FIPDes

Food Innovation & Product Design

FIPDes Day 2026
International talents in Food Innovation and Product Design

Students' Book of Executive Summaries

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Congratulations to the FIPDes Cohort 13!

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Lilou, Giang Yen Tho, Qudsia, Diego, Jenna, Briggitte, Mariana, Christina

Johan, Aqsa, Emily, Renuka, Polina, Busra

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Introduction: Executive Summary 2026

It is always a privilege to introduce the work of our FIPDes fresh graduates.

You are holding in your hands one of the many tangible outcomes of the FIPDes Master adventure. This booklet gathers the executive summaries of the MSc thesis flash presentations and posters presented during the 2026 FIPDes Day, held in September at the AgroParisTech campus in Palaiseau.
It was prepared over the summer thanks to the dedication of our students and the careful work of Lucile Deloince, who coordinated its publication.

Why this book?

These pages offer a vibrant snapshot of the wide range of topics explored by FIPDes students during their MSc theses: food engineering, packaging, reformulation, nutrition, ingredient assessment and much more. Across this diversity, the projects share a common ambition: contributing to more sustainable and innovative food systems.
The projects were carried out within the three FIPDes second-year specialisations in Food Design and Engineering at AgroParisTech, Food Packaging Design and Logistics at Lund University, and Healthy Food Design at Università di Napoli Federico II, in collaboration with international research institutions, companies, organisations and start-ups, all connected through the dynamic FIPDes innovation network.
This booklet is also a way to introduce our newest alumni to our partners and collaborators — who may well become their future colleagues, collaborators or employers.

And what about Cohort 13?

With 24 students representing 19 nationalities — Brazil, Bulgaria, Cambodia, Canada, China, Colombia, Ecuador, Finland, France, Honduras, India, Lebanon, Mexico, Pakistan, Peru, Spain, Türkiye, the USA and Vietnam — Cohort 13 brought to FIPDes an extraordinary diversity of food cultures and perspectives, with first-hand insights into local food products, environmental and economic contexts, and consumer needs and expectations. This diversity fostered particularly rich interactions and knowledge exchange within the cohort.

Selected from more than 800 candidates, Cohort 13 brought together excellent students with remarkably diverse academic backgrounds, from chemical and food engineering to life and environmental sciences, biotechnology and food technology. For me, this diversity is one of the real strengths of FIPDes: each student arrives with their own knowledge, perspectives and skills, and these differences become part of the learning experience — students learn with, but also from, each other.

Introduction: Executive Summary 2026

Dear Cohort 13, you had a very special start to your FIPDes adventure, arriving in Paris right in the middle of the 2024 Olympic Games!

Watching the Olympic Torch Relay together was one of our first shared moments — quite a perfect start for such an international cohort. Two years later, it is already time for you to carry the FIPDes spirit forward, and pass the knowledge torch to the next cohort of students!

I am very proud of what you have achieved and look forward to seeing where your next adventures will take you!
Enjoy the reading!

Barbara Rega
FIPDes Coordinator

On the Crystallization Behaviour of Confectionery Fats: A Systematic Study of Tempering Procedures on Temper- and Non-Temper Mandatory Fats

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Introduction

Confectionery fats must crystallize into stable, well-organized polymorphic networks to deliver the snap, gloss, and shelf-life consumers expect. Crystallization proceeds through nucleation and crystal growth, shaped by cooling rate, shear, and tempering history. Because chemically identical fats can adopt different polymorphic forms (α, β′, β) with distinct melting points and mechanical properties, controlling which form develops is central to product quality.

Existing work mostly focuses on simplified model systems or single fats studied in isolation, without systematic industry context. This thesis addresses three gaps: no comparison exists across confectionery fats with diverse TAG structures under identical processing conditions; cooling rate has rarely been studied across a broad panel of fats rather than one system at a time; and the response of cocoa butter formulations to tempering protocol and diluent composition is not well characterized, despite governing post-crystallization phenomena, such as polymorphic transitions, oil migration, and surface bloom, that directly affect processing behaviour, texture, and shelf life.

Objectives

The goal of this thesis is to characterize the crystallization behaviour of confectionery fats and to define the processing and compositional parameters that govern their functional performance, across two complementary phases.

Phase I

Establish a fundamental understanding of confectionery fat crystallization by systematically varying cooling rate (1, 5, 10, 20 °C/min) across twelve compositionally diverse fats.
Interconnect multiple analytical methods (DSC, XRD, NMR, rheology, microscopy) under identical processing conditions to capture complementary data on crystallization kinetics and structure development.
Evaluate whether fats' actual tempering sensitivity, assessed by comparing a generic versus an industry-standard tempering protocol, aligns with their classification as temper-mandatory or non-temper-mandatory.

Phase II

Establish a fundamental understanding of cocoa butter tempering to define a gold standard as the basis for composition–function relationships.
Examine how blending cocoa butter with palm olein (PO56, 0–25% w/w) under set tempering conditions affects crystallization behaviour, crystal structure, and resulting mechanical properties.

Materials and Methods

Twelve commercially relevant confectionery fats were selected to span a wide range of TAG composition, melting profile, and polymorphic behaviour: palm oil (PO), palm kernel oil (PK), palm mid-fractions (PMF35, PMF49), soft palm mid-fraction (sPMF), interesterified palm oil (POIE), palm olein (PO56), interesterified palm oil fraction (PO75), fractionated palm stearin (POST), cocoa butter (CB), a cocoa butter equivalent (CBE) and shea stearin (SHSt).

Each fat was melted at 80 °C to erase crystal memory, then cooled at four controlled rates (1, 5, 10, 20 °C/min) and characterized in parallel by Differential Scanning Calorimetry (onset, peak, and endset temperatures and melting enthalpy), X-Ray Diffraction (WAXS/SAXS), polymorph identification and crystallinity), pulsed low-resolution NMR (solid fat content, using both a generic and an industry-standard tempering protocol), oscillatory rheology (temperature sweeps tracking storage modulus G′ to identify gelling onset temperature and maximum gel stiffness), and polarized light microscopy (crystal morphology and nucleation density). In Phase II, cocoa butter was blended with PO56 at 0, 5, 10, 15, and 25% w/w, tempered under a fixed protocol adapted from Chen *et al.* (2021), and evaluated by DSC, X-Ray Diffraction, and three-point bending (hardness, brittleness, toughness, elastic modulus) over roughly one week of storage. Statistical comparisons used ANOVA ($\alpha = .05$) and Pearson correlation.

Results and Discussion

Phase I: Cooling Rate Effects

Cooling rate had a significant effect on crystallization behaviour in every fat tested. Gelling onset temperature shifted uniformly to lower values under fast cooling in all twelve fats. Palm oil's onset moved from 12.3 °C (20 °C/min) to 19.8 °C (1 °C/min), and POST shifted from 22.5 °C to 32.6 °C, consistent with fast cooling driving the system further past its equilibrium crystallization point before nucleation occurs.

In contrast, the effect of cooling rate on final network stiffness (maximum G′) was fat-specific rather than uniform. Most fats, including palm oil, POST, POIE, sPMF, and PMF49, formed stiffer networks under fast cooling, contrary to the classical expectation that slow cooling favours a stronger network. A smaller group (cocoa butter, CBE) showed the opposite, more classical pattern of weaker networks under fast cooling. Fat type had a far larger effect on both stiffness and onset temperature ($p < .001$ for both) than cooling rate itself, confirming that network strength is governed primarily by TAG composition rather than processing alone. Figure 1 makes this visible: ranked by mean Max G′, temper-mandatory and non-temper-mandatory fats do not separate into distinct bands, and stiffness varies more within each classification than between them, reinforcing that TAG structure, not category, predicts mechanical performance.

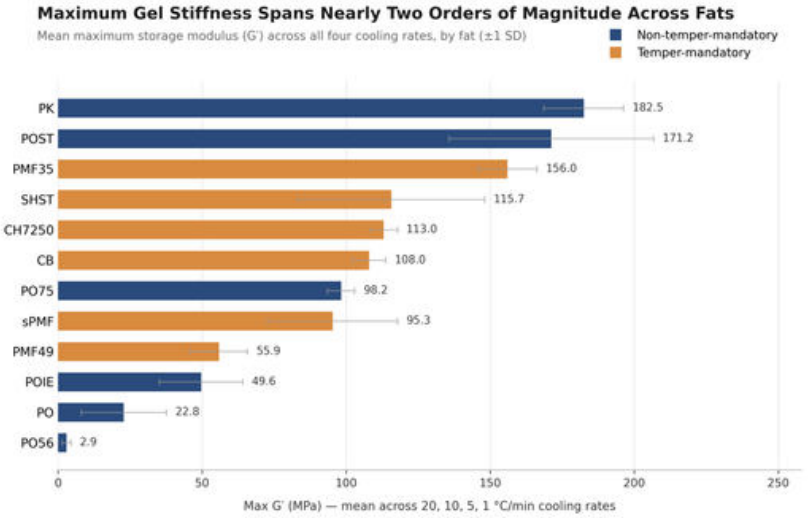

Figure 1. Mean maximum storage modulus (Max G′) across all four cooling rates (20, 10, 5, and 1 °C/min), ranked by fat. Error bars represent ±1 SD across cooling rates. Bars are colored by tempering classification (non-temper-mandatory vs. temper-mandatory).

Comparing a generic tempering protocol (SFCa) against ADM's industry-standard protocol (SFCb) showed that tempering-protocol sensitivity did not always track a fat's industry classification. Protocol significantly affected β′ polymorph content in non-temper-mandatory fats ($p = .039$) but not solid fat content ($p = .911$), while for temper-mandatory fats it significantly affected both β′ content ($p = .017$) and SFC ($p < .0001$).

Cocoa butter showed the largest difference in β′ content between protocols (85.8% vs. 62.0%), showing that even nominally temper-mandatory fats can retain strong sensitivity to small changes in tempering procedure.

Phase II: Cocoa Butter and Palm Olein Blends

As PO56 replaced cocoa butter (0–25% w/w), the proportion of symmetrical monounsaturated TAGs (POP, POS, SOS) declined steadily from 89.0% (pure CB) to 81.0% (25% PO56). This dilution produced a concentration-dependent decrease in WAXS crystallinity ($p = .048$) and significant softening in hardness ($p < .0001$), toughness ($p = .0001$), and elastic modulus ($p = .0002$); modulus fell 47%, from 137.0 MPa (0%) to 72.0 MPa (25%), without significantly shifting the dominant β-polymorph or DSC thermal signature ($p = .072$ for onset; $p = .160$ for enthalpy). This indicates PO56 reduces network connectivity rather than redirecting the crystallization pathway.

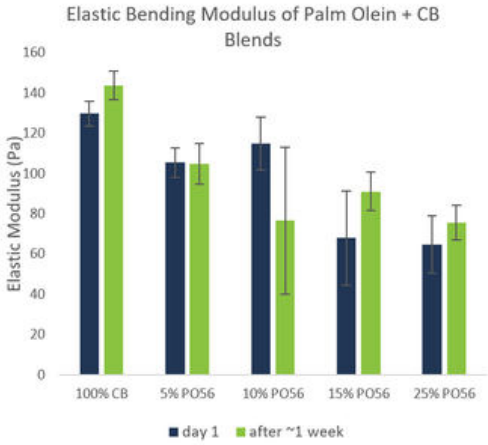

Figure 2. Elastic bending modulus of cocoa butter–PO56 blends (100% CB, and CB with 5%, 10%, 15%, and 25% PO56) measured on day 1 and after ~1 week of storage. Error bars represent standard deviation.

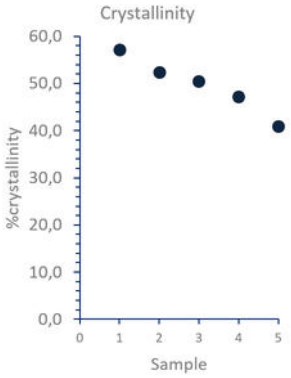

Figure 3. Total WAXS crystallinity (%) vs. PO56 concentration at Day 1: a sharp drop from pure CB to 5% PO56, then a gradual decline to 25%.

Blends at intermediate concentrations (10–15% PO56) showed pronounced structural reorganization over roughly a week of storage: melting enthalpy and elastic modulus continued to rise for the 15% and 25% blends, while the 10% blend was uniquely unstable, softening further with storage and showing the widest measurement variability of any formulation.

Conclusions and Practical Recommendations

Cooling rate is a universal driver of crystallization kinetics: onset temperature was lower under fast cooling in every fat tested, but its downstream effects on network mechanics and polymorphism are strongly fat-specific rather than uniform. This means a fat's actual structural response to processing, not its formulation history or industry category, is the more reliable guide for process design. Fats dominated by symmetric monounsaturated TAGs (cocoa butter, CBE, shea stearin) were the least sensitive to cooling-rate variation, while compositionally heterogeneous fats (palm oil and its derivatives) were far more processing-dependent.

For formulators, the practical takeaway from Phase II is concentration-dependent: up to approximately 5% PO56, cocoa butter's mechanical performance and thermal profile are only marginally affected, offering formulation or cost flexibility with minimal risk to snap or firmness. Beyond approximately 10% PO56, softening becomes substantial and less predictable. Together, the two phases point to a single principle for confectionery fat systems: TAG compatibility governs how forgiving a system is of both processing variation and formulation change, and is a more reliable predictor of performance than formulation history or category alone.

In short, cooling and tempering protocols should be selected according to fat structure rather than transferred uniformly across confectionery fat systems, and PO56 levels below approximately 15% best preserve cocoa butter's texture and stability. The main limitation of this work is single-replicate measurement; future work should replicate these experiments, investigate the anomalous 10% PO56 blend, and extend the TAG-based processing criterion to additional fat systems.

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Molecular Characterization of the Aroma of Cognac Eau-de-vie

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Cognac Eau-de-vie (EDV) is a distilled spirit produced by the double distillation of white wine, primarily from Ugni Blanc grapes, resulting in an alcohol content of approximately 70% (v/v) (International Organisation of Vine and Wine, 2005).

EDV contains a complex mixture of volatile compounds which include esters, higher alcohols, aldehydes, volatile sulfur compounds (VSCs), and organic acids (Qiao et al., 2023). Their sensory contribution depends not only on their concentration but also on their odor perception thresholds. As a result, compounds present at trace levels can have a great impact on its aroma (Grosch, 2001).

Among these compounds, VSCs play a key role, since at appropriate concentrations, they contribute desirable tropical aromas such as passion fruit, grapefruit, blackcurrant, and box tree notes, while excessive levels can generate sensory defects (Roland et al., 2011). This work addressed why certain EDV exhibit a distinctive tropical fruit aroma and succesfully identified an odor-active sulfur compound responsible for shaping this sensory characteristic. Gas chromatography-olfactometry (GC-O), tandem mass spectrometry (GC-MS/MS), and pulsed flame photometric detection (GC-PFPD) were used for the identification and characterization of the eaux-de-vie, followed by the quantification and comparison of VSCs in EDV and Cognac final product.

CONFIDENTIAL TOPIC

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Performance Evaluation of Bio-Based Texturizing Agents

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Texture is a key aspect of food quality, particularly in products such as soups, sauces, and ready meals, where viscosity, stability, and mouthfeel strongly influence consumer perception.
In these applications, bio-based ingredients are commonly used as texturizing agents because they contribute to the formation and maintenance of the desired product structure during processing.
However, conventional texturizing solutions do not always meet the growing demand for healthier, simpler, more recognizable, and more consumer-friendly ingredient declarations.
In this context, bio-based and clean-label texturizing ingredients represent an interesting alternative for developing formulations that combine functional performance with clearer ingredient positioning.
Assessing the performance of these ingredients is particularly important in sauce-type systems, as processing conditions such as thermal treatment (i.e. pasteurization and sterilization) and mechanical shear can significantly affect their functionality and the final product texture.
This master's thesis focuses on evaluating the performance of bio-based texturizing agents in food applications.
The project contributes to the broader challenge of developing products that combine technological reliability, clean-label expectations, and consumer-oriented formulation strategies.

CONFIDENTIAL TOPIC

From Lab to Production Scale: Formulation Development of a 3D-Printed Mycoprotein-Based Whole-Cut Chicken Analogue

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Introduction

Global meat demand keeps rising while livestock remains a major driver of land use, water use and greenhouse gas emissions (Poore & Nemecek, 2018). Meat analogues are a leading response, but their success depends heavily on texture (Kyriakopoulou et al., 2021). Whole-cut products are the hardest case: unlike mince or nuggets, a chicken-breast analogue needs an anisotropic, fibrous structure that most globular plant proteins do not form (Dekkers et al., 2018). Mycoprotein, the filamentous biomass of Fusarium venenatum, is already fibrous at the relevant scale (Finnigan et al., 2019), and combined with 3D printing it offers whole-cut structure without high-shear extrusion.

The aim of this work, carried out with Revo Foods (Vienna, Austria), was to develop and optimise a 3D-printed mycoprotein-based whole-cut chicken analogue through iterative formulation and process development, scaling it from laboratory prototype to commercial production. Particular emphasis was placed on improving raw-mass processability, printability, structural integrity, and cooked texture, while evaluating the influence of methylcellulose equivalent (MCE) concentration and benchmarking the final product against a commercially available vegan chicken analogue.

Methodology

Development ran in three phases. Phase 1 followed the iterative reformulation of an internal prototype through ten recipes (R1–R10), varying mixing sequence, mycoprotein supplier, fibre grade, protein loading and clean-label simplification. Phase 2 isolated MCE by preparing the laboratory optimum (R9) at 0%, 0.75% and 1.5% w/w. Phase 3 benchmarked the final production formulation (R10, "El Pollo") against a commercial vegan fillet (Green Mountain).

Formulations were based on wet mycoprotein, fava bean protein isolate, MCE, bamboo fibre, canola oil, flavouring water, ice and salt. Laboratory samples were moulded and steam-set; R10 was 3D-printed on the industrial line. Cooked samples were pan-fried (1000 W, 7 min). Texture was measured on a TA.XT Plus: back extrusion at 4 °C for raw-mass firmness, consistency, withdrawal force and index of viscosity (Bourne, 2002), and two-cycle TPA for hardness, cohesiveness, springiness and chewiness. Three replicates per formulation; ANOVA with Tukey HSD (Phases 1–2), t-tests (Phase 3), $\alpha = 0.05$, effect size as ω^2.

Results and Discussion

Phase 1 : Iterative development. Formulation strongly affected raw-mass firmness ($F(9,20) = 15.43$, $p < .001$, $\omega^2 = 0.812$), from 10,680 g (R8) to 2920 g (R10). The fall was abrupt, concentrated at R9→R10, where mycoprotein dropped from 55% to 25% wet mass. R9 printed reliably in the lab but failed on the production line, which identified 25% mycoprotein as the industrial printability threshold — confirming that laboratory printability poorly predicts production behaviour.

Figure 1. Iterative formulation development trajectory (R1–R10), showing the principal change at each step and the resulting decision.

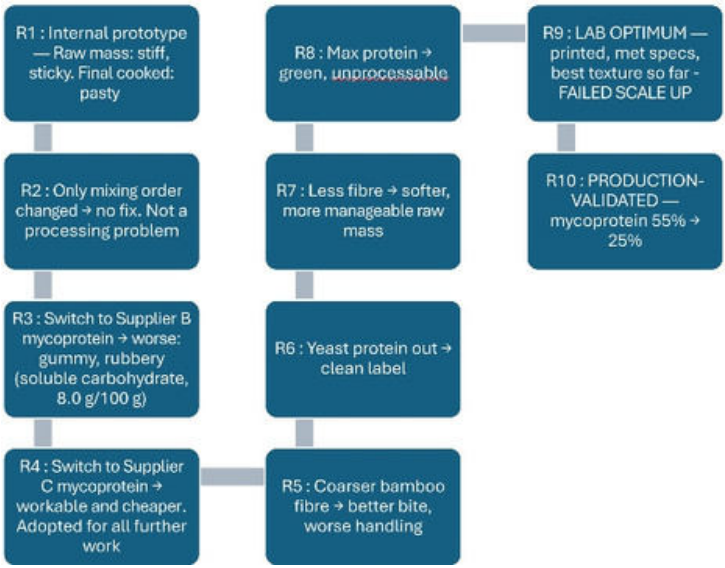
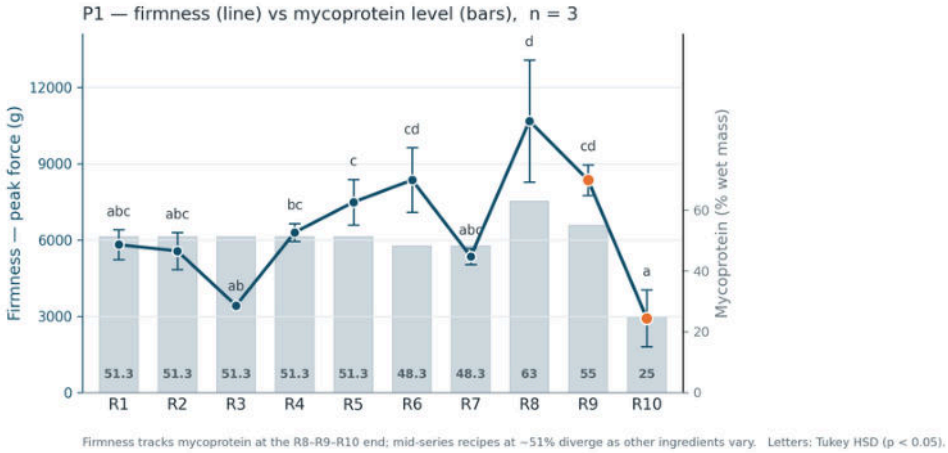
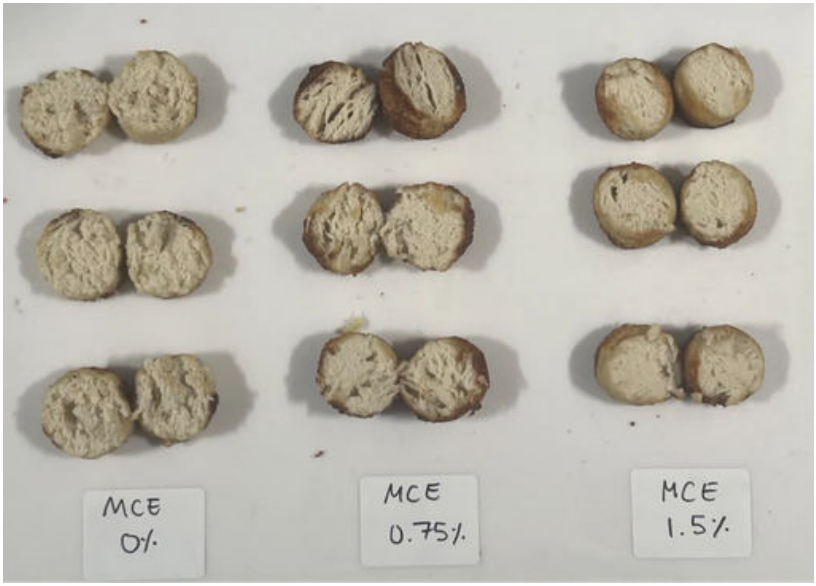


Figure 2. Raw-mass firmness (peak positive force, g) across the ten formulations (R1–R10). Firmness points sharing a letter do not differ (Tukey HSD, p < 0.05); error bars show SD of firmness (n = 3). Mycoprotein content is a fixed formulation input and was not tested statistically.



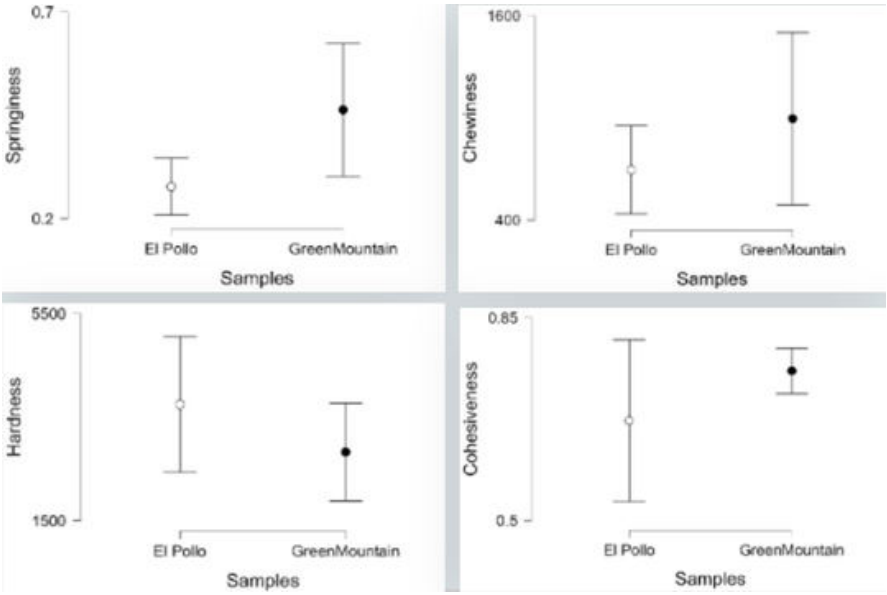
Phase 2 : Effect of MCE. MCE acted selectively. Raw-mass firmness was unaffected ($p = .130$), while withdrawal force rose sharply ($F(2,6) = 69.06$, $p < .001$, $\omega^2 = 0.938$) in a threshold pattern (0.75% and 1.5% differing from 0% but not from each other). Cooked hardness was non-monotonic, peaking at 0.75% (5607 g vs 1724 g at 0% and 3562 g at 1.5%; $\omega^2 = 0.969$), which points to water competition at the highest level. Springiness followed the same threshold ($\omega^2 = 0.902$), showing 0.75% MCE as the functional optimum.

Figure 3. Cooked cross-sections at 0%, 0.75% and 1.5% MCE (w/w). The 0.75% samples show the most open, fibrous interior.



Phase 3 : Benchmarking. El Pollo and Green Mountain did not differ significantly on any uncooked parameter, nor on cooked hardness (p = .071), cohesiveness (p = .063) or chewiness (p = .085). Only cooked springiness differed (El Pollo 0.277 vs Green Mountain 0.463, p = .010), Green Mountain being the more elastic — consistent with the aligned networks that extrusion produces but printing does not.

Figure 4. Cooked TPA parameters for El Pollo and Green Mountain. Points are means; error bars denote 95% confidence intervals.



Conclusion

Mycoprotein concentration, not binder design, was the decisive variable for manufacturability; reducing it to 25% wet mass enabled production-scale printing but defined a processability–texture trade-off. MCE acted selectively, with 0.75% giving the best cooked texture and a route to lower additive content. Benchmarked against Green Mountain, the final product matched on hardness, cohesiveness and chewiness, diverging only in cooked springiness — the clearest target for future work. Small replicate numbers (n = 3) and the MCE study being run on the 55% rather than 25% base are acknowledged limitations.

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Optimization of Sports-Oriented Bars: Effects on protein powder properties on texture, sensory perceptions and storage stability

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Introduction

Sports-oriented bars are complex food matrices designed to provide convenient nutritional support for active consumers. Their reformulation and optimization require balancing nutritional targets with processibility, texture and storage stability. In practice, changes in protein ingredients may affect matrix formation, hardening behaviour, moisture distribution and visual quality during storage.

The aim of this internship was to evaluate and compare different sports-oriented bar prototypes to identify how formulation variables, especially dairy protein ingredients, influence the physical and sensory-related properties of the final products. The work combined pilot-scale formulation trials with instrumental measurements, including texture analysis, water activity, moisture-related follow-up, color/image analysis, and descriptive sensory evaluation where applicable.

The main scientific and technological questions addressed in this study were:

1. How do different dairy protein ingredients influence the texture and stability of sports oriented bar matrices?
2. Can measurable parameters such as hardness, water activity, humidity/moisture evolution, and color changes be used to describe formulation performance?
3. Are differences in composition, such as protein content, mineral profile or particle-size distribution associated with differences in the final bar properties?

CONFIDENTIAL TOPIC

Rheological Properties and Immobilization Behavior of Water-Based Polymer Coatings on Paper Using an Immobilization Cell

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Introduction

The increasing demand for sustainable packaging has accelerated the transition from fossil-based materials to renewable alternatives, such as paper-based packaging (Bauer et al., 2022). To meet the barrier, adhesive, and sealing requirements of food packaging applications, paper substrates are commonly combined with functional coatings (Eslami and Mekonnen, 2023). However, paper is a porous substrate and coating performance depends not only on the material used, but also on how the coating is applied and formed on the paper surface. During application, the coating is applied as a liquid layer and undergoes flow, leveling, and film formation, while water is simultaneously removed through absorption into the paper structure and evaporation (Bakker et al., 2022; Yang, Liu and Gu, 2013a). This dynamic process strongly influences coating quality and final performance (Bakker et al., 2022).

A critical stage in this process is immobilization, where the coating loses its ability to flow and begins to behave like a solid. Immobilization determines when leveling stops, how the coating structure develops, and ultimately influences coating performance (Luo et al., 2020). However, conventional rheological methods cannot fully capture these dynamic changes under process-relevant conditions.

Therefore, this thesis investigates the rheological properties and immobilization behavior of three water-based polymer coating systems, poly(vinyl alcohol) (PVOH), starch, and silk protein, on two paper substrates with different properties.

The study employs an Immobilization Cell (IMC) developed by Anton Paar and mounted on a rheometer to investigate how intrinsic polymer properties, substrate-controlled dewatering, and experimental conditions influence immobilization behavior. Furthermore, the ability of bulk characterization methods, including rheology and dynamic light scattering (DLS), to support the interpretation of immobilization behavior under dynamic conditions is evaluated.

Methodology

Three water-based polymer systems representing different classes of coating materials were investigated: PVOH, starch, and silk protein. Polymer dependent immobilization behavior was first evaluated using paper A as a reference Substrate. Subsequently, Two paper substrates, Paper A and Paper B, with different properties were selected to evaluate substrate effects on immobilization behavior.

The main experimental technique was the Anton Paar Immobilization Cell (IMC) mounted on a Modular Compact rheometer MCR302. The IMC enables simultaneous monitoring of complex viscosity and coating thickness (gap evolution) as a function of time during dewatering through a paper substrate. This allowed the transition from a liquid-like coating to an immobilizes structure to be studied under process-relevant conditions.

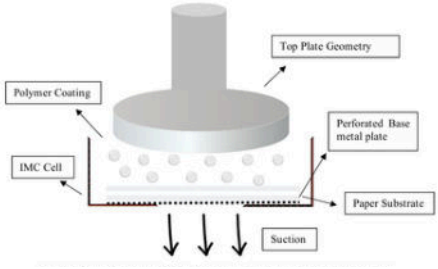

Figure 1. Schematic representation of the IMC showing the measuring top plate geometry, polymer film, paper substrate, permeable support, and suction-driven dewatering.

To support the IMC measurements, bulk rheology and dynamic light scattering (DLS) were performed to assess rheological behavior and solution stability. In addition, adhesion (tack) and Cobb water resistance tests were conducted to evaluate coating performance in terms of adhesion development and water resistance.

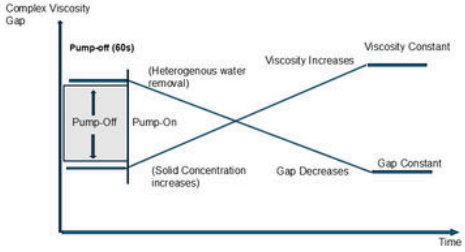

Figure 2. Schematic representation of the process followed for Immobilization Cell.

Results and Discussions

The IMC results revealed clear differences in immobilization behavior between the investigated polymer systems. Starch exhibited the earliest and most rapid immobilization, characterized by a sharp increase in viscosity, which is consistent with rapid hydrogen-bonded network formation during dewatering (Tako et al., 2014).
In contrast, PVOH showed the slowest and most gradual immobilization response, reflecting progressive chain association and entanglement as concentration increased (Parisi et al., 2022). Silk protein (60 mg/ml) exhibited intermediate behavior, indicating a balance between molecular mobility and aggregation-driven structure formation (Boulet-Audet et al., 2013b).

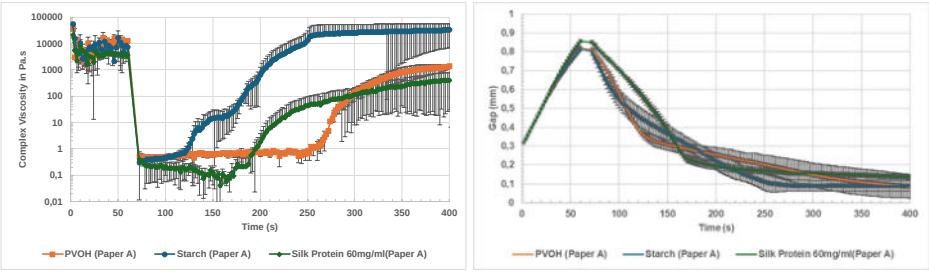

Figure 3. Comparison of complex viscosity and gap during IMC measurements of PVOH, starch and silk protein 60mg/ml on paper A. The complex viscosity and gap are shown as an avarage curve based on three replicates, with error bars indicating variability between measurements.

The paper substrate significantly influenced immobilization behavior. The more porous Paper A promoted faster dewatering and earlier immobilization, whereas the denser Paper B delayed the transition. The effect was most pronounced for PVOH, while starch and silk protein (60 mg/ml) immobilized on both substrates, albeit at a slower rate on Paper B. This suggests that substrate properties affect immobilization kinetics by controlling the rate of water removal from the coating layer (Mesic, Martinez-Hermosilla and Rättö, 2024).

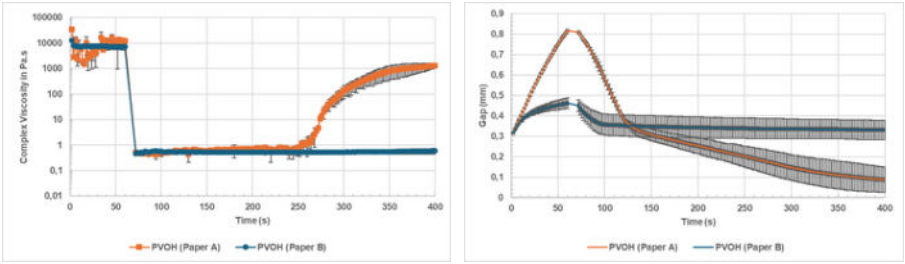

Figure 4. Complex viscosity and gap during IMC measurements of PVOH coating on paper A (orange squares) and paper B (blue circles). The complex viscosity and gap are shown as an average curve based on three replicates, with error bars indicating variability between measurements.

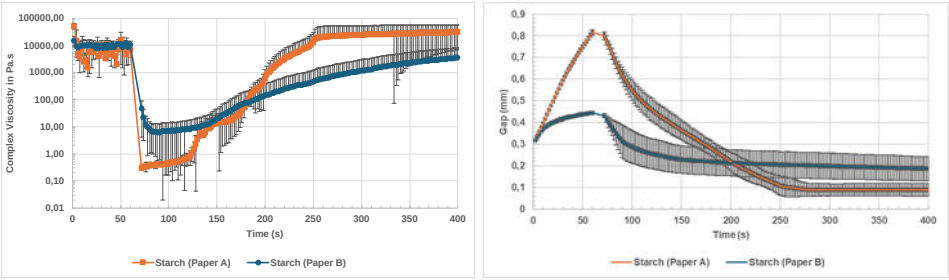

Figure 5. Complex viscosity and gap during IMC measurements of starch coating on paper A (orange squares) and paper B (blue circles). The complex viscosity and gap are shown as an average curve based on three replicates, with error bars indicating variability between measurements.

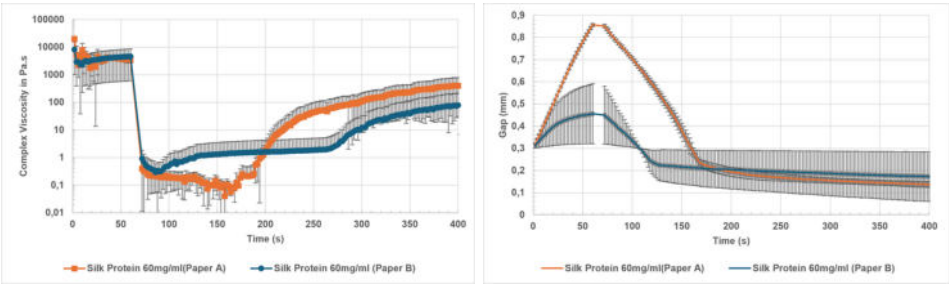

Figure 6. Complex viscosity and gap during IMC measurements of silk protein coating on paper A (orange squares) and paper B (blue circles). The complex viscosity and gap are shown as an average curve based on three replicates, with error bars indicating variability between measurements.

Bulk rheology and DLS measurements confirmed that all polymer solutions remained stable throughout the study. However, these methods could not fully predict the immobilization behavior observed in the IMC, highlighting the importance of studying coating systems under dynamic dewatering conditions (Luo et al., 2020).

In addition to polymer and substrate effects, the results showed that IMC measurements were sensitive to experimental conditions. Parameters such as stabilization time, applied normal force, and suction conditions influenced signal stability and reproducibility, highlighting the importance of carefully controlled measurement conditions when evaluating immobilization behavior.

Adhesion(Tack) and Cobb tests provided indications of coating performance. Starch and high-concentration silk protein showed rapid adhesion development, whereas PVOH developed adhesion more gradually. PVOH and silk protein coatings improved the water resistance compared with uncoated paper, whereas the starch coating exhibited instability during water exposure, as indicated by negative Cobb values that may result from coating dissolution or coating detachment during testing.

Conclusion

This study demonstrates that immobilization is not an intrinsic material property but a process-dependent phenomenon governed by the interaction between polymer properties, substrate-controlled dewatering, and experimental conditions.

Starch exhibited the fastest immobilization, PVOH the slowest, and silk protein (60 mg/ml) an intermediate response. The results further showed that substrate permeability strongly influences immobilization kinetics, while conventional bulk measurements alone cannot capture the dynamic behavior occurring during dewatering. Overall, the findings contribute to a better understanding of coating formation and provide knowledge that can support the development of sustainable, high-performance paper-based packaging systems.

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Study of the caking phenomenon on yeast powders during their storage - Development of caking characterization protocols

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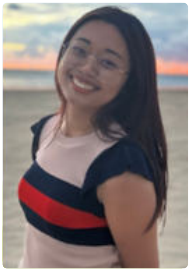

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Introduction

Postbiotics are preparations of inactivated microorganisms and/or their cellular components that provide demonstrated health benefits (Salminen et al., 2021). For commercial use in food and animal feed, postbiotic preparations are often converted into powders by freeze-drying or spray-drying to improve stability, handling, storage, dosing, and incorporation into formulations (Thorakkattu et al., 2022).

However, dried postbiotic powders may cake during storage, forming cohesive aggregates or solid masses (Aguilera et al., 1995). Elevated temperature and relative humidity can promote caking through moisture adsorption, particle adhesion, surface plasticization, and the formation of interparticle bridges (Aguilera et al., 2011; Nabil et al., 2020; O'Donoghue et al., 2019; Shah et al.,2023). When storage temperature exceeds the powder's glass-transition temperature, the amorphous matrix becomes more mobile and stickier, increasing particle deformation, sintering, and permanent bridge formation (Roos, 2010; Roos & Karel, 1991) (see Figure 1).

Texture analyzers can quantify caking by measuring the mechanical resistance of an aged powder bed through penetration or compression tests. However, no standardized protocol exists, and test conditions such as probe geometry, sample quantity, bed dimensions, compaction, penetration depth, and speed vary according to powder characteristics (Addo et al., 2019; Fitzpatrick et al., 2017; Fitzpatrick & Bremenkamp, 2019; Xia et al., 2023).

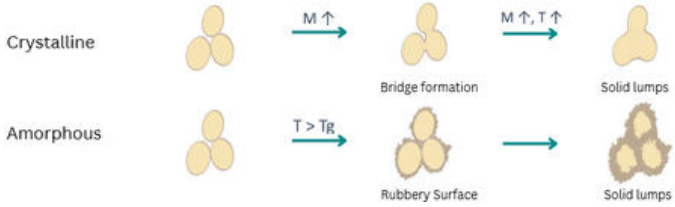

Figure 1. Overview of the caking phenomenon in powders.

Objective: To develop a characterization method to evaluate caking in dry yeast powders (postbiotics) qualitatively (sensory evaluation) and quantitatively via a Texture Analyzer.

Methodology

Four yeast powders (Table 1) were prepared as shown in Figure 2 and aged in the dark without air renewal for 20 days to assess their caking behavior at room temperature (RT) and 40°C, under low (≈ 33%) and high (≈ 77%) relative humidity (RH). Caking was evaluated independently on days 2, 7, and 20. For visual assessment, a scale was proposed taking into account the two behaviors observed (crust formation and sticky paste) (Table 2). For quantitative texture assessment, a penetration method was adapted from Xia et al. (2023), using a TA.HDplusC texture analyzer (Stable Micro Systems, UK), with a 10 g trigger force, a penetration speed of 1 mm/s, and an 8 mm penetration depth using a 5 mm diameter cylindrical probe. Day 0 represented the native state and served as the baseline for comparison.

Table 1. Description of the four yeast powder samples, derived from the yeast strain Saccharomyces cerevisiae obtained by spray-drying.

Sample	Description
Extract	**Soluble material** (high concentration of intracellular proteins, peptides, enzymes, and metabolites) from inside the yeast cell
Cell wall	**Outer structural layer** (peptidoglycan, β-glucan, a small amount of chitin, and polysaccharide) of the yeast cell
Liquid-mixed	Mixture of yeast extract (67%w) and cell wall (33%w) **before** spray drying
Dry-mixed	Mixture of yeast extract (67%w) and cell wall (33%w) powders **after** spray drying

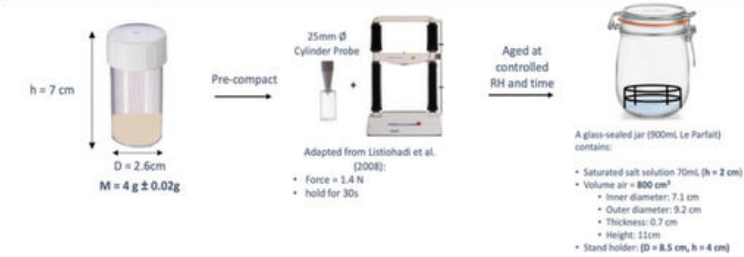

Figure 2. Overall schematic of yeast powder preparation before caking assessment.

Table 2. Semi-quantitative grading of powder caking based on visual assessment, with color codes indicating intensity.

Score	Description
-	No visible caking/free-flowing behavior
+	Top-layer crusting
++	Slight caking
+++	Moderate caking
++++	Strong caking
x	Hard and sticky
xx	Soft and sticky
xxx	Viscous, paste-like texture

Results and Discussion

Visual observation (Table 3) shows that all powders were initially free-flowing. High-humidity storage (RT, 77 ± 1.2% RH) caused the most rapid and severe caking, with partial dissolution in some samples; this behavior was likely associated with moisture uptake due to hygroscopicity and/or a reduction in the glass-transition temperature, thereby increasing molecular mobility.

Among the formulations, the liquid-mixed powder exhibited the greatest overall tendency to cake. Elevated temperature (40°C, 30 ± 0.6% RH) produced moderate, progressive caking, whereas low temperature and humidity storage (RT, 33 ± 0.4% RH) caused only minor changes, mainly surface crusting, probably due to low moisture absorption, which did not trigger sufficient liquid-bridge formation throughout the powder bed (Brockbank et al., 2021). The cell wall powder was the most resistant to caking, likely because its higher insoluble material content, such as peptidoglycan, β-glucan, a small amount of chitin, and less polysaccharide (Zhao et al., 2024), limited moisture-induced dissolution and reduced the formation of liquid bridges between particles, although caking developed after prolonged exposure to high humidity.

Table 3. Visual assessment (sensory evaluation) of four dry yeast powders before and after aging under different storage conditions and different time points (2, 7, and 20 days).

Sample	Condition	Timepoint (days)			
		0	2	7	20
Extract	RT, 33 ± 0.4% RH	-	-	+	+
	40°C, 30 ± 0.6% RH	-	+	++	++
	RT, 77 ± 1.2% RH	-	++++	xxx	xxx

Cell wall	RT, 33 ± 0.4% RH	-	-	-	-
	40°C, 30 ± 0.6% RH	-	-	-	-
	RT, 77 ± 1.2% RH	-	-	++	++++
Liquid-mixed	RT, 33 ± 0.4% RH	-	-	+	++
	40°C, 30 ± 0.6% RH	-	++	+++	++++
	RT, 77 ± 1.2% RH	-	++++	x	xx
Dry-mixed	RT, 33 ± 0.4% RH	-	-	+	+
	40°C, 30 ± 0.6% RH	-	+	++	+++
	RT, 77 ± 1.2% RH	-	++++	xx	xx

During penetration testing, the four yeast powders exhibited distinct mechanical responses after aging. The liquid-mixed powder mainly fractured during penetration, whereas the extract, cell wall, and dry-mixed powders generally retained a more intact powder bed. The force–distance curves were interpreted using two complementary parameters: cake strength, defined as the maximum force recorded between 0 and 8 mm and representing the resistance of the whole powder bed, and the slope of force (N/mm), representing the resistance of the surface layer to initial penetration, which measures how rapidly resistance builds during the first few millimeters of penetration, indicating cake stiffness. Figure 3 compares these parameters across powder types, aging times, and storage conditions.

In the native state, cake strength ranged from 0.3 to 1.1 N. Under low-humidity storage at room temperature (Figure 3A), mechanical changes were limited, and differences were initially non-significant ($p > 0.05$). By day 20, the extract and dry-mixed powders showed increased apparent cake strength, largely due to surface crusting and free-flowing powder underneath, while the liquid-mixed powder exhibited the highest slope, consistent with a stiff surface that fractured at shallow penetration. The cell wall powder remained soft and exhibited negligible resistance under these conditions.

At 40°C and 30% RH, Figure 3B cake strength increased significantly ($p < 0.05$) in all powders except the cell wall, reaching 21.5 N for the extract, 9.1 N for the dry-mixed powder, and 4.5 N for the liquid-mixed powder by day 20. The extract formed a denser, more deformable cake with high bulk resistance, whereas the liquid-mixed powder exhibited the highest slope on day 20, indicating strong pre-fracture resistance but lower whole-bed integrity due to its brittle failure.

Under high humidity (see Figure 3C), the response became non-linear. The extract, liquid-mixed, and dry-mixed powders caked rapidly, but prolonged moisture uptake caused softening, partial dissolution, and a marked reduction in both cake strength and slope by day 20. In contrast, the cell wall powder developed the highest late-stage resistance, reaching 30.1 N in cake strength and 14.7 N/mm in slope, indicating formation of a dense, intact cake.

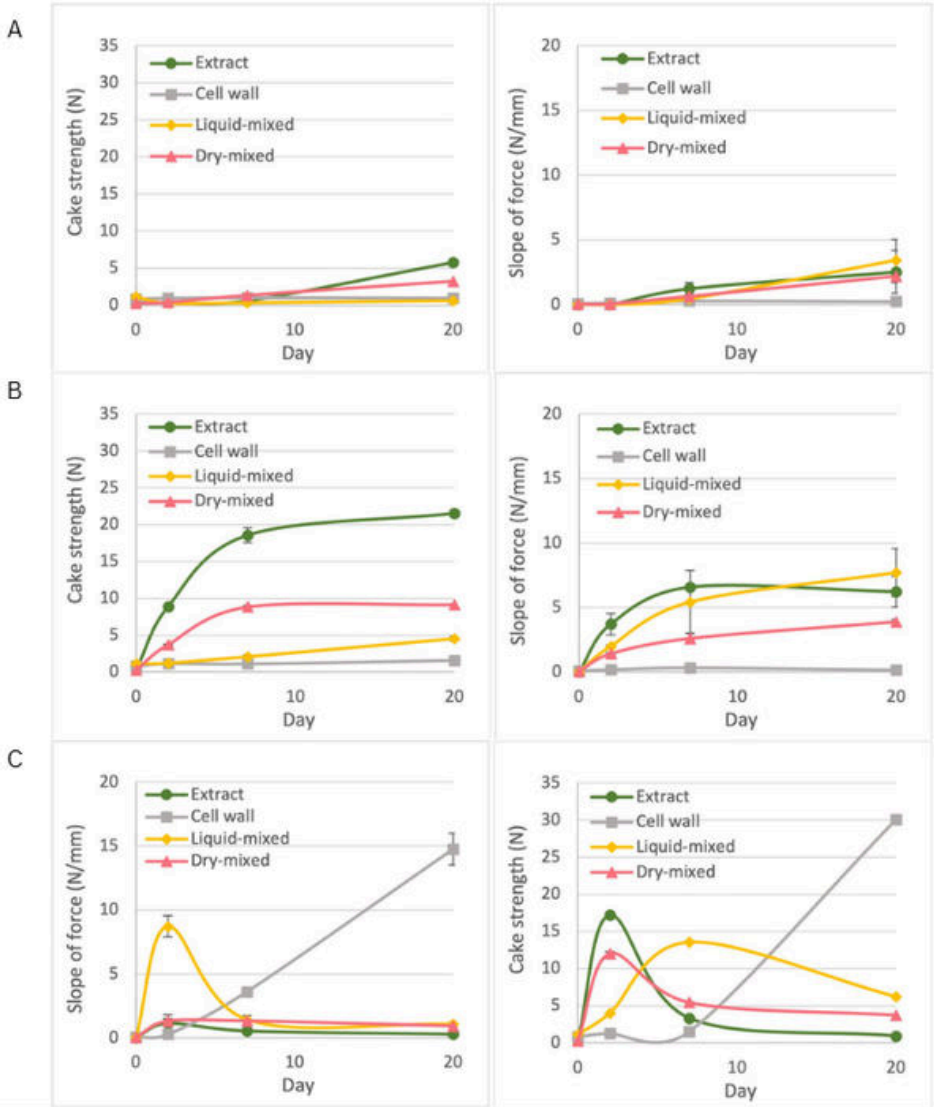

Figure 3. Data comparison between cake strength and slope of force after penetration method of four yeast powders stored under (A) RT, 33 ± 0.4% RH, (B) 40°C, 30 ± 0.6% RH, and (C) RT, 77 ± 1.2% RH at different time point.

Conclusion

Storage conditions strongly influenced caking, ranging from minimal at room temperature and 33% RH to moderate–severe at 40°C and 30% RH, and hard cake formation or partial liquefaction at room temperature and 77% RH. The liquid-mixed powder exhibited the highest overall caking susceptibility, followed by the yeast extract and dry-mixed powder, whereas the yeast cell wall remained the most resistant; furthermore, texture analysis confirmed that cake strength and force slope provide complementary information on the resistance of the entire powder bed and the mechanical properties of its surface, and both parameters are required to fully characterize the caking phenomenon. Future work should standardize the analytical approach, develop predictive models, and improve sample preparation to better reproduce real storage, handling, and distribution conditions.

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Towards Life Cycle Assessment Implementation in a Decentralized Manufacturing Organization: Drivers, Barriers, and Group-Wide Recommendations at Alfa Laval

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Introduction

Due to environmental challenges, sustainability is being pushed to one of the main organizational agendas worldwide. The external drivers towards sustainable practices include regulatory requirements from the government, pressure from stakeholders, and other regulatory requirements, while internal drivers include committed leadership and strong ethical values in the companies (Lozano, 2024). Life Cycle Assessment (LCA) is a method used to assess environmental impact across its entire life cycle (ISO, 2006a). Despite its growing potential, many organizations struggle with its implementation because they may lack the capabilities to incorporate it into their operations. The literature on LCA implementation exists; however, most of it offers a limited view or is outdated (Hjellvik & Kirkels, 2025).

This thesis addresses a gap in LCA guidance by developing LCA recommendations for large manufacturing companies. The case company, Alfa Laval (AL), is a global manufacturing company working in heat transfer, separation, and fluid handling operations. At present, AL incorporates LCA in parts of its operations; however, these efforts remain scattered across the organization. The factors that drive or hinder the LCA implementation are poorly understood, and thus it is difficult to ensure consistency regarding LCA practices across the company. This explains the importance of recommendations for a company-wide LCA guideline that will ensure a consistent LCA implementation across the organization. The study also demonstrates the applicability of the LCA guideline recommendations in a packaging case study for a lightweight pallet.

Methodology

This study follows a qualitative, embedded single-case study design, with Alfa Laval as the unit of analysis. Insights from the three main divisions of the company (Food and Pharma, Energy, and Ocean) along with several support functions were gathered to map current LCA practices across a large, decentralized organization. Since these practices had not previously been documented, the study combined an exploratory and descriptive approach (Saunders et al., 2023). The research design draws on Hjellvik & Kirkels (2025), whose work on LCA implementation in manufacturing firms provided the basis for structuring both the data collection and the analysis, grounded in the TOE (technological, environmental, organizational) framework and the stepwise diffusion of innovation theory.

Data were gathered through semi-structured interviews, analyzed through thematic analysis following the approach of Braun and Clarke (2006), and coded in NVivo software. Participants were selected as they had direct involvement in sustainability or LCA-related activities. Additional information came from internal company documentation, surveys, and site visits to Alfa Laval's facilities.

Results and Discussion

Alfa Laval has explored LCA as part of the company's sustainability strategies for several years. These efforts have remained scattered, with adoption uneven across Business Units (BU) and Supporting Functions (SF) and awareness and knowledge varying from one unit to another. By mapping the diffusion of practices across BUs as shown in Figure 1, it can be seen how units sit between the matching and routinizing stages, meaning some have yet to explore LCA relevance in their work while others have already adapted it in their practices.

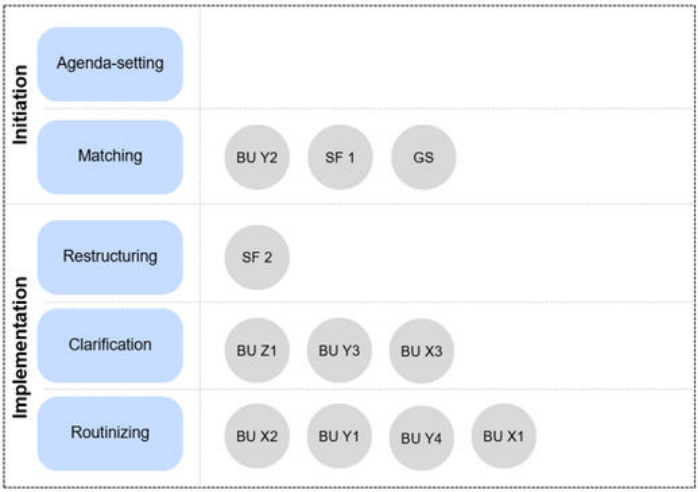

Figure 1. Mapping of the diffusion of LCA practices across BU

Data management practices differ significantly across the organization, with supplier and customer data remaining hard to obtain. The LCA studies currently rely heavily on generic databases due to the difficulty of collecting primary data. Stakeholders mention the importance of more alignment in how LCA is conducted, particularly around a shared data library.

Using the TOE framework, several factors were identified as shaping LCA adoption. **Technological** factors include trust in LCA as a weak to strong driver, data limitations as a weak to strong barrier, and the complexity of the methodology and SimaPro software as another weak to strong barrier. **Organizational** factors range from product innovation and cost-saving potential as weak drivers to resource constraints and supply chain complexity as weak to strong barriers. **Environmental** factors such as regulation and marketing act as weak drivers, while customer demand shows up as both a driver and a barrier depending on the BU. Overall, no single factor stands out as decisive, pointing instead to a combined influence across the organization.

Looking ahead, respondents pointed to Scope 3 reporting requirements under CSRD as a major driver for LCA's growing importance alongside the push toward Digital Product Passports.

Recommendations for LCA work in AL: Based on the findings mentioned above, recommendations for LCA work and an LCA guideline are proposed.
From the survey conducted on TOE factors, key influencing factors were observed, and targeted recommendations were provided, including the following main themes.

- **LCA Knowledge, Skills and Organizational Awareness:** Enhancing the internal capabilities through training, dedicated LCA support, and improved knowledge sharing.
- **Data Systems and Supply Chain Integration:** Developing a centralized LCA data library and strengthening environmental data sharing with suppliers and customers.
- **Strategic Implementation into Product Development and Decision-Making:** LCA integration in early product development to identify hotspots and support cost-effective decision-making.
- **Resource Prioritization and Organization Support:** Adopting a phased implementation approach, dedicated resources, leadership commitment, and broader access to LCA tools.

From the diffusion of innovation theory classification of the BUs and SFs according to their current stage of LCA adoption, recommendations addressed both at the unit and at the company level are suggested:

Matching stage:
- Identify internal advocates for LCA within the unit
- Company to offer onboarding modules alongside consultant training

Restructuring stage:
- Standardize templates for inventories and LCA/EPD reports
- Keep investing in LCA training across roles

Clarification stage:
- Strengthen internal protocols and LCA-based tools per unit
- Track LCA projects centrally and define success metrics

Routinization stage:
- Share best practices from advanced units across the company
- Upgrade existing LCA tools for better data quality

LCA Guideline: The proposed company-wide LCA guideline prioritizes clearly defined roles and responsibilities, LCA methodology, AL-specific processes, and technical foundations to ensure effective and consistent LCA implementation. Medium- and low-priority sections provide information on the guideline document itself, templates, training resources, knowledge sharing, and governing documents, and potential business unit specific protocols to facilitate group-wide adoption.

Applying the LCA recommendations to a real case helps bridge theory and practice, showing how the guideline holds up in context. SF1 was chosen for this reason, as it spans multiple BUs with packaging as a common denominator. The unit ships spare parts through seven Distribution Centers using a lightweight wood half pallet as shown in Figure 2. They are exploring lighter, more recyclable alternatives despite trade-offs between weight, durability, and recyclability. An LCA study could help resolve these by identifying hotspots and supporting more structured decisions.

Figure 2. Lightweight pallet used in Alfa Laval SF1 operation

SF1 is still early in its LCA journey, with a few team members in training but limited expertise and unclear ownership, given its role as a support function rather than a product owner, with gaps around supplier data and end-of-life tracking, as shown in Figure 3. The guideline proposed can offer initial methodological direction and role clarity; however, the generic structure would not be tailored to packaging-specific applications, such as in the pallet case. The recommendations lie mainly in working on data gaps, strengthening internal knowledge, embedding LCA in product development an decison-making and securing dedicated resources. The guideline is a useful starting point, but may need packaging-specific adaptations to be fully effective.

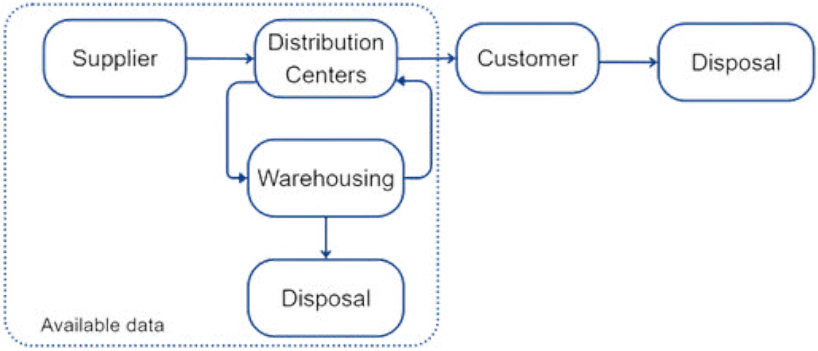

Figure 3. Lightweight pallet summary of the current supply chain

Conclusion

The study examined the current state of LCA practices at Alfa Laval to develop recommendations for company-wide LCA implementation and guideline. Using semi-structured interviews, surveys, company documents, and site visits, the research identified that LCA implementation is influenced by several interconnected TOE factors. While drivers such as trust in LCA, internal willingness, and customer demand support LCA adoption, barriers such as limited data availability, methodological complexity, resource constraints, and complex supply chain cause hindrance in the process. The findings revealed a decentralized approach with unclear ownership. Based on the insights, the study proposed recommendations to strengthen LCA knowledge, improve data systems, integrate LCA into product development, establish company-wide guideline that clarify roles and provide consistency for the group-wide LCA implementation. A packaging case study demonstrated the practical value of these recommendations and also highlighted the further need for improvement. Overall, the study provides a foundation for improving the management and implementation of LCA across Alfa Laval.

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Extended Producer Responsibility in Food Packaging: Exploring the Compliance Process

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Introduction

With the current push for sustainability initiatives, stricter packaging waste regulations have been introduced, creating significant changes in how companies develop, manage, and improve their packaging. One of the most impactful policies in these efforts is Extended Producer Responsibility (EPR), which shifts the responsibility for packaging waste management onto producers who put products on the market.

Under EPR, producers must report their packaging volumes, pay fees to fund the collection, sorting and treatment of packaging waste, and adhere to specific design restrictions and requirements when developing their packaging. However, EPR systems across the EU vary significantly from country to country, making it difficult for global companies to manage EPR compliance across all of their markets.

Our thesis aimed to explore the differences in EPR systems across the EU and how global food and beverage companies can improve the way they work with EPR. To do this, we studied EPR in 10 European countries to show the complexity and differences that exist between each system. Additionally, we collaborated with a global food and beverage company to understand how they worked with EPR across multiple markets. Together, these learnings were used to draw conclusions on how EPR systems across Europe affect company practices and outline strategies for companies to improve their current ways of working with EPR.

Methodology

This study examines the Extended Producer Responsibility (EPR) packaging compliance process at a global food and beverage manufacturer, referred to as the Company, operating across European markets. An explanatory single case study with embedded units of analysis was used (Yin, 2014), a design well suited to studying EPR compliance given its deep entanglement with national regulatory context. The Company was selected through purposeful sampling as a theoretically relevant, typical case of a global manufacturer navigating fragmented EU packaging regulation. Two embedded units were analysed: market-level regulatory variation and EPR implementation across markets, allowing both within-case and cross-market comparisons.

To evaluate fee variation across the chosen three markets, Sweden, Denmark and the UK, a simplified Excel-based calculator was built, modelling EPR fees for a representative five-product packaging portfolio using packaging material fee rates. The calculator incorporates country-specific base fee rates, SUP rates and eco-modulation rates and criteria, then validated against an independent fee calculation model developed by Lund University researchers, showing strong alignment.

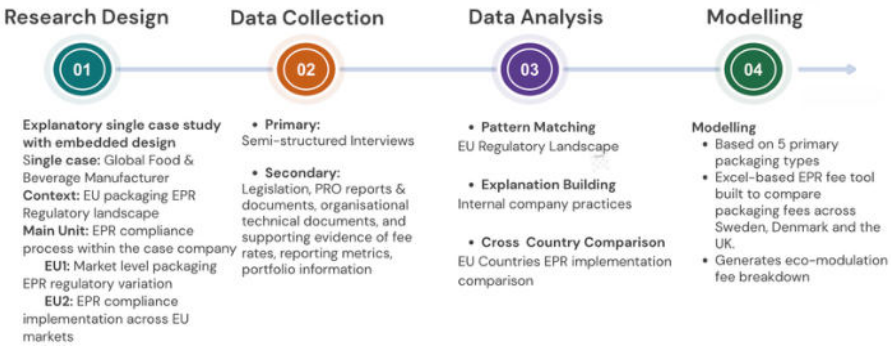

Figure 1. Research Design.

Results and Discussion

Findings revealed that European EPR compliance presents fundamentally different challenges for global food and beverage manufacturers compared to single-market operators. While the PPWR aims to harmonise EPR across the EU, national frameworks remain highly fragmented, creating three interconnected pressures: operational (varying registration and reporting requirements), strategic (differing eco-modulation criteria, meaning a packaging redesign that helps in one market can raise costs in another), and organisational (fragmented internal compliance ownership).

Fragmentation of EPR Landscape (Challenges)

Analysis of ten European countries confirms that each Member State designed its EPR system independently and was shaped by local infrastructure and PRO systems rather than a common standard, which aligns with Pruess's (2023) findings on PRO structural variation across 25 countries. For example, the Netherlands operates with a single centralised PRO, while Germany requires contracts with multiple competing PROs plus a central registry. Physical waste infrastructure also further shapes what EPR designs are feasible per country. This means knowledge built for one market (e.g. Sweden) transfers poorly to another (e.g. France): the same packaging material can be classified differently across borders, component-declaration rules vary, and reporting frequency, platforms and granularity all differ.

Opportunities

The challenges observed reflect inherent difficulties in the navigation of EPR compliance due to its complex and cross-functional nature in addition to the heterogenous landscape of this policy. As a result of these challenges, gaps exist in the compliance process, highlighting areas which serve as opportunities for improvement. These can be summarised under three core enabling processes: leadership, resourcing, and systems & tools (Pålsson & Hellström 2023). Further optimisation of EPR compliance can be achieved by creating a circular process, using portfolio organisation and modelling to bridge the input and output of the current system.

Packaging Improvement Framework

The findings of this study highlighted the difficulties experienced not only within the regulatory landscape but also within the implementation of internal management strategies. Due to its dynamic nature, EPR compliance remains a dynamic, cross-functional process, managed as a cooperative task across departments. Based this study's observations of the legislative landscape and internal management within the case study company, an improvement framework, shown in Figure 2 (next page), was developed as guide for companies looking to establish or optimize EPR compliance. This framework, based on the PDSA Cycle (Plan-Do-Study-Act) by Deming (1986), consists of a four key phases: Plan (which includes forecasting, data collection and regulatory monitoring), Do (in which EPR is reported and cost evaluations are performed), Check (the assessment of communication and performance) and Act (the integration of feedback to optimize the innovation and overall process).

By integrating these four phases, the framework seeks to provide a structured guide that can help companies shift from reactive, reporting-focused compliance towards a more adaptive and strategic approach.

Figure 2. Packaging EPR Improvement Framework.

Conclusion and Recommendation

This study aimed to explore the packaging EPR landscape across the EU and its relationship to compliance requirements within a global food and beverage company. Using an explanatory case study approach, national EPR implementation across 10 countries was compared to build case context, with a single global food and beverage company examined in depth to understand the compliance process, its challenges and opportunities for optimisation.

Our findings highlighted both external and internal challenges in the mangement of EPR compliance, stemming from the fragmentation of the EPR landscape across Europe and the lack of internal management strategies or guidelines established within global food companies. Recent changes in EPR legislation, such as the implementation of PPWR, have escalated both the requirements and penalties regarding Extended Producer Responsabilities, amplifying the need for global food companies to establish efficient compliance systems. Based on observations from the case study and cross-country comparison of EPR implementation, various recommendations were made, highlighting areas of difficulty in the implementation of a formal EPR compliance system and approaches to be used in the development of an effective and circular compliance process.

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Impact of different ingredients on sensory properties of yogurt with reduced sugar

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Impact of different ingredients on sensory properties of yogurt with reduced sugar

Yogurts are naturally acidic due to the lactic acid coming from the fermentation. In this context, the added sugar is essential to counterbalance the sourness and improve the palatability.

The aim of the project was to evaluate the impact of different ingredients in the key sensory attributes of reduced sugar yogurt.

The project consisted of a literature review to identify potential ingredients, followed by the yogurt production at a micropilot and laboratory scale. The experimental phase was grouped into four series of trials, to assess the effects of varying the formulation parameters. Physicochemical and sensory analysis were conducted to characterize and evaluate how these changes influenced the sensory attributes, respectively.

CONFIDENTIAL TOPIC

Impact of Yeast Mannoprotein Based Oenological Additives on the Sensory Profile and Consumer Acceptance of White and Red Wines

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Wine is a staple of the Mediterranean diet and a major cultural, social, and economic driver in the EU. Despite this, shifting preferences have resulted in declining interest, particularly among young adults. To address this challenge, the research group Flavorsen at CIAL is developing yeast mannoprotein oenological additives to enhance wine's organoleptic profile, aiming to realign it with young consumers' preferences.

This work studied the effect of yeast mannoprotein based additives on white and red wine regarding young consumers' hedonic appreciation and perception of key sensory attributes. In addition, the role of wine neophobia in influencing acceptability was also studied. For this purpose, a consumer study with 207 volunteers (aged 18–35 years) was carried out. Participants evaluated 10 wine samples (five red and five whites) with and without yeast mannoproteins through a hedonic rating of orthonasal aroma, overall liking after wine intake, retronasal aroma persistence assessment, and a Rate-All-That-Apply test to rate the intensity of selected wine sensory attributes

The insights generated by the study will be valuable for the wine industry, as previous research on this type of oenological additive has mostly been carried out using *ex-vivo* methods and trained panels, leaving their effectiveness in enhancing the experience of naive consumers largely unvalidated.

CONFIDENTIAL TOPIC

Closures with different oxygen permeability: an advanced tool to modulate wine aroma and enhance antioxidant protection

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Introduction

Wine aroma is a key determinant of perceived quality, consumer acceptance, and product identity, and it is particularly sensitive to changes that occur after bottling (Mota et al., 2025). One of the main factors influencing these changes is the type of wine closure, as closures affect the internal bottle environment through their different oxygen transmission rates (OTR). Variations in oxygen ingress can lead to distinct evolution pathways (Ugliano, 2013). High oxygen ingress in the bottle can significantly lead to the loss of fruity and varietal characteristics and promote the development of oxidation products and aromas such as bruised apple, boiled potatoes, whisky, etc. (Cui *et al.*, 2025). Conversely, insufficient oxygen can lead to wine reduction, resulting in the formation of aromas such as garlic, onion, boiled cabbage, or rotten eggs (Ugliano, 2013).

Interestingly, controlled oxygen exposure may promote favorable ageing processes. Nevertheless, the suitability of a closure also depends on the wine variety, since different wines respond differently to oxygen exposure according to their intrinsic composition and aging potential (Furtado et al., 2021). On top of that, by tailoring oxygen exposure, it is possible to slow oxidative degradation and reduce the dependence on chemical preservatives, particularly sulfur dioxide (SO_2). Since sulfites are associated with adverse allergy-like responses (Silva et al., 2019), minimizing their use seeks to improve product safety and controlled development of aromas. In order to achieve this, it is essential to acquire scientific knowledge about how wines evolve in relation to oxygen ingress in the bottle and their specific chemical composition.

Methodology

Red wines were sealed with five different cork closures (Figure 1): one natural cork (NC) and four microagglomerated cork closures with different oxygen permeabilities. The wines were analyzed after four years of bottle ageing (Aglianico, Primitivo, and Sangiovese) and five years (Nebbiolo). Sensory evaluation included Free Sorting Tasks, Ranking Test (Aromatic Opening and Odor Liking), Astringency Intensity, and Olfactory Profiles. Volatile organic compounds were determined using HS-SPME coupled with GC–MS.

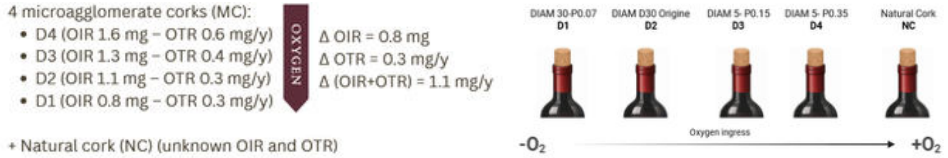

Figure 1. Cork closures and oxygen permeability.

Results and discussions

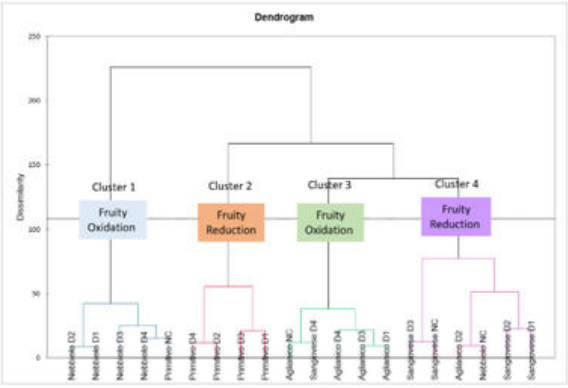

Figure 2. Free Sorting Task dendogram.

Wine clustering was mainly driven by grape variety (Figure 2), with Nebbiolo and Aglianico associated with oxidative evolution, whereas Primitivo showed a more reductive profile. Sangiovese exhibited greater variability. These differences were related to phenolic composition, particularly the Tannin/Anthocyanin ratio, highlighting the role of varietal characteristics in oxygen reactivity.

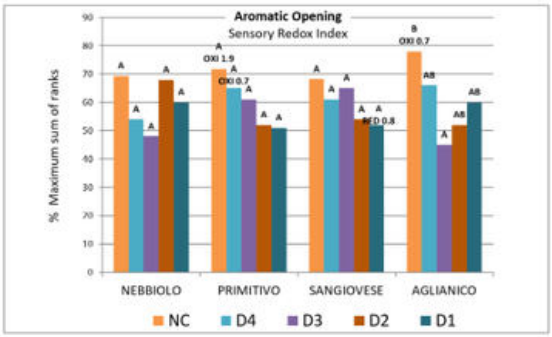

Figure 3. Histogram from the results obtained on the "Aromatic Opening" ranking test.

In the Aromatic Opening (Figure 3), Primitivo and Sangiovese exhibited a clear tendency toward increasing oxidation with increasing closure permeability. In the Odor liking test showed a general tendency toward higher preference for wines sealed with lower oxygen permeability closures, while the Astringency Test did not reveal significant differences among closure conditions, at least at the sensory perception level.

Results and Discussion

Closure oxygen permeability influenced both volatile composition and sensory perception, although the effect depended on the wine variety. Wines sealed with more oxygen-permeable closures generally exhibited higher oxidative defects, whereas less permeable closures preserved fresher sensory attributes in Primitivo and Aglianico (Figure 4), but promoted reductive notes in Nebbiolo (Figure 5) and Sangiovese.

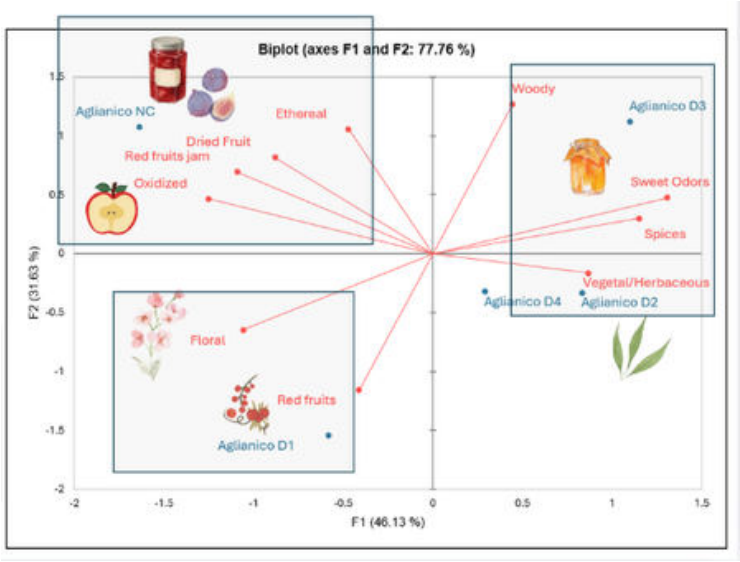

Figure 4. PCA of the olfactory profiles obtained for Aglianico.

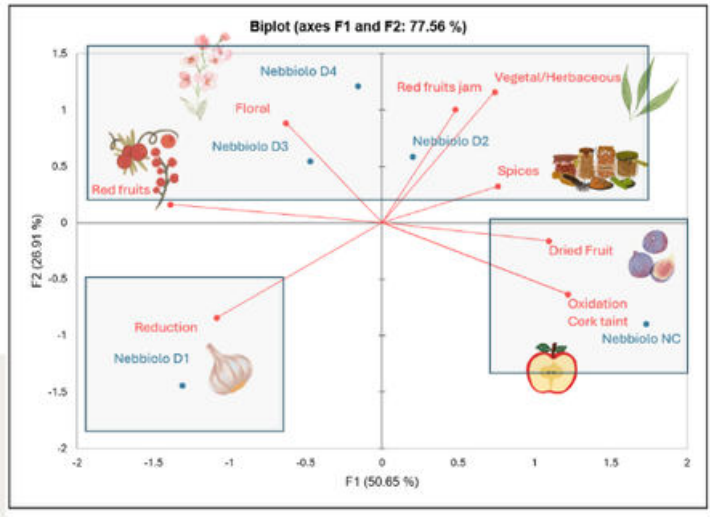

Figure 5. PCA of the olfactory profiles obtained for Nebbiolo

Table 1. Influence of closure oxygen permeability on the sensory profile of different wine varieties.

	D1	D2	D3	D4	NC
Nebbiolo	Reduction	Good profile with varietal aromas	Good profile with varietal aromas	Good profile with varietal aromas	Oxidation
Primitivo	Good profile	Reduction	Good profile	Oxidation	Oxidation
Aglianico	Good profile	Initial oxidation	Initial oxidation	Initial oxidation	Oxidation
Sangiovese	Reduction	Good profile	Good profile	Oxidation	Oxidation

Conclusion

The objectives of the study were achieved, demonstrating that post-bottling oxygen exposure plays a key role in wine evolution. The best closure should be chosen not only based on the type of wine, but also on the expected time of consumption. Selecting closures according to the wine matrix represents an effective strategy to modulate bottle ageing while preserving wine quality and potentially reducing the use of SO_2.

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Effect of Flaxseed and Chia Seed Format and Hydrothermal Pre-Treatments on the Extensibility of Grain-Enriched Tortillas During Storage

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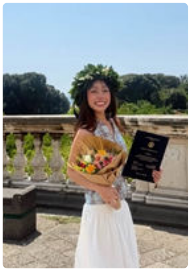

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The global double burden of malnutrition (DBM) has intensified demand for functionalized staple foods that deliver both nutritional value and improved shelf stability. Plant seed mucilage from chia (Salvia hispanica L.) and flaxseed (Linum usitatissimum) is a promising clean-label alternative to synthetic hydrocolloids for enhancing bakery texture and staling resistance. However, the combined effects of seed geometry (whole grain versus milled) and hydrothermal pre-treatment temperature on flatbread structural performance during storage remained poorly characterized. This study evaluated how seed type **(chia versus flaxseed)**, physical format **(whole grain versus mashed)**, and pre-treatment condition **(unhydrated, Low Temperature, and High Temperature)** affect the physical dimensions and extensibility of wheat mashed tortillas over a 7-day storage period.

Chia seeds and flaxseed, supplied by Puratos, were prepared as whole grain or mashed and pre-treated as unhydrated, hydrated at room temperature, or cooked at High Temperature prior to tortilla production. Thirteen formulations were developed, including a standard control, combining each seed type, physical form, and pre-treatment condition at a defined inclusion rate (baker's percentage), added to a standardized tortilla recipe. Tortilla thickness and diameter were measured for each formulation, and extensibility (peak rupture force) was assessed with a texture analyzer on Days 1, 4, and 7 of storage to characterize staling behavior across the different seed treatments using extensibility.

Seed incorporation influenced tortilla dimensions and extensibility through a three-way interaction between seed type, physical form, and pre-treatment temperature. Unhydrated seeds generally increased dough rigidity, producing thicker but narrower tortillas due to restricted radial expansion. Anti-staling performance over 7 days diverged sharply by seed type: for flaxseed, milling combined with High Temperature thermal activation gave the most favorable outcome, maintaining extensibility across the full storage period, attributed to even dispersion of arabinoxylan and rhamnogalacturonan fractions forming a continuous, moisture-retentive network in the dough. For chia, the whole-grain form pre-cooked at High Temperature performed best, retaining the highest extensibility of any formulation by Day 7 (569.68 g), likely because the intact seed acts as a slow-release mucilage reservoir. Milling chia reduced its long-term staling resistance rather than improving it, and pre-treatment at Low Temperature was insufficient to fully activate either seed's mucilage, yielding inconsistent results.

Chia and flaxseed require distinct processing strategies to optimize tortilla shelf life. While High Temperature hydrothermal activation benefits both seeds, milling is advantageous for flaxseed but detrimental for chia. These findings support a viable, seed-specific, clean-label strategy for extending flatbread shelf life without synthetic additives.

CONFIDENTIAL TOPIC

Development and Evaluation of an Innovative Hybrid Sourdough System: Effects on Leavening Capacity, Psycochemical characteristics, and Stability

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Hybrid sourdough systems combining sourdoughs may provide improved functionality for industrial baking applications; however, their fermentation behaviour and storage stability remain insufficiently understood. The aim of this study was to develop and evaluate novel hybrid sourdough systems by combining Sourdough α with Sourdough B, integrating rapid fermentation performance with flavour development while maintaining stability during refrigerated storage.

Sourdough formulations were produced and characterized through physicochemical, microbiological, and functional analyses. pH, total titratable acidity (TTA), yeast and lactic acid bacteria populations, sugar composition by HPLC, and fermentation performance were determined. Stability was assessed during 8 weeks of refrigerated storage through fermentation performance, microbial counts, and qualitative off-flavour evaluation.

The incorporation of Sourdough α significantly enhanced fermentation performance compared with B alone. In both hybrid sourdough systems, increasing TTA was associated with reduced performance, indicating that progressive acidification negatively affected fermentative performance during storage. Residual fermentable sugars and increasing acidity suggested that microbial metabolism continued under refrigerated conditions. Although yeast populations remained relatively stable, performance progressively declined, suggesting that reduced yeast metabolic activity rather than loss of cell viability limited technological performance.

CONFIDENTIAL TOPIC

Design and In Vitro Validation of Postbiotic Containing γ-Aminobutyric Acid Produced through the Fermentation of Industrial Byproducts

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Background

Food Waste as a Functional Resource

The linear model of food production (in which byproducts are routinely discarded) is increasingly recognized as environmentally and economically unsustainable. Spent coffee grounds (SCG), generated at a scale of approximately 60 million tons globally per year, and broken wafer sheets, rejected by the confectionery industry on purely cosmetic grounds, represent two such underutilized streams that retain biologically valuable compounds including polyphenols, dietary fiber, and glutamate-rich proteins (Mussatto et al., 2011; Banu et al., 2021). Their valorization through biotechnological processing aligns directly with the circular bioeconomy principles enshrined in the United Nations Sustainable Development Goal 12.3, which targets a 50% reduction in food waste by 2030 (Belardi et al., 2025).

Lactic acid fermentation of plant-based substrates by Lactobacillus brevis represents a compelling strategy for converting these waste matrices into high-value functional ingredients. L. brevis is distinguished by its capacity to produce GABA through the glutamic acid decarboxylase pathway, a mechanism activated under acidic fermentation conditions (Yao et al., 2021). GABA is a non-protein amino acid with well-documented roles as the principal inhibitory neurotransmitter of the central nervous system and has been associated with stress reduction, blood pressure regulation, and immune modulation (Hepsomali et al., 2020). The resulting fermented preparation qualifies as a postbiotic, defined by the International Scientific Association for Probiotics and Prebiotics as "a preparation of inanimate microorganisms and/or their components that confers a health benefit on the host" (Salminen et al., 2021).

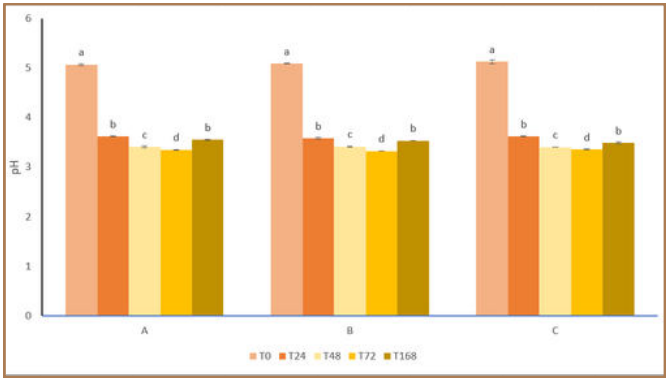

Figure 1. pH Monitoring.

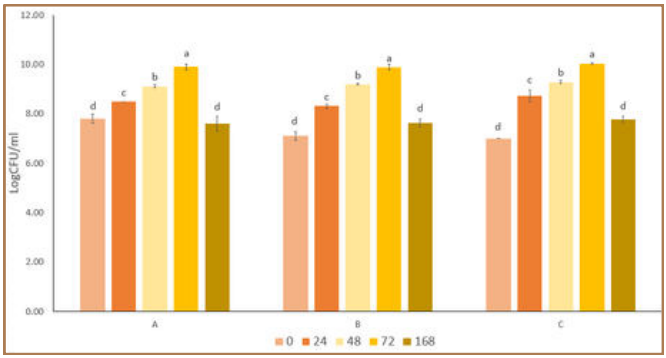

Figure 2. Microbial Growth Monitoring.

GABA Quantification

GABA quantification revealed that the fermentation significantly increased GABA content relative to the unfermented control at both T72 and T168 in the postbiotic ($p < 0.001$). Critically, in vitro digestion uncovered a substantially larger and statistically differentiated GABA pool: the T168 bioaccessible fraction yielded the highest GABA content of any sample analyzed (~16,000 µg/g), significantly exceeding both T72 (~9,500 µg/g; $p = 0.001$) and the unfermented control (~6,000 µg/g; $p < 0.001$). This finding that bioaccessible GABA at T168 was approximately 4.6-fold higher than the corresponding postbiotic value at PB168 indicates that a substantial proportion of GABA in the fermented matrix is structurally associated with the insoluble fraction and is selectively released during gastrointestinal enzymatic processing, highlighting the critical importance of bioaccessibility analysis in the functional characterization of postbiotic ingredients (Pérez-Jiménez et al., 2013).

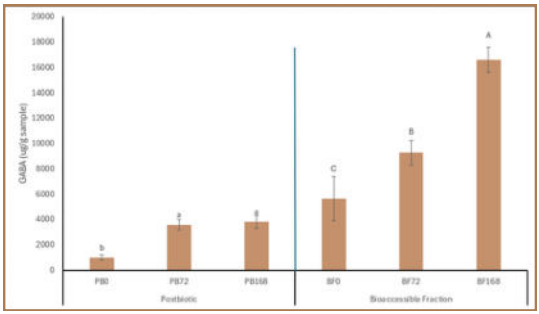

Figure 3. GABA Quantification of postbiotic powders and their respective bio accessible fractions.

Antioxidant characterization

The characterization by TAC DPPH and TAC Quencher assays revealed complementary and scientifically significant patterns. TAC DPPH (soluble antioxidants) did not differ significantly across fermentation timepoints in the undigested postbiotic ($p>0.05$), suggesting that fermentation time did not substantially alter the pool of rapidly reactive soluble antioxidants. In contrast, TAC Quencher (bound antioxidants) values were almost undetectable in all postbiotic samples but increased dramatically following in vitro digestion, with T72 and T168 bioaccessible fractions exhibiting significantly higher quenching activity than the unfermented control ($p<0.001$).

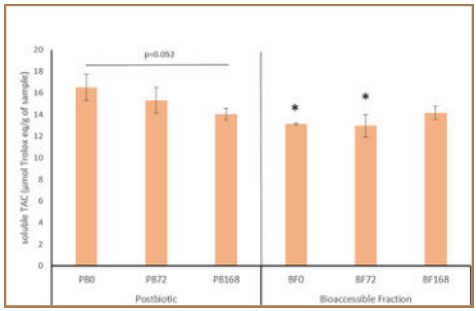

Figure 4. TAC DPPH for postbiotics and their bio accessible

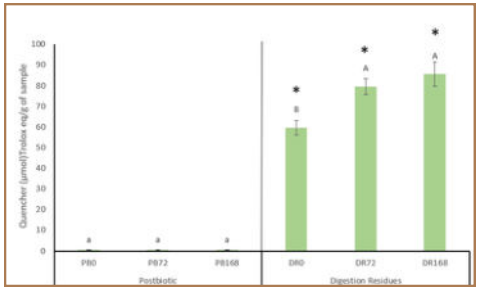

Figure 5. TAC Quencher for postbiotics and their digestion residues fractions

These findings are consistent with the concept of non-extractable polyphenols, antioxidant compounds covalently or noncovalently associated with insoluble dietary fibre and the cell wall polysaccharide matrix that are selectively liberated during gastrointestinal enzymatic processing (Pérez-Jiménez et al., 2013). The significantly higher bio accessible quencher activity in fermented samples relative to the unfermented control confirms that lactic acid fermentation enhanced the digestive release of bound antioxidants beyond what was achievable with the unprocessed substrate alone, likely through microbial enzymatic disruption of the cell-wall polysaccharide matrix during fermentation (Falah et al., 2021).

Food Application

The T168 fermented postbiotic powder was selected for incorporation into the functional cracker PB168C based on its superior bio accessible GABA content. At 10% w/w addition of PB168, and accounting for moisture loss during baking, the PB168C cracker is estimated to deliver approximately 32 mg of GABA per 100g of product, equivalent to approximately 10 mg per single 33g serving. A systematic review of human clinical trials identified effective oral GABA doses for stress reduction ranging from 20 to 100 mg, suggesting that regular consumption of two to three daily servings of PB168C would approach the lower boundary of the clinically relevant dose range, positioning the product as a sustainable, food-matrix-delivered source of bioavailable GABA comparable to commercially available GABA-enriched functional foods such as GABA rice and GABA tea (Hepsomali et al., 2020).

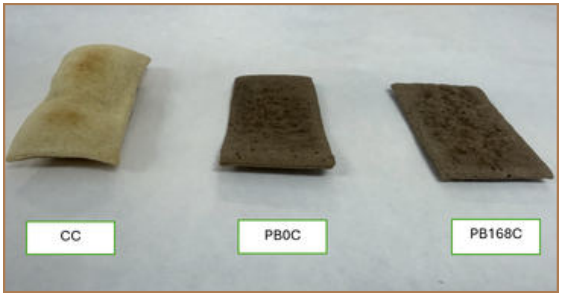

Figure 6. CC (Conventional Cracker), PB0C (cracker incorporating PB0) and PB168C (Cracker incorporating PB168).

Analysis of the cracker and its bioaccessible fractions confirmed that the functional benefits of fermentation persisted through thermal processing at 160°C: PB168C incorporating T168 fermented W+SCG exhibited significantly higher bioaccessible soluble TAC (~4.27 µmol Trolox eq/g; $p < 0.05$) and dramatically higher bioaccessible DPPH quenching activity (~14.959 µmol Trolox eq/g) than both the unfermented equivalent and the unenriched control cracker, demonstrating a clear and progressive functional advantage attributable directly to fermentation and preserved through baking and gastrointestinal digestion.

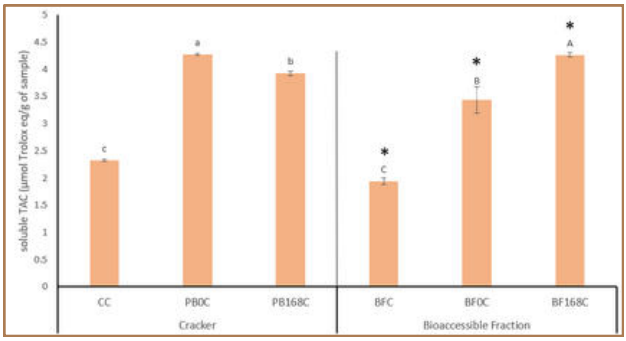

Figure 7. TAC DPPH of crackers and their bio accessible

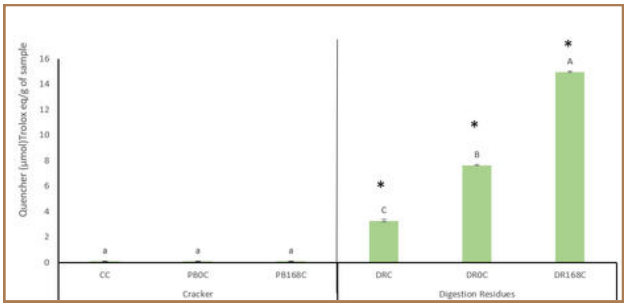

Figure 8. TAC Quencher of crackers and their digestion residues fractions

Conclusion

- **Dual food waste valorization demonstrated.** The simultaneous co-fermentation of spent ground coffee and broken wafer with L. brevis constitutes a feasible and scientifically robust strategy for producing a GABA-enriched postbiotic from two industrial waste streams, a combination not previously reported in the literature.

- **In vitro digestion is indispensable.** The application of the INFOGEST 2.0 static in vitro digestion protocol revealed that the true functional potential of the fermented postbiotic (both in terms of bioaccessible GABA and bound antioxidant capacity) is substantially underestimated by conventional extraction without digestion.

- **Fermentation enhances bioaccessibility.** Lactic acid fermentation significantly enhanced the digestive release of both GABA and bound antioxidant compounds relative to the unfermented control, confirming that fermentation-induced structural modifications to the substrate matrix confer measurable and meaningful functional advantages.

- **Translatable to real food matrices.** Incorporation of the fermented postbiotic into a functional cracker formulation demonstrated that the antioxidant and GABA-related benefits of fermentation survive thermal processing and remain recoverable during gastrointestinal digestion, validating the practical food application potential of the ingredient.

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Impact of Vacuum Mixing on Yeast, Dough Structure, and Final Product Characteristics

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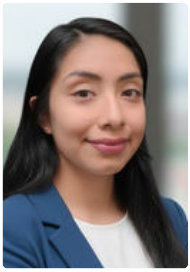

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Summary

Breadmaking is a technological process that involves processing a mixture of flour, water, salt, yeast and other ingredients through a sequence of physical, chemical and physicochemical transformations that determine the quality of bread. Among the stages of breadmaking, mixing plays a central role by ensuring the homogenization of ingredients, the development of the gluten network, and the incorporation of air bubbles into the dough.

The application of partial vacuum during mixing modifies the incorporation and distribution of air, altering gas cell formation, which in turn affects dough rheology as well as crumb structure and texture, leading to a finer and denser crumb structure. Therefore, this research focused on analysing the impact of vacuum mixing on baker's yeast activity, dough structure, and the characteristics of the final product.

The first stage of the study was carried out using a standard mixer to analyse the effect of mixing time on void fraction values. The second stage focused on optimising the pressure and duration of the vacuum mixing steps. Response Surface Methodology (RSM) was used to determine the optimal mixing parameters. The results suggest that vacuum mixing produces a finer crumb while maintaining high specific volume and crumb softness.

CONFIDENTIAL TOPIC

Unravelling the Processing & Microstructural divers of Cappuccino Foams

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Introduction

Cappuccino foams are volatile multiphasic dispersed systems subject to destabilization through liquid drainage, bubble coalescence, and disproportionation. While dairy proteins facilitate initial gas incorporation, the specific interfacial mechanisms governing macroscopic foam survival under mechanical stress require further clarification. This research investigates whether foam longevity relies on the dynamic mechanical flexibility of the adsorbed protein film or the bulk viscosity of the continuous phase.

The study systematically compares three dairy foaming agents. These include structurally rigid Whey Protein Isolate (WPI), flexible random coil Sodium Caseinate, and micellar Skim Milk Powder (SMP).

Foam generation was executed using low shear diffusional sparging and high shear convective whisking across an aqueous concentration gradient of 0.125% to 1.0% w/w. The physical lifecycle of these aerated dispersions was tracked using bulk rheology, dynamic drop tensiometry, real time microstructural imaging, and macroscopic drainage analysis.

CONFIDENTIAL TOPIC

NIR Spectroscopy for Breadmaking Applications

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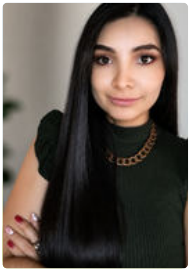

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Summary

Bread is the main stone for different cultural gastronomies, with several varieties from country to country. In each region and cultures around the world there is a wide variety of bread options with their unique ingredients, preparation methods and nutritional profiles.

Despite all the factors involved in its production process, flour can be considered a crucial component, due to how its chemical and rheological properties can influence all the subsequent stages. The strength and behavior of the dough, even the specific conditions required for the fermentation and baking steps, are influenced by the flour's characteristics. Therefore, in a breadmaking industrial context, the knowledge and understanding of its properties is primordial.

On the other hand, Near-infrared spectroscopy is an optical non-destructive technique which allows a rapid access to physical and chemical properties, which contributes to more time effective analyses and decision making. Furthermore, the main objective of this research work was to implement, validate, and expand the applications of NIR spectroscopy as a fast analytical tool for flour characterization and breadmaking process-monitoring with a focus on fermentation.

CONFIDENTIAL TOPIC

Evaluation of the efficacy of antimicrobials in acidic sauces

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Master Thesis tutors:
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Growing consumer demand for clean label products has driven food manufacturers to explore natural alternatives to chemical preservatives. This study, conducted at Kraft Heinz Nijmegen as part of the Natural Preservation Platform, evaluated the efficacy of natural preservatives in two high-acid sauce matrices: tomato ketchup zero and light mayonnaise, with the goal of supporting the transition away from synthetic additives in acidic sauce formulations.

The project involved the full validation cycle of a natural antimicrobial ingredient: beta-acid rich hop extract (BRHE) in tomato ketchup zero. This included optimising the ingredient concentration, studying the impact of pH, homogenization pressure, cooking time and storage conditions on antimicrobial performance. In parallel, two novel natural flavouring ingredients were screened as potential replacements for sorbate in light mayonnaise emulsion formulations.

Each production batch was evaluated through microbiological challenge tests, physico-chemical characterisation and structured sensory evaluation, providing a comprehensive picture of how natural preservatives behave in complex food matrices. The findings contribute to the broader challenge of replacing chemical preservatives while maintaining product safety, quality and consumer acceptability.

CONFIDENTIAL TOPIC

Optimisation of Salt and Baking Soda Concentrations in Immersion Brines for Cooked Chicken Breast Using Response Surface Methodology

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Factor, (HelloFresh, Netherlands)

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Carol England (Factor)

Introduction

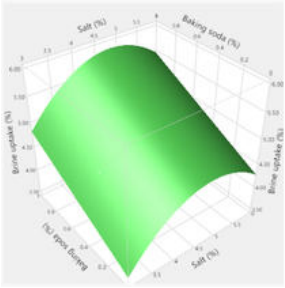
Chicken breast is a core protein in Factor_'s ready-to-eat meals, and key quality parameters for consumers are tenderness, juiciness, and flavour (Mir et al., 2017).. Brining is extensively used in industry to raise the water-holding capacity (WHC) of meat, improving the key quality parameters and increasing cooked yield (Krasnow et al., 2013; Volpato et al., 2008, Choi et al., 2026). Salt (S) improves WHC by solubilising myofibrillar proteins and expanding the muscle filament lattice, while baking soda (BS) offers a clean-label way to raise muscle pH away from the isoelectric point, further increasing WHC without the negative perception associated with phosphates (Offer & Trinick, 1983; Xiong, 2005, McKee, 2003; Petracci et al., 2012). Factor_'s current immersion brine (0.88% S) had not been optimised until this study. Moreover, literature lacks studies that aim to optimise these two ingredients in immersion brines both in terms of moisture retention and sensory characteristics, prompting the research quesiton: how do varying S and BS concentrations affect chicken breast quality in terms of moisture retention and sensory properties?

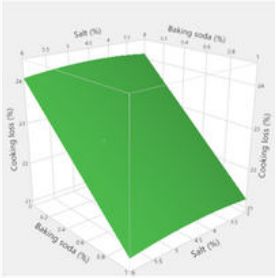
Methodology

Preliminary trials established the S and BS ranges for the main experiments, which involved a face-centred central composite Response Surface Methodology (RSM) design with concentrations of 3.0–6.0% S and 0.0–1.0% BS (9 coordinates, 11 processing runs), alongside a control representing the current brine of the company (0.88% S/0.0% BS) and internal/external validation points (4.0% S/0.3% BS). Chicken breasts were brined in lab-scale trials (n=3 per brine) for 4 hours, cooked in a combi oven, blast-chilled, packed in modified atmosphere, and chilled for 7 days before being microwaved to serving temperature, mimicking Factor_'s production process as closely as possible. Mass was tracked at each step to calculate brine uptake, cooking loss, and cooked yield; pH was measured pre- and post-brine; and an 8-person semi-trained internal panel rated texture and flavour using rapid descriptive analysis. Data were analysed via ANOVA/Tukey's HSD and modelled with RSM in JMP.

Results and Discussion

All experimental formulations improved key moisture retention parameters numerically compared the control, and most improved parameters significantly. Brine uptake rose by 2–4 percentage points, cooking loss fell by 4–7 percentage points, and cooked yield increased by 4–10 percentage points versus the control. BS increased post-brine pH directly, with pH 6.54 at 1.0% BS vs. pH 5.76 in raw chicken, and reduced cooking loss, aligning with the theory behind alkaline-induced electrostatic repulsion expanding the myofibrillar lattice (Alvarado & McKee, 2007; Offer & Trinick, 1983) (see figure 2). S showed a parabolic effect on brine uptake, potentially linked to a "salting-in/salting-out" effect peaking around 4.5–4.9%, in line with earlier findings (Lemos et al., 1999; Offer et al., 1989) (see figure 1). Sensory evaluation showed that all RSM samples scored significantly higher than the control for chickeny and salty flavour, with no soapy off-notes detected even at the maximum BS level, though texture attributes showed no clear formulation trend. JMP's optimisation profiler identified 4.89% S / 1.0% BS as the optimal formulation (desirability score 0.521), predicting a brine uptake of 5.85%, a cooking loss of 21.29%, and a cooked yield of 83.30%, resulting in almost a tripled brine uptake, ~7-percentage point decrease in cooking loss, and a ~9-percentage-point improvement in cooked yield vs. the control. Internal and external validation samples confirmed the model's predictive accuracy, with all error margins below 11%.





Figures 1 (left) and 2 (right). Response surface 3D graph modelling brine uptake (%) (left) and cooking loss (%) (right) as continuous function of brine S (%) and BS (%) concentrations.

Conclusion

The study demonstrated that RSM-based optimisation of a clean-label immersion can substantially improve cooked chicken breast yield and flavour over Factor_'s current formulation, while also indicating that higher BS levels can potentially compensate for lower salt use. Besides improving quality, the ~9-percentage-point increase in yield represents an opportunity for resource efficiency, requiring less raw meat per unit of finished product. Future research should involve scaled up trials at pilot-plant level with larger sample sizes, a more refined sensory protocol, and assessment of sodium quantity in the final product, to confirm lab-scale findings and evaluate nutritional impact. Overall, the study highlights that applying rigorous statistical optimisation to traditional processes like immersion brining is a viable, low-investment way for product and process innovation for both large producers and smaller-scale operations.

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Investigating Localized Discoloration in Retorted Meat Products Packed in Tetra Recart®

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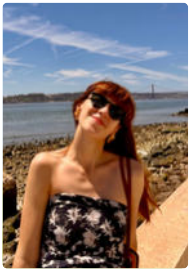

Profile in a nutshell:

- MSc. Food Innovation and Product Design (FIPDes) with specialization in Food Packaging Design & Logistics, Lund University (Sweden), AgroParisTech (France), TU Dublin (Ireland), UNINA (Italy).
- Bachelor of Chemical Engineering with specialization in Process & Food Technology, The Hague University of Applied Sciences (The Netherlands)

Interests:
Research and Development, Food & Culinary Innovation, Food Product Development, Packaging Design, Photography, Traveling & Exploring New Things.

Master's Thesis hosting lab/company:
Tetra Pak Packaging Solutions AB, Lund, Sweden / Division of Packaging Logistics, Department of Design Sciences, Lund University

Master's Thesis tutors:
Lars Palm, Daniel Hellström, Katarina Flemmer

Introduction

Tetra Recart® is a retortable multilayer laminate developed by Tetra Pak, composed of paperboard, polymer layers, adhesives, and aluminum foil, and used across a wide range of retorted foods, including meat, vegetables, and sauces. Retorting sterilizes sealed packages under heat and pressure (115-130 °C), but for meat products, color stability afterward remains an important quality attribute.

In some Tetra Recart®-packed meat products, a localized brown discoloration appears after 1–2 years of ambient storage, around the areas under the highest mechanical stress during converting. Because the discoloration occurs on the product itself, it suggests that micro-level oxygen ingress through these zones may be reaching the meat and triggering oxidative reactions in reactive compounds that remain after retorting.

Research Objectives

This thesis aims to identify the most likely chemical and packaging-related mechanisms behind this discoloration, with four objectives:

- Describe the oxidation pathways in retorted meat that could drive color change over time;
- Examine possible oxygen-entry pathways in Tetra Recart®, particularly through seals and creases;
- Link observed discoloration patterns to mechanisms identified in the literature; and
- Propose a practical evaluation method for future monitoring of similar cases.

Strategy and Methodology

As controlled laboratory experiments were not feasible within the thesis timeframe, the study relied on qualitative visual analysis of two photographic datasets – an archival set (A: 47 cases, 42 packages, storage 12–100 months) and a controlled supplementary set (S: 12 packages, storage 11 months) – interpreted mechanistically against the meat-oxidation and packaging literature.

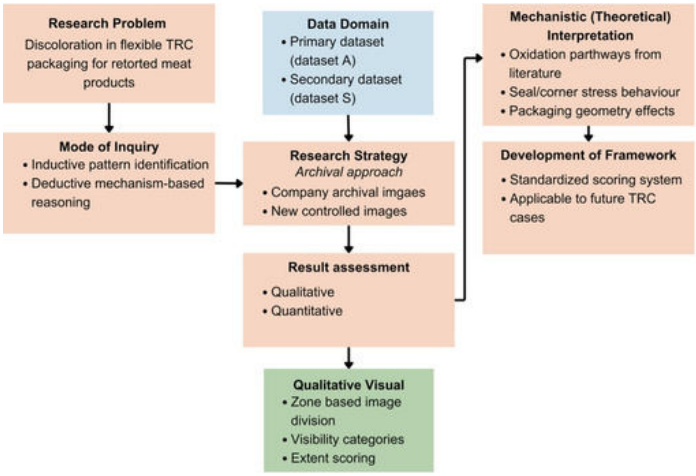

Figure 1. Methodological workflow, from the research problem to the proposed evaluation framework.

Each image was divided into five zones based on the package's converting geometry, graded on a four-level visibility scale and a 0-3 intensity score, and used to calculate a severity value (ΔE × extent %) from CIE L*a*b* measurements taken with a custom pixel-analysis tool built for this thesis.

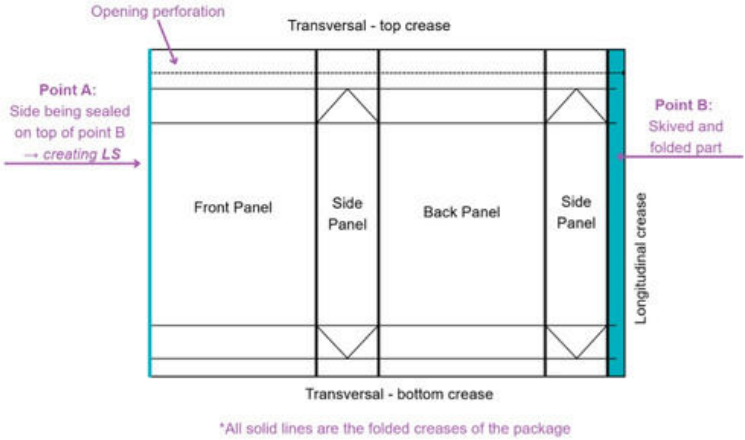

Figure 2. The five structural zones are used to classify discoloration location on the unfolded package.

Results and Discussion

Of the 54 packages analyzed (45 assessable cases in dataset A after 2 exclusions for runny texture; 12 in dataset S), storage time ranged from 10 to 100 months, averaging just under 25 months (Figure 3). 38 of 45 dataset-A cases (85%) and 7 of 12 dataset-S cases (58%) showed visible discoloration, almost all graded “slightly visible” with a Low extent score.

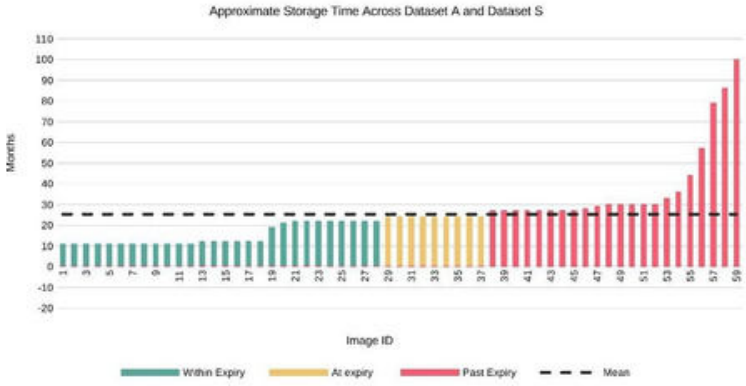

Figure 3. Storage time (months) of all analyzed samples, dataset A and S, mean shown as reference.

Severity (ΔE × extent %) in dataset A ranged from 0.05 to 6.83 (mean 0.74) but correlated only weakly with storage time – R^2 drops from 0.43 to 0.19 once the single outlier (A06) is excluded (Figure 4) – indicating that seal integrity, formulation, and pre-retort oxidation history likely matter more than storage duration alone. Location was concentrated at the seals: of the 31 dataset-A cases with an identifiable zone, 84% were at the LS or TS-bottom seal (73% across both datasets combined), and none at the TS-top seal.

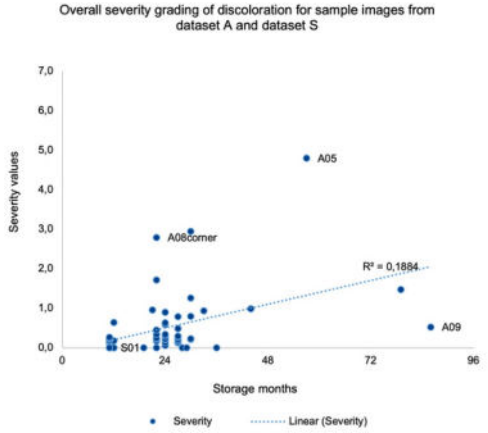

Figure 4. Severity value versus storage time for both datasets (R^2 = 0.19, excluding outlier A06).

Conclusion

The localized discoloration in Tetra Recart®-packed meat products is most likely driven by slow, sustained oxygen ingress through mechanically stressed packaging zones, initiating a self-reinforcing cycle of iron and lipid autoxidation that gradually produces brown discoloration. The colorimetric analysis showed that the dominant color change in discolored areas was toward darker tones, consistent with the progressive oxidation of Fe^{2+} to Fe^{3+} in hemochrome pigments formed during retorting, while lipid autoxidation produces reactive compounds that can accelerate the pigment-oxidation cycle even in low-oxygen environments. These two mechanisms are mutually reinforcing and self-sustaining, which explains why discoloration appears gradually over one to two years of storage instead of immediately after retorting.

The severity of this discoloration, however, appears to depend not only on storage duration but also on product-specific factors – such as fat composition, initial oxidation state before packaging, use of additives, vegetables, and mixtures of multiple meats – as suggested by the low R^2 value (0.19) once the outlier is excluded. The proposed evaluation method presented in this thesis provides a practical, low-resource framework that the company can use to document, grade, and mechanistically interpret future discoloration cases: a step-by-step checklist, a mechanistic decision tree, standardized photo-documentation guidelines, and template forms – laying the groundwork for more focused future investigations.

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