circular economy prize' in the 'Research' category in 2018 (delivered by the French Ministry for Ecological and Socially-Responsible Transition).

– prompted and is set to be pursued through the ANR [French national research agency]-funded ProBHYM project (2018–2023) where H_2 bioprocess control and optimization strategies will be implemented at lab and pilot scales.

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Context

Anaerobic digestion processes are one of the main pillars of the French energy transition for the green growth act in France, and the anaerobic digestion industry has taken off over the past few years. However, questions remain around whether anaerobic digesters have a viable long-term future, making sense to start exploring new, innovative and complementary waste-to-value process routes. Fermentation processes can fit right in by producing clean industrial commodity compounds and a 'green' ecology-conscious biological hydrogen, also called biohydrogen. The challenges surrounding fermentation bioprocess technologies today are to stabilize them and secure their long-term operability.

Results

Research has homed in on the influence of culture media on the waste fermentation (where waste is the fermentable 'organic fraction of municipal solid waste') in mixed microbial cultures. Although the inhibitory effect of certain solute ions–mainly ammonium and sodium ions–had already been reported, we showed here that the main factor inhibiting the microbial activity was not the individual ionic composition but the total ionic strength of the culture medium (where total ionic strength aggregates not just the concentration but also the characteristics of all in-culture ions). Furthermore, we found that fermentative hydrogen-producing bacteria (*Clostridiaceae* and *Enterococcaceae*) were specifically impacted by this parameter, and we identified a critical upper ionic strength threshold (around 0.75 M). However, the ionic strength of complex media remains tricky to estimate without advanced fine-grained ionic composition data. To address this issue, we showed that the electrical conductivity, largely resulting from the ionic strength, gives a reliable approximation for measuring and identifying potentially inhibitory conditions. On-line conductivity measurement proves to be a rapid, robust and inexpensive solution for on-site facility bioprocess control, with the advantage of being adaptable for all types of fermentation in mixed microbial cultures, and whatever the substrate or waste stream considered.

Future outlook

The results of this work raise fresh prospects for operating fermentation bioprocess technologies. Looking beyond the production of green hydrogen, the integration of fermentation processes in anaerobic digestion industries will help to materialize the environmental biorefinery concept to deliver a broader panel of energy vectors and green commodity compounds.

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Delving into the phyllosphere to gain inspiration for thermophilic bacteria-driven waste-to-value processes

Read more

Godon JJ *et al.*

An "overlooked" habitat for thermophilic bacteria: the phyllosphere.

BioDiscovery . 2020 - https://doi.org/10.3897/biodiscovery.23.e47033

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Context

Thermophilic microorganisms already drive many of the biological processes we use to turn our waste streams into value, like composting and anaerobic digestion. However, there is still huge untapped potential in these microorganisms and their allied enzymes, and the fact that they are found thriving in so many different natural biotopes cannot be explained solely by the presence of geothermal sources at specific niches dotted across the planet.

Results

We set out to find out which is the predominant habitat for thermophilic microorganisms on Earth. An early candidate is the 'phyllosphere'–the total above-ground surface of plant organs–as the temperature at the surface of plant can reach upwards of 50 °C, thus approaching thermophilic conditions. To test this hypothesis, we collected leaves from 11 species of tree across three continents and analyzed their leaf-surface ecosystems. 16S rDNA sequencing found that 0.2 % to 7 % of the bacteria present on fresh-cut leaves were clearly thermophilic, and that leaves incubated at 55 °C under aerobic and anaerobic conditions reached up to 99 % thermophiles in some cases. These evidence-based observations lend coherence to our hypothesis that the phyllosphere is already a major biotope for thermophilic bacteria on Earth and that they can grow substantially if they are given favourable conditions.

Future outlook

Our findings open up a spectrum of opportunities for industrial biotech process control and optimization. To start with, our findings challenge the mainstream idea that processes need to maintain a constant temperature–as is the case in geothermal energy sources–as temperature at the leaf surface fluctuates wildly over the course of the day and the microorganisms at the leaf surface can draw benefit from these fluctuations. Moreover, the ability of these microorganisms to withstand major stressors like dessication and UV radiation could serve as the inspiration to guide the design of new processes and thus new routes to even more efficient organic waste-to-value solutions.

Agronomic use of digestates from sewage sludge and their co-digestion with olive pomace biomass and red macroalgal residue from agar-agar extraction. Tomato plants at 28 days of growth.
© Doha El Alami

Pretreatment and co-digestion: key factors for biogas production and digestate quality

Read more

Elalami D *et al.*

Effect of coupling alkaline pretreatment and sewage sludge co-digestion on methane production and fertilizer potential of digestate.

Science of Total Environment . 2020 - https://doi.org/10.1016/j.scitotenv.2020.140670

Carrere H *et al.*

Review of pretreatment strategies for improved feedstocks anaerobic biodegradability: from lab-scale research to full-scale application.

Bioresource Technology . 2020 - https://doi.org/10.1016/j.biortech.2015.09.007

Partnerships

UMR IATE, APESA et UM6P, Univ Cadi Ayyad et OCP (Maroc)

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Context

Circular economy principles for waste-to-value processes are a vital part of the effort to minimize the use of dwindling fossil fuel resources. Circular economy principles are especially pivotal in developing nations where most organic waste ends up either burned or landfilled. Anaerobic digestion combines the triple advantage of reducing the amount, producing biogas, and affording an organic soil improver. Pretreatments effectively and efficiently improve waste conversion to biogas, but their impact on digestate quality has rarely been studied. The pretreatment needs to be adapted to type of substrate, and choosing the right pretreatment upstream of a multi-waste-stream co-digestion project is a problem in itself. The aim of this study was to optimize a waste-to-value process that uses macroalgal residue (MAR) from agar-agar extraction and olive pomace biomass via co-digestion with sewage sludge to produce biogas and organic fertilizer.

Results

Biogas output was maximized in scenarios that included sludge co-digestion with the two biomass streams and substrate-mix pretreatment with alkali. All the digestates were trialled as biofertilizers for tomato plants, and all led to identical germination indexes across trials. Adding the digestates as biofertilizers improved tomato plant growth compared to unfertilized soil, with the strongest improvement coming from sludge-only or sludge-plus-MAR and olive pomace digestates. This growth was correlated to phosphorus content (added by the sludge inputs) and the total and ammonia nitrogen content of the digestates. The alkali pretreatment that promotes protein degradation also increased ammonia concentration. Furthermore, adding the digestates increased the C, N and chlorophyll contents of the tomato plants.

Future outlook

This important work opens up pathways to the integration of pretreatment processes in biorefinery process stages, including anaerobic digestion where our research aims to evidence strategic mechanisms that not only enhance the biodegradation of organic waste but also optimally modify the digestates for use as agronomically-valuable soil improvers. This kind of interdisciplinary approach to support nexus thinking for the bioeconomy could valuably enlist other divisions, such as AgroEcoSystems.

Lab-scale anaerobic biogas reactor.
©LBE - INRAE

Anaerobic digestion: a pivotal waste-to-value pathway in the energy transition for green growth

Read more

Braga Nan L *et al.*

Biomethanation processes: new insights on the effect of a high H2 partial pressure on microbial communities.

Biotechnology for Biofuels . 2020 - https://doi.org/10.1186/s13068-020-01776-y

Figeac N *et al.*

Temperature and inoculum origin influence the performance of *ex-situ* biological hydrogen methanation.

Molecules . 2020 - https://doi.org/10.3390/molecules25235665

Mobilization and impact

These research issues are part of two ongoing PhD, an ANR-funded 2020 project, and a partnership (being finalized) with a French energy company.

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Context

Anaerobic digestion processes can convert hydrogen and carbon dioxide or carbon monoxide into biomethane that can be stored or injected into the gas grid. This bioprocess is an important technological building block for biomass and organic waste-to-value pathways and renewable energy production:

i. applied in the power-to-gas concept, it allows the valorisation of electricity surplus generated by intermittent renewable energy sources like wind or solar, by an electrolyzer plant that converts electricity into hydrogen

ii. coupled with the gasification of dry biomass or solid recovered fuel, it can convert the syngas produced (a mixture of H_2, CH_4, CO and CO_2) into high-grade biomethane.

Whatever the configuration, the anaerobic digestion/biomethanation process needs to be optimized, and optimization hinges on research into the microbial actors and processes involved.

Results

Seven microbial ecosystems from various industrial waste treatment facilities (wastewater treatment plants, sewage sludge digesters, manure digesters) were used to inoculate anaerobic digestion reactors. The reactors were then fed with glucose and hydrogen for a period of 12 days. After H_2 injection, the determinants of methane and acetate production were investigated. The most efficient methane productions were observed at the beginning and the end of incubation, when the *Methanosarcina* genus was dominant. Key indicators of high *in situ* biomethanation process performance were identified: (i) a high and persistent 'archaea-to-bacteria' ratio, (ii) a high ratio of hydrogenotrophic methanogenic archaea to homoacetogenic bacteria, (iii) presence and persistence of *Methanosarcina* spp.

Future outlook

Recent research shows that France has the resource potential to replace its entire natural gas consumption by renewable biogas by 2050, through a combination of anaerobic digestion, pyro–gasification, and methanation. In this context, the connection between these three processes has been launched at the LBE and must be expanded in its 2021–25 project. One of the directions is to intensify biomethanation coupled with methanization, based on an understanding and control of critical abiotic factors (gas–liquid transfer, pressure) and valuable biotic factors (use of microbial consortia enriched with hydrogenotrophic archaea).

Data, modelling and integration of knowledge sets

TRANSFORM researchers integrate their knowledge-sets on specific subdisciplines to track and trace target molecules in foods and select the compounds that are most beneficial to human health. They create fresh datasets and mobilize data from the literature to study potential transitional scenarios.

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Cold-chain-to-energy: tapping into the thermal inertia of products in a cold store

Read more

Akerma M *et al.*

Experimental characterization of demand response in a refrigerated cold room
Caractérisation expérimentale de la réponse à la demande dans une chambre froide.

International Journal of Refrigeration . 2020 - https://doi.org/10.1016/j.ijrefrig.2020.02.006

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Context

The growing share of renewable energies in electricity grids means that distribution needs to learn to flexibly adapt to power-source availability and intermittency. When the share of renewable sources in the energy mix dips, the demand response system may ask heavy consumers to reduce –or 'curtail'– their electricity consumption at critical times. Agri-food industry cold chains mobilize countless cold storage warehouses that hold huge potential as front-line support for load shedding and curtailment. Cold-chain curtailment is a workable option provided it comes with solutions to guarantee effective and efficient energy-use conditions that maintain critical in-storage food safety.

Results

A cold store (simulating a cold storage warehouse) loaded with 4 pallets of test products was set up inside another cold room to simulate varying weather conditions, and used to investigate the energy-demand impact of variations in key curtailment parameters such as duration, load-fill rate, outdoor temperature and setpoint temperature. The load-fill volume, which inputs substantial thermal inertia, can significantly dampen the product temperature rise during curtailment. Increasing setpoint temperature or decreasing outdoor temperature also has an impact on temperature rise, as the heat loss from the cold storage room to the outer space is reduced.

This study found that curtailment does not drive up power consumption and can even–in specific configurations– bring power consumption down (as the machine is turned off during the curtailment) by as much as 10 %. This research has developed and delivered new indicators to capture and characterize these effects (temperature rise, postponing power effect and consumption variation).

Future outlook

The effort is now turning to reliably predict how the system (cold storage room plus in-store products) responds to fluctuations in temperature and electricity consumption. To support this effort, we are in the process of developing two modelling approaches–a black-box model (machine learning via deep learning artificial neural networks) and a white-box (physical) model. We intend to bridge these two approaches together into a grey-box model.

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A statistical tool developed to select protein sources nutritionally adapted to the needs of seniors

Read more

Duval A *et al.*

Development of a Statistical Workflow for Screening Protein Extracts Based on Their Nutritional Composition and Digestibility: Application to Elderly.

Foods . 2020 - https://doi.org/10.3390/foods9101499

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Context

Risk for undernutrition and malnutrition in the elderly affects 4%–10% of people living at home, 15%–38% of people living in eldercare facilities, and up to 70% in hospitals. Ageing increases protein demand: in quantity, as seniors need a roughly 20%-higher-protein diet to maintain total body protein, and in quality, as the protein they need has to meet compositional and nutritional-value characteristics that are important to evaluate. This study set out to develop a statistical workflow for screening a panel of protein extracts and to identify their potential value as high-nutritional-quality ingredients for functionally-formulated senior-appropriate recipes.

Results

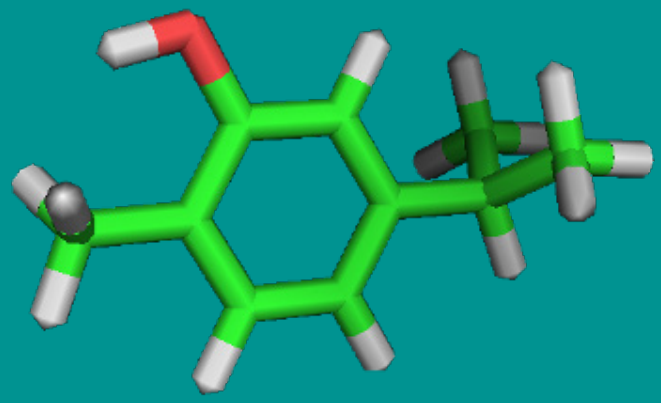
The statistical analysis workflow developed here serves to: i) synthesize the compositional and nutritional data on each extract in the form of latent variables and ii) use these variables to cross-compare the full set of powdered protein extracts. First, hierarchical agglomerative clustering is used to produce a global visualization of the relationships between variables and protein extracts as a heat map of the compositional and digestibility variables. Cluster analysis then reduced the set of 48 quantitative variables into 15 qualitative latent variables defined against compositional, nutritional, or bioactivity-related criteria. We then applied *k*-means clustering on each latent variable to classify the protein extracts by partitioning into three levels of intensity (low, medium, high).

Multiple correspondence analysis (MCA) then emerged groups of protein extracts with varied underlying patterns. Two salient examples: one cluster gathering three dairy-source extracts with high contents of proteins, late-digestive peptides and essential amino acids, and another cluster gathering two animal-source extracts that get rapidly digested in the gastric phase..

Future outlook

This purpose-developed workflow served as a platform to cross-compare the protein extracts and select out the best candidates on the basis of their nutritional quality. This statistical analysis-driven approach has found protein extracts with complementary profiles that can be combined to not only offer valuable dietary support by blending micronutrients and macronutrients but also packed with readily-digestible proteins and essential amino acids.

The assets of this approach are that it is generic enough to work for other ingredients and ready to work with technical–functionality data and sensory analysis input.



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Mobilizing medicinal chemistry for more healthful food

Read more

Meurillon M *et al.*

Mitigation of heterocyclic aromatic amines in cooked meat. Part I: Informed selection of antioxidants based on molecular modeling.

Food Chemistry . 2020 - https://doi.org/10.1016/j.foodchem.2020.127264

Partnerships

Project "MARMEAT" bringing together a 3-partner consortium and funded by the division Transform:

- INRAE, UR370 QuaPA, MASS, Saint-Genès-Champanelle
- IRIM, Montpellier
- INRAE, Toxalim, Toulouse / Metatoul-Axiom Platform, MetaboHUB, Toxalim, Toulouse

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Context

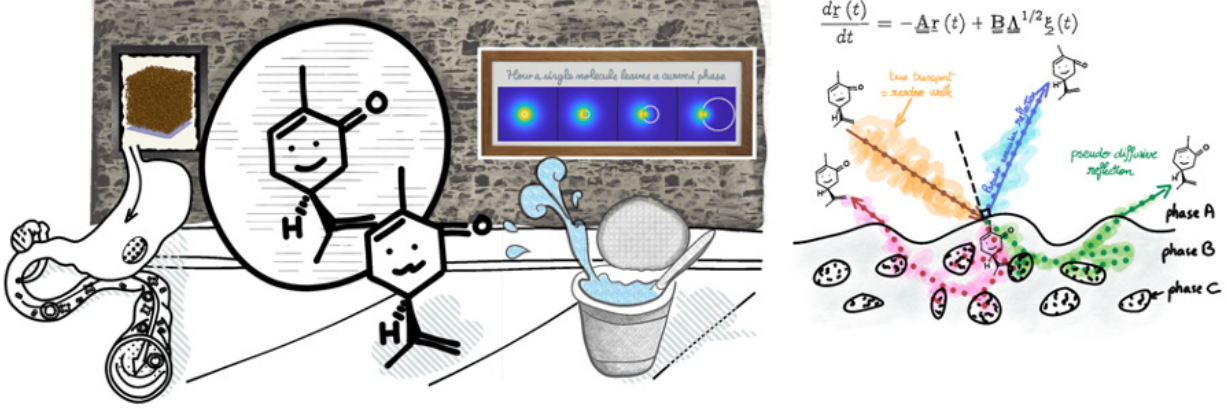
In 2015, the International Agency for Research on Cancer (IARC) categorized red meat as 'probably carcinogenic', singling out in particular the heterocyclic aromatic amines (HAAs) that form during cooking. One of the most promising methods to mitigate the formation of HAAs is to act on formulation by adding antioxidants, but the process of selecting the right antioxidants remains essentially empirical. To break this bottleneck, a reasoned method for choosing the best antioxidants is needed.

Results

We developed a unique and original method mobilizing knowledge from medicinal chemistry to find the antioxidants best equipped to inhibit HAA formation.
Borrowing loosely from the drug discovery process, we emerged the most potent candidate antioxidants via analogue design approaches that work by improving an existing molecule to neutralize its undesirable properties (i.e. off-taste).
Structural and conformational similarity analysis shortlisted 4 natural antioxidants: resveratrol, quercetin, epicatechin and carvacrol. Then, development of a pharmacophore model, which describes the molecular features necessary for bioactive response, revealed that the polyphenolic scaffold and two *meta*-position hydroxyls were pivotal to increasing the reactivity of these antioxidants. Electrostatic potential surface analysis served to map out the biological reactivity of these 4 candidate antioxidants.
We then tested out their capacity to inhibit HAAs. Resveratrol proved the most potent candidate, as it totally inhibited some HAAs and reduced the formation of other HAAs by 40 % -70 %.
We finally turned to look at ingredients that are naturally rich in these antioxidants. Oregano, which is rich in carvacrol, proved the most promising candidate.

Future outlook

This original method has made it possible to rationalize the choice of antioxidants that can inhibit HAA formation in meat. A three-division project based on these results has now been launched to investigate the protective role of carvacrol against HAA-induced carcinogenesis. This original approach could also reach beyond the selection of active antioxidant ingredients to encompass the selection of culinary ingredients and, from there, to factor in the role of other compounds found in natural ingredients. Furthermore, this same method may also transpose to the mitigation of other process-induced toxicants like polycyclic aromatic hydrocarbons that form when meat is smoked, flash-fried or flame-grilled.



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Modelling mass transfers in foods across every scale

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Vitrac O *et al.*

Modeling in food across the scales: towards a universal mass transfer simulator of small molecules in food.

SN Applied Sciences . 2020 - https://doi.org/10.1007/s42452-020-03272-2

Partnerships

This Langevin dynamics implementation code is just one brick in a far more ambitious simulation ecosystem capable of describing changes in food microcomponents simultaneously with the evolution of food macrocomponents and structures using concurrent multiscale modelling.

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Context

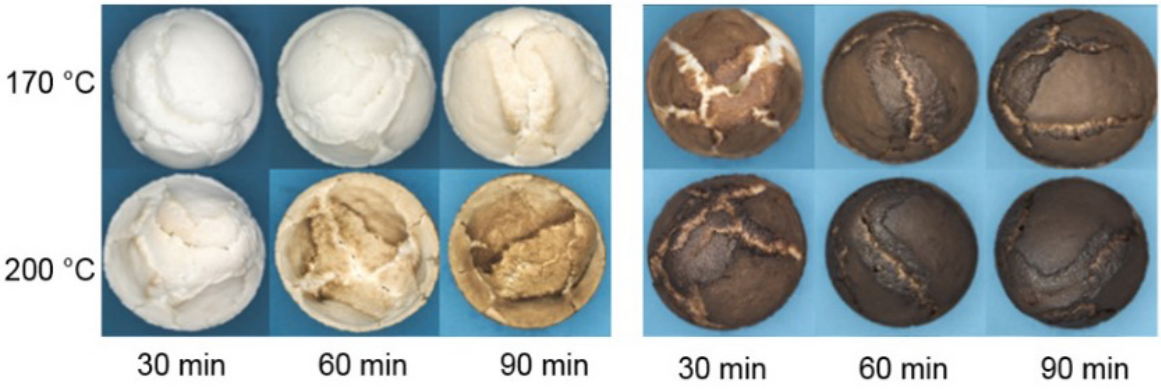
At macroscopic scales, the compartmentalized and evolving structure of foods proves a barrier to using the standard modelling tools for food processing and digestion simulations. At microscopic scales, physics laws prove a barrier to any attempt to precisely predict the exact number of different solutes in a given region of space at a given point in time. Conventional mass transfer descriptions calculate the first statistical moments (mean particle densities or fluxes), which critically lacks the granularity needed to describe the same transport phenomena occurring at microscopic scale around interfaces, agglomerates, or macromolecules. The net result is that it is difficult to build generic predictive models that factor in food structures and compositions in any detail.

Results

The diffusive motion of small solutes in multiphasic or structured foods is radically different from free diffusion. Multiple interface crossings and hits tend to reduce the molecular mobility of the solutes and create long-term correlations in their displacements, from which macroscopic properties emerge that are qualitatively different from those deduced from microscopic disorder. The new numerical implementation invokes a stochastic process (Langevin dynamics) to preserve the essential microscopic details while accounting for local thermodynamic equilibrium at interfaces and confined spaces with almost limitless resolution. A straightforward parameter-set is proposed to describe the diffusivity of micronutrients, flavours, or contaminants in digitized-object structures such as emulsions, micelle suspensions, liposomes, cells. The final physical formulation shares analogy with optical phenomena such as reflection, dispersion, refraction, and diffraction, and lends itself well to parallel integration. Just like in raytracing algorithms, each substance freely moves around its environment space independently of all others. The finest-grained feature details are continuously resolved using exact probabilistic interpretations for 1D or 2D flat interface hits and crossings.

Future outlook

It is now possible to calculate the macroscopic diffusivities in foods at every stage from processing to digestion without going through spatial discretization. The properties can be extracted from confocal laser microscopy or X-ray microtomography observations then integrated into continuum mechanics simulations as material laws. The combination of tandem macro- and micro-scales opens up a wealth of possibilities for optimizing food structure and engineering controlled barrier and release properties.



Levels of browning on glucose-enriched model cakes with vs without leucine, at different baking intensities.
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Model cakes purpose-designed for dynamic investigation of in-cooking reaction mechanisms

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Lee J *et al.*

Potential of model cakes to study reaction kinetics through the dynamic on-line extraction of volatile markers and TD-GC-MS analysis.

Food Research International . 2020 - https://doi.org/10.1016/j.foodres.2020.109087

Bousquières J *et al.*

Rational design to develop a non-reactive model food imitative of a baked cereal product by replacing the functional properties of ingredients.

Food Hydrocolloids . 2017 - https://doi.org/10.1016/j.foodhyd.2016.09.036

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Context

Food production routes involve interactions between physical and chemical events that shape the quality of the food. Understanding how these interactions occur is a critical asset to mastering formulation–process interactions and the resulting quality outcomes. When bakery goods are cooking they undergo thermal reactions that produce and shape key aroma-note and colour compounds–but also potentially toxic compounds such as furan derivatives. A large bulk of the research on in-cooking reaction mechanisms has used liquid model systems, which fail to translate the structural and compositional heterogeneity of solid foods brought about by heat transfers. A solid model product that can stage targeted reactions is therefore a vital step forward to track the in-cooking kinetics of key chemical markers under firmly controlled chemical composition and transfer conditions.

Results

We mobilized formulation engineering to design a model cake mimicking a sponge cake structure. The reactive ingredients (sucrose, egg, and flour proteins) were replaced by small amounts of cellulose derivatives conferring the same in-food functional features (swelling, thickening, gelling) as the ingredients swapped out. A suite of analyses confirmed that there was absolutely no trace of precursors and products of thermal reactions, even at relatively extreme cook-temperature programs (200 °C for 90 min)–the model cake crumb stayed perfectly white, with zero signs of browning. However, when the model cake was added with glucose (a precursor to caramelization reactions) or glucose and leucine (precursors to Maillard reactions), both reaction pathways were triggered by baking and continued through to browning, although at different levels and speeds according to baking time–temperature conditions. The volatile compounds formed in each model prove representative and characteristic of the reaction pathways that the substrate or substrates are expected to induce. A quantitative method for dynamic on-line extraction sampling coupled with chromatographic analysis gave as a rapid technique for tracking 10 different marker chemicals in a scale range from 32.5 µg down to 0.041 ng.

Future outlook

These compelling results, completed by in-model marker data measurements, will be put to work to develop robust and rich databases to enable stoichiokinetic modelling. Once coupled with transfer models, this work will lead to a better understanding of the chemical phenomena at play when baking cereal-based food. This strategy also opens promising perspectives for delivering new product innovations through rationalized formulation engineering.

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Unraveling the literature chaos around free ammonia inhibition in anaerobic digestion

Read more

Capson-Tojo G *et al.*

Unraveling the literature chaos around free ammonia inhibition in anaerobic digestion.

Renewable and Sustainable Energy Reviews . 2020 - https://doi.org/10.1016/j.rser.2019.109487

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Context

Anaerobic digestion is a biological process that is widely used to manage a host of biowaste effluents and food–farming slurries (from livestock, slaughterhouses, dairies, and so on) and produce biogas. The ammonia (NH_3) found in these effluent streams is one of the main inhibitors of the process. Ammonia nitrogen is a key macronutrient that helps stabilize digester pH, but concentrations above 1000–1500 mg $N\text{-}NH_4^+$ L^{-1} are widely flagged reported as inhibitory. A number of scientific studies show huge disparity in inhibition values, which rules out finding a consensus on ammonia concentration thresholds and thus bottlenecks efforts to extrapolate results up to industrial-scale processes. We therefore engaged this study to: i) propose a unified method for calculating ammonia nitrogen in digesters and ii) tease out the factors causing such broad disparity in inhibition values

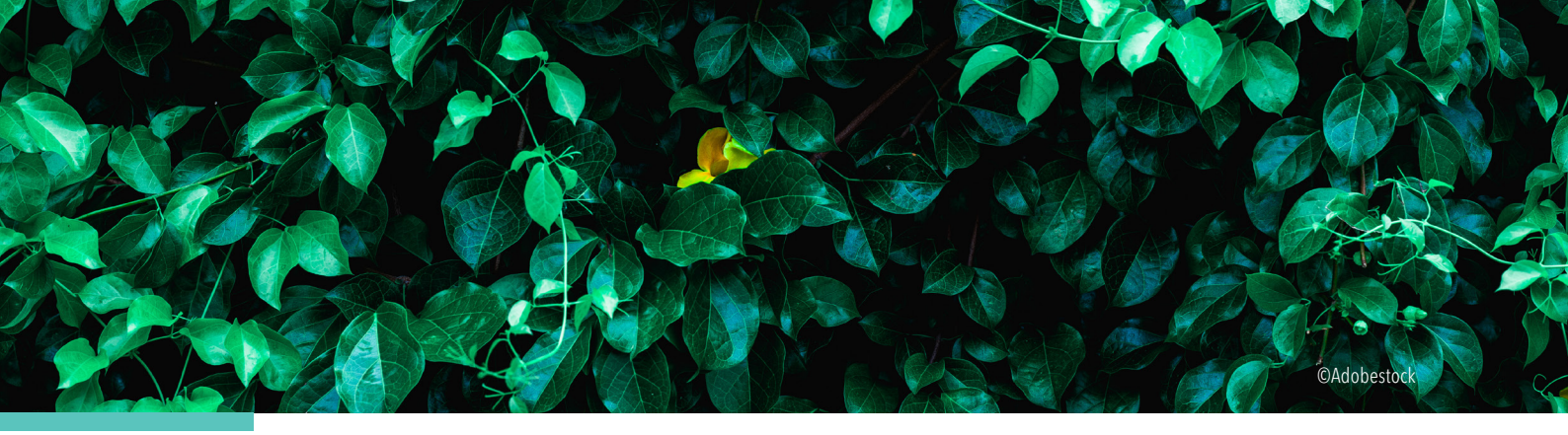
Results

We started out by comparing various different algorithms for calculating ammonia concentrations in digesters. We recalculated the ammonia inhibition limits based on data gleaned from more than 50 published papers on the topic, and then produced a classification stratified by substrate, operating conditions, and the microbial communities present. Our results showed that the ideal equilibrium equation should not be used for calculating ammonia as it significantly overestimates the concentrations (by up to 37 %). The Davies equation, slightly modified to account for the activity of the ions present, emerged as the best compromise between complexity and precision, but it is still necessary to measure the sodium and potassium contents of the digester in order to get a proper estimate of the ammonia concentration.

We therefore went back over all the data available in the literature (1590 datapoints) to recalculate the inhibition thresholds, and showed that pH and temperature are the main factors affecting ammonia inhibition. This work also highlighted the importance of microbial adaptation, which is hugely dependent on the methanogen populations present at the onset of inhibition.

Future outlook

This exhaustive fine-grained analysis of the literature made it possible to finally lift the veil shrouding ammoniacal nitrogen inhibition threshold values in anaerobic digester processes and unpack the operational factors that can influence anaerobic digester performances. This work opens up a number of pathways to optimizing biogas production, which is a big issue for agricultural anaerobic digesters processing livestock manures and slurries.



Towards an automated workflow for reading the mass spectra of plant oligosaccharides

Read more

Lollier V *et al.*

Oligator: a flexible interface to draw oligosaccharide structures and generate their theoretical tandem mass spectra.

Bioinformatics . 2021 - https://doi.org/10.1093/bioinformatics/btab412

Mobilization and impact

These tools are publicly available in the GitHub source code repository.

A scope brief is being drafted to help mobilize these valuable software technologies.

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Context

Glycans are the main plant cell wall components. They are known to have effects on nutrition and hold strong potential in green chemistry, but further applications are bottlenecked by the unmet challenge of resolving their precise structure. Tandem-mass spectrometry (MS/MS) is a mainstay analytical technique for resolving the structure of biopolymers. However, a shortage of good-quality reference leaves this high-throughput technology underequipped in terms of tools to support an automated workflow for reading mass spectra, especially for plant glycans. The structural analysis of these complex molecules demands specific methodological developments where the interpretation of mass spectra has to be done manually, which is a painstaking and laborious task that fails to capitalize on the powerful analyses carried out.

Results

The BIBS platform has developed two software packages, Oligator and mzLabelEditor, to facilitate the interpretation of mass spectra and the collection of spectral reference data. These two software programs standardize the process of structural sketch-up and annotation of MS/MS spectra but keep the flexibility needed to explore new chemical forms of oligosaccharides.

Oligator provides a graphical interface to sketch up a candidate oligosaccharide structure and then produce its theoretical MS/MS spectrum based on the usual ion nomenclature. To store the structures and explore unreferenced chemical substitutions, Oligator uses the popular chemoinformatics notation 'simplified molecular input line entry system (SMILES)'.

MzLabelEditor is designed for building a library of reference spectra. The software interface can keep the instrumental information (manufacturer, ionization mode, fragmentation mode, etc.) associated with a given annotated spectrum. A spectrum is annotated by putting labels on the peaks of interest. MzLabelEditor is the only purpose-dedicated mass spectrometry tool that allows free-form editing of these annotations.

To facilitate the interpretation and annotation of a spectrum, mzLabelEditor proposes a workflow that compares it to a 'model', which is ideally a theoretical spectrum generated with the Oligator tool.

Future outlook

The two programs used in tandem help to collect and compile reference data into a spectral library and raise prospects for an automated workflow for reading the MS/MS spectra of plant glycans.

Finally, most of the features of MzLabelEditor are essentially generic and it could readily support other MS/MS fragment nomenclatures in the comparative analysis module in order to extend the tool to other types of molecules.

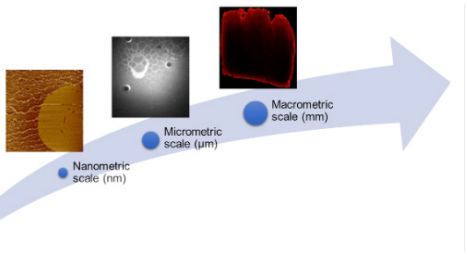
Collective output

TRANSFORM scientists coordinate community-forward initiatives led with agents from various TRANSFORM-division units, colleagues from other INRAE divisions, and even partners outside France. Here we showcase various examples of actions we have engaged in the form of papers written up after input from the community on a given focal issue, training and education initiatives put into place in response to the Covid-19 pandemic, participatory action research engaging different stakeholders and constituencies, and evidence-based advisories on food, diet and nutrition.

COLLECTIVE ARTICLES, VOLUMES AND DIGITAL TOOLS

Super-small but super-useful: enzymes driving bioproduct science

Enzymes are ubiquitous biocatalysts that are widely used in biotech conversion processes, but they also make exceptionally sensitive probes for exploring the structure and composition of all kinds of complex bioproducts, from lignocellulosic biomass to meat tissue and back to colloidal systems. Working up from an exhaustive systematic review of the literature, we detail the latest cutting-edge ways that enzyme probes can be applied to explore the structure of various bioproducts, and take a closer look at the new sources of enzyme probes and the allied enzyme engineering and high-throughput screening strategies mobilized. We go on discussing the structure–function relationships that determine enzyme–substrate interactions and the latest experimental methods developed to characterize these key interactions at various spatio-temporal scales. Combining multimodal and multiscale approaches with modelling brings a better understanding of native-form or processed-form bioproduct architecture.



Read

Bourlieu C *et al.*
Enzymes to unravel bioproducts architecture.
Biotechnology Advances . 2020 - https://doi.org/10.1016/j.biotechadv.2020.107546

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Top-down look at INRAE-led research into multicriteria assessment

With food–farming systems under mounting pressure to deliver triple-bottom-line performance, INRAe elected to step back and lead a state-of-play review on the use of multicriteria assessment in its own research work. Experts enlisted from practically every INRAe division annotated and statistically analyzed a bibliographic evidence-base corpus of 954 published papers authored by INRAe scientists in the period running from 2007 to 2017. The taskforce group singled out the contrasts and complementarities between disciplines, flagged up the potentialities for multicriteria assessment methods, and proposed pathways for our future food and farming research. Efforts to transition towards agroecological food and farming systems that address today's social and environmental challenges, multicriteria assessment methods can valuably help to tease our sustainable alternative solutions.

Read more

Gésan-Guiziou G *et al.*
Diversity and potentiality of multi-criteria decision analysis methods for agri-food research.
Agronomy for Sustainable Development . 2020 - https://doi.org/10.1007/s13593-020-00650-3

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Understanding recalcitrance of lignocellulosic biomass and predicting its ability to be hydrolyzed

Lignocellulosic biomass is an abundantly available and renewable plant-crop resource composed mainly of polysaccharides (cellulose and hemicelluloses) and lignin. They are polymers with a heterogeneous multi-scale structure in plant cell walls plant that makes them recalcitrant to (bio)chemical processing. The markers affecting this recalcitrance are tightly interconnected and tough to tease apart, but it is vital to understand their impact in order to optimize the processes in biorefinery platforms. This review paper offers a state-of-play update on the relative impact of the two big classes of markers (chemical and structural) on lignocellulosic biomass, and descriptive walk-through of the most advanced techniques for assessing these markers. We arrive at the conclusion that even though we have no universal marker, there are composite measures using spectrometry or approaches tied to hygroscopy properties that can fairly confidently predict the processability of a biomass.

Read more

Zoghlami A *et al.*
Lignocellulosic biomass: understanding recalcitrance and predicting hydrolysis.
Frontiers in Chemistry 7 . 2019 - https://doi.org/10.3389/fchem.2019.00874

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COLLECTIVE ARTICLES, VOLUMES AND DIGITAL TOOLS

A collective volume on the bioeconomy

60 co-authors from 27 organizations–mostly affiliated with INRAe–have published a textbook setting out a manifesto for responsible and rational use of renewable resources that harnesses the complementarity between food and non-food value chains–including farming and forestry biomass resources and their allied waste streams and processables. Written for an audience of students in chemistry, biology and engineering, as well as practitioners and academics in R&D, this work marks a big step forward in knowledge transfer, mobilization and impact. Prepared and produced with input from four SMEs and four industry partners, it is the culmination of a public–private partnership forged by INRAE research teams, but it also heralds the start of a new adventure as industry begins to get on board with the bioeconomy as a platform for growth.
This work was a shortlisted finalist to win to the Roberval prize in the 'Higher education' category.

Read more
Chimie verte et industries agro-alimentaires – Vers une bioéconomie durable (2020). S. Baumberger (Coord.), Lavoisier, France, Coll. Tech et Doc, 560 p.
http://prixroberval.utc.fr/iso_album/ROB20/ROB20-Communiqu%C3%A9_de_presse_les_finalistes.pdf

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Food engineering students pivot to 'labwork from home'

Labwork projects give students invaluable first-hand experience working and operating semi-industrial-scale pilot plants. So how do you go about deploying 'labwork-from-home' learning in the space of just a few short weeks?

Four food engineering 'labs from home' were devised and delivered during the spring-2020 lockdown forced by the COVID-19 pandemic. Six research lecturers, a pedagogical engineer and the head of the technology platform were all on board. Various educational resources were purpose-developed, including 360° virtual tours, an interactive gamified presentation, a personal progress tracker sheet, interactive technical documents, a simulator, and a skills badge. These instructional resources were pieced together into scenarios to provide students with a learning pathway for each of the unit operations studied (appertization of cans, evaporation, frontal filtration, spray drying). Given that it had to be rushed through with only limited resources, the experiment ultimately proved a relative success. The instructional delivery team came away with a set of recommended principles and practices and with lessons learned for the future.

Read more
Debacq M *et al.*
Delivering remote food engineering labs in COVID-19 time.
Education for Chemical Engineers . 2021 - https://doi.org/10.1016/j.ece.2020.10.002

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MESTRAL, a digital tool for food–process learning

E-learning is a hot topic. Effective e-learning hinges on tools and technologies that facilitate knowledge transfer and ready students for real-world situations. This patent conclusion prompted a team of 26 researchers and senior lecturers to develop a digital research training module on 'Models and simulators for food process engineering', acronymed MESTRAL. MESTRAL was built from electronic knowledge books (eK-books) that represent body-of-knowledge as concept maps hyperlinked together for easy web-based navigation. MESTRAL counts 15 modules (about 150 h of teaching). Each module represents a food-product–process system, and includes a model-based simulator to graphically visualize system responses to a change in process parameter or in food composition, along with training exercises and tests. MESTRAL can help to guide and educate students on the power of modelling and innovative process engineering.

Read more
Suciu I *et al.*
A digital learning tool based on models and simulators for food engineering (MESTRAL).
Journal of Food Engineering . 2021 -https://doi.org/10.1016/j.jfoodeng.2020.110375

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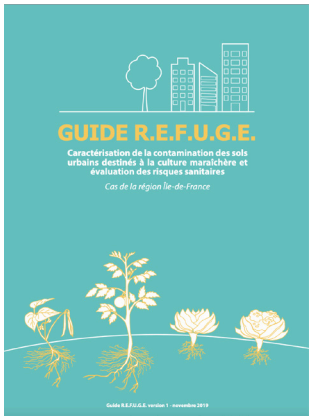
COLLECTIVE ARTICLES, VOLUMES AND DIGITAL TOOLS

REFUGE—'Risk in urban farms: assessment and management support'



There are more and more constituencies looking to set up urban agriculture projects in France. The REFUGE action research program implements a method and procedure for assessing and managing ground pollution-related health–hygiene risks as upstream groundwork for various market gardening projects in urban or urban-fringe communities. This framework has been operationalized as two tools that are transferable to the people tasked with provisioning a plot–typically local councils–and then managing that plot project.

- The REFUGE Guide: Characterization of soil pollution in urban plots earmarked for market gardening and assessment of pollution-related health–hygiene risks: Ile-de-France region case-file https://www.inrae.fr/sites/default/files/guide_refuge.pdf
- The 'Food Safety Standards Control Plan–Urban Agriculture' for controlled management of food health–hygiene risks.https://www.inrae.fr/sites/default/files/plan_de_maitrise_sanitaire.pdf

These deliverables have come through collaborations between researchers (INRAE, INERIS, INP–Toulouse), on-the-ground constituencies, the health authorities, government operators, and project sponsors.

Read more

Grard B *et al.*
Potential of technosols created with urban by-products for rooftop edible production.
International Journal of Environmental Research and Public Health . 2020 -https://doi.org/10.3390/ijerph17093210

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A practical multicriteria argumentation-based app for multistakeholder decision support

Food–farming commodity chains have to grapple with challenges that articulate a number of different criteria (environmental, economic, functional, health–hygiene, and more) and mobilize a number of different agents (administrators, businesses, citizens, scientists, etc.). Different agents in a given commodity chain may have different rationales and so chase goals that pull in different directions, in which case the only way to move forward to a final decision is to engage in some kind of compromise building support process.

MyChoice is a user-friendly web-based decision support app that enables project participants/agents to:

- analyze, compare and evaluate where the stakeholder constituencies stand on different alternatives
- review explanatory arguments that come from a range of sources and reflect a range of concerns
- explain the criteria, objectives and features pursued
- identify potential synergies or competing concerns
- propose different modes of decision support.

Recently registered with the "Agency for the Protection of Programs" [European organization for the defence of authors and publishers of digital works] under key number IDDN.FR.001.280002.000.R .P.2020.000.20900, and soon to be rolled out under an open-source license.

Read more

Thomopoulos R *et al.*
A Generic Software to Support Collective Decision in Food Chains and in Multi-Stakeholder Situations.
Proceedings of FoodSim . 2020 - https://hal.inrae.fr/hal-02484363v2

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EXPERTISE

Quality of animal-sourced foods is shaped by production system and processing routes

The objective of this inquiry was to characterize the quality of animal-sourced foods according to farming-system conditions and processing routes. Product quality was broken down into seven sets of core food quality traits–safety, saleability, palatability, processability, use value, image value, and nutritional value. The scope of inquiry encompassed beef, lamb, pork, poultry, milk, eggs, fish, and all the allied processables.

Certain factors create antagonisms between different dimensions of product quality, which can be contained and controlled by mobilizing multicriteria modelling approaches. Official quality-sign production standards (typically 'organically-farmed', PDO, PGI and *Label Rouge*) craft product quality though their production-standard commitments. The correlations we have between consumption of animal-sourced foods and increased or decreased risk for certain chronic non-communicable diseases would gain vital robustness if they accounted for the broad variability in food production-system conditions and processing routes.

Read more

Prache S *et al.*
Qualité des aliments d'origine animale - Production et transformation. Editions Quae - 2021.

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Bits in the baby's food!

It is essential to offer infants textured foods soon after the onset of complementary feeding so that they can learn to chew properly and develop a healthy food repertoire. To promote the introduction of foods of different textures between the ages of 8 and15 months, we tested the effect of recommendations that went beyond the PNNS (French National Nutrition and Health Program) dietary recommendations at the time of the study, which dated from 2005. These specific recommendations led to a significant increase in the introduction of small soft pieces but not harder pieces. In addition, observations of children during meals in the laboratory confirmed that exposure to a wide variety of food textures from 8 months favoured the acceptability of solid foods at 15 months. These new recommendations form a firm foundation to inform the development of future guidelines on complementary feeding practice for young children.

Read more

Tournier C *et al.*
Fostering infant food texture acceptance: a pilot intervention promoting food texture introduction between 8 and 15 months. Appetite 158, 104989 . 2021 - https://doi.org/10.1016/j.appet.2020.104989

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The ambitious AlimaSSenS project delivered on its promise

AlimaSSenS was led as a public–private partnership alliance federating 10 university partners, 4 industry partners, and a precious network technical hubs. It articulated communities and practitioners in odontology, physiology, sensory analysis and consumer science, nutrition, epidemiology, data mining, food process routes, mechanics, sociology, and economics. The project was built to fashion a food offer that caters to elderly people (aged 65 and over) living at home. It delivered an innovative food offer combining meal enjoyment with nutritional value to help overcome ageing-related problems with chewing and swallowing.

AlimaSSenS has enabled a number of major advances: it has brought the concept of 'in-mouth comfort', evidence that saliva plays a pivotal role in in-mouth processes and food liking; it has designed, developed and tested 14 innovative new formulated food matrices, brought evidence for different subpopulations of elderly subjects stratified on dental health–self-image linkage, and highlighted the importance of the nutritional and sensory value messages vectored in the offer. AlimaSSenS has informed and reached broad scientific and public population audiences and bridged to a number of openings and opportunities (launching a national and international collaborations, a participatory research project, and more).

https://anr.fr/Projet-ANR-14-CE20-0003#

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TRANSFORM collective scientific facilities and infrastructures

AGRORESONANCE - UR QUAPA

Nuclear magnetic resonance (NMR) spectra or images (MRI) are exploited for a broad range of applications to determine the chemical structure, to quantify the concentration, to understand the dynamic of small molecules, and to characterize the organization of various samples at different scales. It therefore gives access to valuable information on agro-resources, foods and living organisms.

The AgroResonance facility is part of the INRAE Clermont-Auvergne-Rhône-Alpes research centre. It hosts cutting-edge MRIs driven by highly skilled scientists able to develop original experimental design and then address key questions in food-farming, plant science, nutrition and health.

AgroResonance is ISO 9001 certified as well as granted by the INRAE infrastructure facility label. As founder member of IBiSA-sponsored regional multimodal imaging platform *In Vivo Imaging in Auvergne* (IVIA), it has also access to the vast majority of Clermont-Ferrand *in vivo* imaging modalities for animals and humans.

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BIORESOURCES: IMAGING, BIOCHEMISTRY & STRUCTURE (BIBS) - UR BIA

The BIBS platform brings together high-level expertise in several fields of analytical and data sciences, which allow to unravel the structures and architectures of agro-food biomass systems and investigate their component biopolymers (polysaccharides, proteins, lipids) by different modalities and on a range from mm down to nm scales.

The methods we mobilize are capable of: i) characterizing the structure of biopolymers (identification, quantification, modifications) and their interactions, their organization (ordered schemes, mobility), and their localization; ii) track and trace their degradation and/or transformation; iii) screen libraries of samples against chemical and structural criteria; iv) image the systems using multiple modalities and at different scales, and perform correlative imaging; v) capture dynamic parameters (diffusion).

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BIO2E PLATFORM - UR LBE

Bio2E–the Environmental Biotechnology and Biorefinery platform–transfers and translates technologies to process urban, farming and food-industry effluents and biosolids into energy and material commodities using integrated bioprocesses (anaerobic digestion, biomethanation, biohydrogen, microalgae) in tandem with physico-chemical routes (pre- and post-treatment) to minimize the environmental impacts of these value streams. Bio2E pulls together LBE's R&D partnerships offer with the INRAE–Transfer business unit's portfolio of contract-service activities. This articulation enables the platform to deliver bespoke solutions tailored to partner needs, from in-lab tests up to industrial facility commissioning and diagnostics: collaborative R&D, contract-service analytics, feasibility studies, training and education, advisories and expertise, and hosting.

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CHEMOSENS- UMR CSGA

ChemoSens is the research and methods engineering platform serving INRAE's Centre for Taste & Food Science (CSGA) in Dijon. It breaks new science ground by combining chemistry with sensory analysis to develop novel approaches for characterizing foods and foodways.

ChemoSens mobilizes techniques borrowed from physical-chemical analysis to characterize the flavour compounds in a food and profile the tastant molecules that get released as we eat it. It possesses advanced scientific expertise in lipid profiling in foods and neurosensory tissue.

ChemoSens is also internationally reputed as a lead authority in the sensometrics arena, and some of its flagship methods–like 'temporal dominance of sensations'–have gained currency across the globe. ChemoSens has compiled vast databases and developed the TimeSens® online software bundling sensory data acquisition with statistical analysis.

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MILK SCIENCE PLATFORM (PFL) - UMR STLO

PFL is an 'experimental facility' (https://www6.rennes.inrae.fr/plateforme_lait) equipped to co-host a suite of dairy technology processes at different scales and through flexible yet firmly controlled routes including fractionation of milk compounds, fashioning dairy matrices to a gradient of concentrations with or without fermentation (fresh produce, cheeses or condensed milk), and matrix dry-out. The 800m² facility was entirely refitted in 2013 and has been ISO 9001-certified since 2009. The platform is open to university and industry partnerships. It mobilizes in-house expertise (technology, process engineering, biochemistry, microbiology, nutrition, and eco-design) that is put to work on university or private-sector research projects and advanced training programmes delivered to the next generation of food-industry leaders.

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PLANET - UMR IATE

PLANET–'PLANt products with Emergent Technologies'–is an experimental platform developed and run by the INRAE–IATE joint research unit that boasts around 700 m² of research space–including 150 m² dedicated to food science–housing around a hundred instrumented equipment systems working from lab scale (with a few grammes) up to pilot scale (10 or so kg) alongside prototypes developed in tandem with the unit's research engineers. These equipment systems are tasked with scaling unit-operation process routes for transforming plant biomass streams into commodity feedstocks to support food, energy, material or green chemistry applications. The platform tackles focal challenges ranging from cereal commodity fractionation and structure science to dry refinery of lignocellulosic biomass, agrimaterial formwork, and back to characterization of crude feedstocks, process powders, and end-products. A core team of 6 dedicated FTEs runs the unit and leads its technology and methodology development effort.

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TOULOUSE WHITE BIOTECHNOLOGY (TWB)

TWB delivers expert project engineering to support the development of sustainable bio-driven process pathways by leveraging alternative economically-compelling industrial biotechnology solutions. With that vision, TWB federates collective intelligence by creating new research–industry–investor intersections, and connects this community to its science and technology resource platforms delivering cutting-edge strain engineering and culture and fermentation processes.

TWB was created in 2012 via the joint authority INRAE–INSA–CNRS stewardship and support agreement and by 2021 it had built up a consortium of 53 public-/private-sector partners. In this time, TWB has helped to launch 214 collaborative R&D research projects and helped to grow a hive of start-ups that in total have attracted nearly €100M in seed capital.

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RECOGNIZED INFRASTRUCTURES

PROBE, a research infrastructure dedicated to the characterization of bioresources

PROBE, the Platform for profiling properties of food and biobased products, is one of the 16 research infrastructures of INRAE roadmap.

Food and non-food agricultural crops share a complex yet versatile array of structures and compositions that shape and dictate their properties in use. The sensory attributes of raw and processed foods, for example, depend on the ability of key molecules like aroma compounds to diffuse in the food-material matrix. The success of the bioeconomy also hinges on our ability to characterize bioresources and bioproducts and predictively map out how agricultural raw materials could be repurposed to make innovative materials with specific functional properties. This means that regardless of whether the purpose targeted is food or non-food use, we need to develop methods and concepts to (i) analyze a diverse array of complex heterogeneous crop resources and (ii) capture the structural changes occurring through processing trajectories that shape the functionalities of the end-products.

The PROBE distributed research infrastructure is setting out to acquire and integrate advanced science on the structure, properties, and functionalities (including sensoriality) of the input materials, in-process products, and end-product outputs. The strategy is to deploy a battery of physical-chemical methods at a range of scales in order to pinpoint the impact of pivotal structural parameters on product quality, properties, and functionality–whether for food or non-food use. PROBE leverages advanced competences across 4 platforms articulating highly complementary competences in terms of molecules studied and approaches mobilized in order to:

- Provide structural information at different scales (from molecule to matrix) ;

- Connect food properties and functionalities by analysing sensory properties at behaviour and brain levels ;

- Merge information acquired at different scales using various techniques to improve knowledge and understanding of food and non-food systems

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TRANSFORM at the heart of IBISBA

EU-IBISBA

IBISBA (Industrial Biotechnology Innovation and Synthetic Biology Acceleration) is a distributed European infrastructure project that is present since September 2018 on the ESFRI roadmap (www.ibisba.eu). Currently IBISBA is supported by European H2020 funding (H2020 projects IBISBA 1.0 and PREP-IBISBA). On the 1st January 2020, EU-IBISBA entered into preparatory phase, meaning that the project is moving forward towards future implementation of the research infrastructure in the form of a new European legal entity. The preparatory phase provides the time and funds to study the business case and model for this entity, and also to prepare its legal statutes.

IBISBA-FR

As a distributed European infrastructure, EU-IBISBA is built upon existing infrastructure in different member states. IBISBA's French node is supported by INRAE, the CEA and the CNRS. Currently, the INRAE components involved are Toulouse White Biotechnology and ICEO, a core facility that offers enzyme screening and engineering services. The INRAE contingent of IBISBA-FR is completed by the contribution of third party services from other INRAE infrastructure (METATOUL, a component of IR METABOHUB and GeT-Biopuces, a component of GenoToul) and from the MICALIS laboratory.

What does IBISBA aim to do ?

IBISBA's mission is to provide world-class cutting-edge research and innovation services enabling the development of biotechnology as a technology cornerstone of the circular bioeconomy. To achieve this, IBISBA develops new science concepts, tools, and methodologies to underpin the production of modular, interoperable services that are interlinked in workflows to support the seamless development of bioprocesses. At the heart of IBISBA are research infrastructure facilities distributed in different countries and their staff that are trained to work together and thus achieve operational interoperability. Currently, funding available in the framework of IBISBA 1.0 is providing subsidized infrastructure access to researchers across Europe and from third countries.

Harmonization and FAIRization of knowledge assets

As a European research infrastructure, IBISBA is conducting cutting edge work on FAIR data and is promoting harmonization of practices, in favour of research reproductibility. Currently, IBISBA operates a data repository (IBISBAhub - hub.ibisba.eu) that can be used by anyone (IBISBA members and non-members alike can create an account) to FAIRize data and knowledge assets. IBISBAhub can do lots of things, including minting of DOIs. The idea behind IBISBAhub is to create a knowledge commons that will provide a means to share standardized protocols, experimental and automated workflows, as well as other research items that are of interest to the wider industrial biotechnology community.

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