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Table des matières

Table of contents

Tendances & innovations en matière d'alternatives aux produits d'origine animale

Trends & Innovations for Alternatives to Animal-based Products

1. Maillard Reaction Products from Carboxylic Acid Modified Sugars: The Role of Glucuronic Acid in Generating Hydroxy-pyridinium Compounds

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The Maillard reaction is an important nonenzymatic browning reaction occurring throughout food processing, significantly enhances sensory attributes. Its reaction products are responsible for the distinctive and appealing browned and roasted flavor developed during cooking protein-rich foods. The sensory attributes of plant-based meat analogs, which are the key factors in consumer acceptance, simulate traditional meat products while exhibiting differences. Therefore, the intervention of Maillard reactions through the addition of natural and synthetic chemical compounds shows potential for intensifying color and aroma, developing meat-like flavor, and reducing undesirable off-notes. While many studies on the Maillard reaction have been focused on neutral sugars, it is noteworthy that acidic sugars, such as glucuronic acid (GlcA), have not been studied yet within this context. Despite their potential to modulate food pH, generate novel compounds, and undergo decarboxylation to yield highly reactive pentose sugars, their involvement in the Maillard reaction remains largely unexplored. This study investigates the impact of carboxylic acid-modified sugars and amino acids on the Maillard reaction using mechanochemistry. The process involves ball milling (30 Hz, 30 min) of the sugars and amino acids to generate early-stage Maillard reaction intermediates followed by controlled heating to generate post-glycation products. In this study, we have reported the thermal properties of the mechanochemically activated glucuronic acid-alanine in comparison with glucose-alanine. Our results indicate that, relative to glucose, glucuronic acid demonstrates a faster development of browning. Using ESI-qTOF-MS/MS, we have tentatively identified the formation of GlcA derived disaccharides, ribose and their respective Amadori products with amino acids such as alanine, glutamic and aspartic acids. The specific family of betaines derived from Amadori products of glucuronic acid were also characterized as hydroxy-pyridinium compounds whose specific role in the Maillard reaction has not been studied yet. The formation of these unique products may help to explain the higher reactivity of GlcA. This study opens new research perspectives on the role of carboxylic acid modified sugars in the Maillard reaction, suggesting their potential application as color additives and flavor precursors for use in food products with plant-based proteins.

2. Water Lentils (Duckweed) Protein Purification by Chemical & Electrochemical Acidification: Composition, Structure & Functional Properties vs. Commercial Isolates

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Water lentils are free-floating aquatic plants that have a great agronomic potential since they can double their biomass in 24-48h and are very rich in RubisCO, a protein that has promising properties for human consumption thanks to its high nutritive value and excellent functional properties when it is extracted from its leaf matrix. However, the use of leaf proteins for human food is limited because of the very low protein yields during the purification steps. In a previous work of our team, an optimized protocol combining protein extraction by solubilization followed by protein purification by isoelectric point precipitation was developed to produce a water lentil protein concentrate containing 57% protein with an extraction yield of 60%, the highest ever reported in literature for leaf protein extraction. However, this protocol required the use of a large quantity of sodium hydroxide and hydrogen chloride, which is not environmentally friendly, and the protein concentrate by-product could be valorised if it was demineralized. Therefore, water lentil proteins were purified for the first time using electrodialysis with bipolar membrane (EDBM), a technology that has been developed as an ecofriendly alternative to chemical acidification. The obtained products were compared in terms of proximal and protein composition, protein structure (FTIR), and functionality such as solubility in the pH 3 to pH 7 range, foam capacity and stability, gel strength by texturometry and emulsifying properties. Their functional properties were also compared to egg white, soy, and whey protein isolates as references. Overall, the water lentil protein concentrates, and their by-product had similar to superior functional properties compared to conventional proteins. These results confirm that water lentils protein can be successfully purified using EDBM and could be an alternative and sustainable protein source for human nutrition and food formulation.

3. Characterization of Quinoa Varieties Grown in Quebec & Assessment of the Protein Isolation in the Search for a Milder Extraction Process

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McGill University

Quinoa (Chenopodium quinoa Willd.) protein has attracted attention as a sustainable alternative to animal-based sources. Quinoa stands out as an environmentally friendly crop since it can tolerate adverse climate conditions, can adapt to different environments, and needs low input of agricultural resources to grow. Quinoa protein is considered higher quality than the ones found in other cereals, because of its aminoacidic composition, especially lysine, methionine, and tryptophan content; as well as its high PDCAAS score of 0.89. The protein quality and composition of quinoa depends on factors such as genotype, processing, growing conditions and location. The present study aims to analyze the impact of growing locations in nutritional composition. Eight varieties cultivated in three areas of the Quebec province (Ste-Anne-de-Bellevue, Normandie and St-Augustin-de-Desmaures) in 2022 were submitted to compositional profiling. Protein, lipid, ash, crude fiber and moisture were analyzed; as expected, the results varied between the growing conditions and locations, the protein content ranged from 16% to 26%, Normandie being the region with varieties that have the highest protein content, especially "R-Marie" and "Jessie", the crude fiber content varied between 5.3% to 13.2% w/w with "R-Marie" from Ste-Anne-de-Bellevue having the highest value, followed by "Bastille" from the same location. The variation of saponin content was between 1.08% to 7.2% w/w, St-Augustin-de-Desmaures being the location with varieties showing lower saponin content, especially "Calix-D" and "Jessie". It is known that quinoa has a balanced mineral content that includes potassium, sodium, magnesium, calcium and iron, and a lipid content in which 88% come from unsaturated fatty acids.

In search of a higher added value for quinoa, isolation of its protein has been assessed. In this case of study, the "Bastille" variety was used to analyze wet/dry fractionation and combination of methods. Wet fractionation was tested with diverse parameters. The highest purity was 90.1%. Dry fractionation was done with milling and sieving methods, creating protein-rich fractions. The highest protein content was 28% in fraction 1, which represents the protein-fraction of the embryo. The combination of wet and dry methods will bring a milder process to obtain high-quality protein isolate without compromising the purity of the result.

4. In vitro Protein Digestibility & Physicochemical Properties of Lactic Acid Bacteria Fermented Beverages Enriched with Plant Proteins

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The objective of this study was to develop probiotic beverages, enriched with plant proteins, with high nutritional value. A rice-based beverage fermented with a specific probiotic formulation comprised Lactobacillus acidophilus CL1285, Lactobacillus casei LBC80R and Lactobacillus rhamnosus CLR2 has been enriched with a combination of pea and rice proteins (PR) or pea and hemp proteins (PH) at 13 and 11% total protein, respectively. These protein associations have been selected because their amino acid ratio was > 1, as recommended by the FAO. The beverage enriched with protein significantly increased its viscosity by more than 10 times thanks to the enrichment, while the fermentation reduced it by 50% for PR and 20% for PH. In vitro protein digestibility results showed that the protein enrichment and the fermentation treatment significantly increased digestibility values of the beverages with value of 72.7% for fermented PR beverage and 61.4% for unenriched fermented control beverage ($p \leq 0.05$). Peptide profiles of PR and PH enriched beverages indicated that the fermentation led to a reduced level of high molecular weight (HMW) peptides of about 60% and an increase of low molecular weight (LMW) peptides by over 50%. Therefore, both the fermentation and the enrichment in protein increased the nutritional value of the rice-based beverages.

5. Impact of Composition & Water Content of Yellow Pea & Black Beluga Lentils Purees on their Foaming Properties

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The consumers are looking for products made of a short list of ingredients that are natural and locally produced. In that context, pulses like peas or lentils could be transformed into a food ingredient by cooking and grinding them to produce a puree. However, little is known of their functional properties. The aim of this study is to determine the impact of water content on the foaming properties of pulses purees. Whole yellow pea and black Beluga lentil purees were produced with 95.0, 92.5, 90.0 and 87.5% of water. Textural properties of the purees were determined by a back extrusion method while the flow curves were modelled with the Power law to obtain the consistency index (K). The effect of pH was studied by the addition of 0.2% of citric acid. The overrun and viscoelastic properties of the foams were determined.

The firmness, consistency, cohesiveness, work of cohesion, and consistency index (K) of the purees increase when their water content decreases. Pea purees textural properties and consistency are generally higher than those of lentil purees. This could be attributed to the difference in their composition with the higher content of starch and fibers in pea purees. In general, lentil purees produce foams with higher overrun values probably due to their higher protein content. The overrun is higher when the foams are made from purees containing 92.5% of water and it decreases when the water content decreases. The addition of citric acid contributes to increasing the overrun and the storage modulus of the foams. The foams made from purees containing 90.0 and 87.5% water are the most stable after 24h storage at 4 °C.
These results show that pulses purees can be used in foamed products. Water content revealed to be a lever to modulate pulses purees properties; an optimal water content would allow having enough protein to form the foam and enough particles to stabilize the film around the air bubbles. Pulses purees become an ingredient with great potential for use in foamed food such as chocolate mousse or fruit mousse allowing creating new textures.

6. High Pressure Impregnation of Foods for Value Addition

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High pressure processing (HPP) is a nonthermal processing technique for food preservation, value addition, extraction, and transformations. It has received much attention in recent years as a replacement for conventional thermal processing of foods. Food formulation and supplementation is a necessary technique for enhancing quality and functionality of foods. Many valuable components are supplemented to foods that lack them in order to compliment quality aspects and value addition.

High pressure impregnation has been used as an effective technique for adding the necessary nutrients to a food matrix that traditionally lack them so that the resulting product is more nutritionally complete.

In this study, high pressure processing is employed for impregnating/adding valuable components such as nutrients, texture enhancers, antimicrobials, acids, salts etc. to promote value addition and or facilitate necessary functions. In this technique, the product to be enriched is packaged in a liquid containing the desired nutrients/components and then treated under pressure. The high pressure used drives the covering liquid rapidly and uniformly into the product. Immersed dry products will absorb the liquid and the associated components up on treatment and they are dried again to trap and enrich them and at the same time preserve them.

Examples of liquid transfer to various food grains will be demonstrated as proof of concept.

7. Heat Transfer Consideration in Intermittent Oscillatory Rotational Agitation Thermal Processing of Fluid Particle Mixtures

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McGill University

Thermal processing is a technique used to destroy microorganisms and make a food product safe and shelf stable for human consumption. Lately, more focus is being given on quality of food and cost savings. This leads to the introduction of novel technologies that can face these challenges. The novelties include the use of high temperature short time heating, thin profile processing, aseptic processing, and agitation processing as well as nonconventional heating media such as microwave, radio frequency and ohmic heating.

Among the novel agitation thermal processing techniques to reduce process time, increase the quality of canned food while assuring the safety of consumption and reducing the energy usage, the agitation processing offers a significant advantage. These include traditional rotary agitation systems involving end-over-end, axial, or biaxial rotation of cans and the more recent reciprocating (lateral) agitation systems. Another novel technique which is not well explored is the use of intermittent oscillatory rotational mode processing in conventional rotary retorts.

This study compares end over end rotation with this new intermittent oscillatory agitation thermal processing using food simulating nylon particles in a can, filled with different viscosity fluids (water, oil, and glycerine), and under different rotation speed (10, 20, 30 RPM) and particle to liquid ratios (25, 50 and 75% particles). The efficiency determination will be based on delivered heat transfer rates evaluated in terms of heat penetration parameters like heating rate index and lag factors as well as the process times to achieve a targeted process lethality.

8. Study on Effect of HPP on Salmon for Texture & Color Modification Across Storage

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McGill University

Salmon is a highly popular seafood as it remains an attractive choice for the consumers because of its health benefits and high omega-3 fatty acid content. Due to the high lipid content, high moisture, and high nutrient profile, it can undergo rapid deterioration even with refrigerated storage and proper handling. As a result, adequate processing of salmon is important to make the seafood easily accessible, in compliance with food safety and increased nutrition to its consumer. Industries usually adopt thermal or chemical processing methods for achieving processing; however, consumers prefer for salmon that has undergone the least treatment. Furthermore, thermal methods can also induce nutritional changes, that may damage the vitamins, polyunsaturated fatty acids, or other flavor compounds.

This study was carried out to evaluate the effect of high-pressure processing (HPP) on salmon across the refrigerated storage at 4°C for 21 days. The study was carried out with both fresh and hot smoked salmon samples to analyze the effect HPP has on product texture and color.

For the processing of salmon, three HP treatment levels of 150, 250 and 350 MPa were employed with three different holding times of 10, 20, and 30 min, and their texture and color properties were evaluated systematically during refrigerated storage up to 21 days. It was demonstrated that HP treatment can slow down the quality deterioration rate for firmness, tenderness, lightness, redness, hue and chroma, and microbial growth hence extend the refrigerated shelf life of seafood products.

9. Green Extraction of Chickpea (Cicer arietinum)-based Functional Beverage: Assessment of Nutritional Quality & Storage Ability

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Microwave and ultrasound were investigated for their ability to enhance the nutritional content in chickpea (Cicer arietinum)-based functional beverage extraction, and the obtained results were compared to conventional beverage processing. This was followed by the storage stability analyses in terms of changes in physicochemical (pH, TSS, color), microbial, and functional (total phenolic content, total flavonoid content, antioxidant activity) properties for 21 days. The findings of our study indicate that ultrasound and microwave processing techniques exhibit distinct advantages over conventional processing in terms of not only enhancing the protein yield but also retaining the bioactive and functional compounds during storage. Among the extraction methods, microwave was found more effective with respect to higher protein yield (7.89 ± 0.11 g/100 g of beverage), protein solubility (18.54% ± 0.23%), and in vitro protein digestibility (90.79% ± 0.64%) at the optimum conditions (temperature: 65.8°C and time: 6.7 min). Regarding storage stability, microwave processing led to a remarkable increase of 47.32% in total phenolic content and 58.34% in total flavonoid content. The microbial study revealed less total bacterial and fungal counts in microwave and ultrasonically processed beverages over the storage period. Moreover, the study also revealed that the processing treatments applied did not result in significant alterations in the pH and acidity values of the chickpea beverage.

10. Production of Pea Protein-based Fiber Mats with Enhanced Functional Properties Using Electro-spinning

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Electro-spinning is an encapsulation technology used in the production of nano and microfibers and allows the entrapment of bioactive components. It is known to be simple and versatile with no heat usage, which can be beneficial for preserving active components such as antioxidants that can be easily affected by high temperature processing conditions.

Many studies have been done on electrospinning using animal-based proteins, while few research have reported using plant-based proteins. Recently, the interest in the use of plant-based proteins and pea protein as a replacement to soy protein in the food industry has boosted, due to their high availability, well balanced amino acid profile, low allergenic potential, and high nutritional values.

However, the use of pea protein in electrospinning is considered challenging due to it globular nature, low solubility, and reduced surface charge, which causes low potentials for molecular entanglement and poor techno-functional characteristics which can prevents electro-spinning. Recent studies showed that the formation of polysaccharide and plant protein-based conjugates will help overcome this problem through protein glycation, which provides fiber mats with higher stability and enhanced techno-functionality against heat treatments.

In this research, electrospinning technology was used in the production of sodium alginate and pea protein isolate-based fiber mats with improved nanoscale fiber formation and techno-functional properties for further use in the encapsulation of bioactive components.

11. Pasteurization of Acidified Low Acid Vegetables Through High Pressure Processing

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High pressure processing (HPP) which is a nonthermal processing technique for food preservation, value addition, extraction, and transformations can be effectively used for pasteurization of acid foods. Low acid foods (pH.4.6) traditionally require a high temperature process (121.1 C for 5 min) for creating commercial processing conditions for preparing shelf-stable foods. Reducing the pH to below 4.6 before processing allows these products to be processed like acid foods which only requires a pasteurization treatment (90C for 10 min). This will drastically reduce the processing temperature and time and hence the thermal severity of the process and thus results in significant reduction energy costs and thermal damage. HPP can be used for this process adding a non thermal alternative to conventional thermal process.

In this study the above concepts were applied to carrots. Carrots were first acidified by the application of HPP and then processed at 350 MPa (10 and 20 min) for achieving a pasteurization process. Quality and stability of the product were evaluated under refrigerated storage and compared with those that were treated likewise without acidification. Results demonstrated that HPP is an adequate process for both acidification carrots and pasteurisation of acidified carrots (pH <4.6). was used to process the acidity has received much attention in recent years as a replacement for conventional thermal processing of foods.

Transition vers des systèmes alimentaires durables

Transition To Sustainable Food Systems

1. Discovery & Characterization of Selected 4,6-α-glucanotransferases

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4,6-α-glucanotransferases (4,6-αGTs) are the recently discovered subfamily of glycoside hydrolase 70 family. 4,6-αGTs can cleave the α-(1,4) glycosidic linkages of substrates such as starch and starch hydrolysates and introduce novel α-glucan polymers with α-(1,6) or α-(1,3) glycosidic linkages. In this study, a BLAST search was conducted for identification of potential new bacterial strains for the production of the 4,6-α-GTs. The identified sequences were then aligned for construction of a maximum likelihood phylogenetic tree consisting of 172 sequence annotations. Among the identified hits, further studies for the characterization of the enzyme from strain Pediococcus pentosaceus was performed using amylose and soluble starch as substrates. The assessments including total activity, transglucanosylation extent, FTIR and NMR analysis suggests the formation of α-(1,6) glycosidic linkages. α-(1,6) linkages will escape the digestion in the small intestine and reach the colon where they act as prebiotic or dietary fibers which can then contribute to the promotion of the overall health.

2. Do Salmonella Typhimurium Strains Isolated from Different Hosts Carry Different Genomic Traits?

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Foodborne bacterial infections remain a global concern. In Canada, over ten million hospitalizations occur annually due to food-related illnesses, one-fourth of which are contributed by Salmonella enterica, with 99.5% belonging to S. enterica subsp. I (enterica). Based on their host specificity, the serovars in this subspecies are divided into three main groups: host-unrestricted, host-restricted, and host-adapted. As one of the leading causes of foodborne cases, the host-unrestricted serovar S. Typhimurium can invade an extensive range of hosts and pose hazards in numerous environments, from farm to fork. Traditional treatments against such pathogens involve a broad usage of antibiotics in both agricultural and clinical settings, rendering rapid and unreversible emergence of antimicrobial-resistant stains. The transition towards sustainable antimicrobial strategies in the food systems is urgently needed, while One Health, an integrated approach connecting human, animal, and environmental health with collaborative efforts, provides a solution to safeguard food safety.

In this project, we studied whether S. Typhimurium strains isolated from different hosts carry different genomic traits. We surveyed the genomic information of 56 S. Typhimurium isolates obtained from NCBI. The strains were isolated from nine different countries and covered various host sources, including cattle, chicken, pig, and human. We investigated the phylogenomic relationships between the strains and reviewed the presence and absence of the annotated genes. By comparing their genomic patterns, we revealed the similarities and differences of the genomic traits. We want to deliver the message that different bacterial strains isolated from distinct hosts share remarkable genomic similarities, which favors their genomic exchange and likelihood to transfer from one environmental cohort to another. Pathogen control should be performed on all processes from farm to fork, thus ensuring food safety and facilitating the transition towards sustainable food systems. Future technologies, like next-generation sequencing, could help us understand more about our enemies.

3. Enhancing 3D Printability of Plant-based Protein Products

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Protein gels, particularly those derived from plant sources such as pea and soy, are gaining attention in the food industry due to their nutritional and environmental advantages. Natural plant proteins often exhibit poor printability and stability, leading to suboptimal print quality during the printing process. Novel additives are used and play crucial roles in addressing these challenges. One potential additive, epigallocatechin-3-gallate (EGCG), a polyphenol found in green tea, shows promising results in modifying the surface hydrophobicity of soy protein isolate (SPI) and improving its gelation properties. In this study, we investigated the impact of varying EGCG concentration on the printing performance of edible inks formulated from soy protein, wheat gluten, water, and oil in different ratios. Through systematic experimentation varying nozzle diameter, nozzle height, printing speed, and material composition, the printability of the materials were assessed.

This research endeavors to bridge the gap between the inherent challenges of 3D printing with plant proteins and the potential for innovation in additive-based solutions, ultimately advancing the efficiency and sustainability of this emerging technology in the food industry.

4. Upcycling Blueberry Pomace into Functional Polysaccharides & Their Corresponding Oligomers

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Université Laval

Blueberries are popular soft fruits that contain a high concentration of bioactive compounds. These berries can be processed into juice, generating pomace as a by-product. This pomace is particularly rich in polyphenols and cell wall polysaccharides, making it an attractive biomass for generating added-value products. As a result, berry pomaces have attracted a great deal of interest for its potential in generating added-value products. Although there have been reports of pilot-scale extraction of polyphenols from blueberry pomaces, little attention has been given to its cell wall material. Indeed, these cell wall polysaccharides, which constitute more than 60% (w/w) of the pomaces, have the potential to generate added-value products. These complex carbohydrates have diverse applications, such as serving as dietary fibers, bioactive oligosaccharides, and/or techno-functional ingredients.

The analysis of blueberry pomace involved a thorough evaluation of its composition, covering ash, protein, fat, dietary fiber, and carbohydrates. Notably, the structural analysis of the cell wall material of blueberry pomace revealed significant levels of neutral sugars, including fucose, arabinose, galactose, xylose, mannose, and glucose, with concentrations ranging from 71-74%. By employing a sequential extraction technique, four distinct fractions were obtained, providing insight into the complex cell wall structure. This study contributes to understanding the composition of blueberry pomace and its valorization. The goal is to lay the groundwork for creating specific carbohydrates that could be used in functional foods, opening possibilities for new and beneficial food ingredients.

5. Investigation & Optimization of the Mechano-assisted Bioconversion of Lactose & Whey Permeate into Lactobionic Acid

E. Chidar & S. Karboune

McGill University

A novel use use of mechanochemistry, specifically mechano-ball milling, to assist the enzymatic bioconversion process converting lactose and whey permeate into lactobionic acid (LBA) was investigated in our study. This bioconversion explores the synergistic potential of a biocatalytic system comprising LactoYIELD-LY/Catazyme®-Cataz, along with the addition of hydrogen peroxide to facilitate the in-situ generation of oxygen.

Our findings indicated that as the concentration of lactose or whey permeate increased from 100 to 800 mg/ml, we observed a corresponding enhancement in productivity of LBA, reaching higher levels between 30.1-38.9 g/l.h and 8.4-12.7 g/l.h, respectively. However, our investigation also revealed the inhibitory effects exerted by certain components present in whey permeate on the efficiency of the biocatalytic system. However, the addition of polyethylene glycol provided a protective effect. The results also show that the substrate concentration and the hydrogen peroxide amount are significant variables affecting the yield and productivity of lactose bioconversion into LBA, while for whey permeate bioconversion, substrate concentration and LY/Cataz amount were found as the primary contributors.

In conclusion, our study contributes to the development of mechanochemistry-assisted enzymatic bioconversion of lactose present in biomasses into LBA.

6. Bacterial Endophytes with Biocontrol & Biostimulant Properties for Sustainable Agriculture

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BioSun

The increasing prevalence of plant diseases linked to mycotoxigenic species, and their secondary metabolites presents significant economic and public health challenges. Sustainable disease management strategies are sought to mitigate plant diseases and enhance plant growth and productivity. In this study we evaluated endophytic bacteria isolated from Chelidonium majus, a medicinal plant, and Cannabis sativa, as potential plant biostimulants and biopesticides against mycotoxigenic fungi such as Fusarium spp. The obtained total of 138 bacterial isolates, were then screened for various phenotypic traits, including phytohormone production, phosphorus, and zinc solubilization, organic acid production, and antifungal activities. Bacterial candidates showing promising activities were genotypically characterized through whole genome sequencing. Studies were also conducted under controlled conditions and in open fields to assess the bacterial isolates in real-world settings.

Our results showed that isolates identified as Bacillus sp. isolates 120 and 121 demonstrated the best inhibition of the fungal pathogens F. oxysporum, F. graminearum, F. solani, and Rhizoctonia solani (AG-3). Similarly, Bacillus subtilis isolates 115 and 114 exhibited substantial inhibition levels. For growth promotion potential, isolates 114/121, and Pseudomonas putida isolate 26 resulted in the highest IAA/OA production and P/Zn solubilization. Additionally, isolates 114 and 116 displayed the highest kinetin, jasmonic acid, and salicylic acid levels. Field trials with Bacillus subtilis isolate 114 and Pseudomonas putida 26 revealed an improvement in overall plant health and biomass thereby confirming their potential as promising biostimulants.

The findings of this study are anticipated to contribute to the development of novel, safe, and cost-effective biological products for disease management and plant biostimulation, ultimately fostering agricultural sustainability and enhancing food security.

7. Isolation of Highly Adapted Autochthonous Microorganisms from Berries & Berry Pomaces Intended for Producing Fermented Value-added Supplements

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Fermentation of fruits and fruit by-products (FBPs) can enhance their nutritional properties, digestibility, safety, and bioactive secondary metabolites. The use of highly adapted autochthonous strains in the fermentation offers several advantages, primarily because they can resist the antibacterial activities of phenolic compounds and acidic conditions in fruits and FBPs. Accordingly, the main objective of this project is to isolate more adapted microorganisms from berries and berry pomaces so that they can be further employed in the fermentation of these substrates and convert them into value-added supplements. This project commenced with gathering cranberry pomace, wild blueberry and chokeberry from our industrial partners. For isolating autochthonous LAB and Bacillus strains from the samples, two strategies were implemented. Non-heat-treated samples were used to isolate non-spore-forming bacteria, especially lactic acid bacteria. Heat-treated samples were used to inactive non-Bacillus bacteria and therefore isolating Bacillus strains. After that, the samples were serially diluted and spread on Nutrient Agar or MRS agar plates which were then kept at either room temperature or 37°C. The plates were incubated for up to 7 days, and then the most interesting single colonies with different morphotypes were selected for subsequent plating work. Subsequently, to ensure the purity of the colonies, the plating work was continued with two consecutive streak plate methods. To select highly adapted strains, the growth of isolates on the fruit-based media was evaluated by preparing different culture media encompassing berry juice. The media were incubated for 96 h and the growth of microorganisms was monitored during the incubation. Altogether, among 146 isolates from cranberry pomace (42), wild blueberry (53) and chokeberry (51), 57 isolates showed growth on the fruit-based media. Then, considering the differences in the morphology of the colonies, 37 isolates were selected for further evaluation using whole genome sequencing. The results from the whole genome sequencing revealed that the isolates mainly belong to Bacillus strains (e.g., Bacillus licheniformis and Bacillus subtilis) and Lactococcus strains (e.g., Lactococcus cremoris and Lactococcus lactis subsp. Lactis). In addition, the results from WGS will be used for evaluation of the genes associated with desired metabolic and enzymatic activities using metagenomic analysis. Finally, by employing a multidisciplinary approach that integrates in vitro assays, in vivo assays, metagenomics, and metabolomics, a consortium of effective strains will be developed that can be productively used in the fermentation of berries or berry by-products. Overall, this project will deliver economic benefits by creating new revenue streams for companies and positive environmental impacts.

8. Assessment of Abiotic Stress Tolerance & Growth Promotion Properties of Endophytic Bacteria Isolated from Cannabis

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BioSun

Abiotic stresses pose significant threats to soil and plant health, leading to substantial losses in yield production and crop quality globally. In lieu of the environmental sustainability, there have been much interest in exploring endophytic bacteria as an alternative to chemical fertilizers. Despite recognition of the diverse endophytic microbiomes in Cannabis plants, research on their response to abiotic stress remains limited. Thus, this study investigated endophytes isolated from Cannabis and Chelidonium majus for their potential to protect crops against abiotic stressors. Screening for functional traits such as siderophore and exopolysaccharides (EPS) production, proline production and biofilm formation, followed by testing for tolerance to high temperature, drought, and salinity, revealed promising positive results. Among the tested strains, Bacillus sp. isolate 114 showed better heat tolerance when tested under 55°C, Pseudomonas putida isolate 26 showed positive growth under 45°C. Under drought condition simulated using 10% polyethylene glycol (PEG), Bacillus sp. isolate 115, 116, 120 showed high growth, meanwhile the growth rate was not altered for the genera of Pseudomonas, (isolates 26 and 72). Additionally, Bacillus sp. isolate 114 and 115 showed higher growth under salt stress and Pseudomonas putida isolate 26 had optimal growth under salinity conditions which demonstrate their suitability for high salt, water deficit, and high temperature prone agricultural areas. Regarding the growth promotion properties, Pseudomonas putida isolate 26 showed higher siderophores production and proline content than the rest of Pseudomonas. Bacillus sp. isolate 114 possessed higher biofilm formation as well as EPS production. These findings suggest the potential of these endophytes as effective aids in mitigating abiotic stressors, facilitating the development of innovative, safe, and cost-effective biological solutions that can enhance crop resilience for sustainable food security.

Emballages durables & comestibles

Sustainable & Edible Packaging

1. Release Kinetics & Biological Properties of Active Films Based on Cellulose Nanocrystal-chitosan in Combination with Irradiation to Mitigate Microbial Load in Rice

L. Jaiswal, T. Begum, P.A. Follett, S. Salmieri & M. Lacroix

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Nanoemulsions (NEs) of 2 antimicrobial formulations (AF-1 and AF-2), a mixture of essential oils and citrus extracts, were prepared by microfluidization. For optimization, a central composite design was used to ascertain the effect of independent variables (pressure, number of cycles, and emulsifier concentration) on the physical properties of NEs [i.e., droplet size (DS), polydispersity index (PDI), zeta potential (ζ), and encapsulation efficiency (EE)] and compare with coarse emulsion. The optimized AF-1 and AF-2 values had DS of 116 and 40 nm, PDI of 0.17 and 0.2, ζ-potential of 49 and 32.3 mV, and EE of 77 and 79%, respectively. The microbicidal properties of the NEs against Escherichia coli O157:H7, Salmonella Typhimurium, Aspergillus niger, Penicillium chrysogenum, and Mucor circinelloides were significantly ($P \leq 0.05$) higher than the coarse emulsion. The NEs of both AFs were incorporated into a chitosan-based (CH) film. In situ tests with rice using bioactive CH-based nanocomposite films (BCHNF) reinforced with cellulose nanocrystals (CNCs) were tested against selected bacteria and fungi with and without γ-irradiation (750 Gy) and stored for 8 weeks. The BCHNF alone reduced 50–71 % of bacterial and fungal growth compared to the controls, while the combined action of γ-irradiation and films reduced 73–93 % of the tested microbial growth compared to untreated controls. Incorporation of CNC into BCHNF demonstrated a predictable pattern of slower release of active components (32–39 %) over the 8-week period compared to the bioactive films without CNC. The sensory qualities of rice did not change significantly ($P > 0.05$) after BCHNF treatments.

2. Development of a Gelatin-based Bioactive Film Photo-crosslinked by UVC-activated Riboflavin for the Preservation of Fresh Meat

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This study introduces a novel crosslinking technique to enhance the physicochemical properties of gelatin (GT) films by exposing them to UV-C irradiation in the presence of riboflavin (RF, natural photosensitizer). Then, GT-RF-antimicrobial films were also prepared by incorporating an essential oil (EO)-based antimicrobial formulation (AF) at 3 concentrations (0.5, 0.75, 1% v/v) in order to use as an active packaging film for prolonging the shelf life of meat. The physicochemical properties of the crosslinked films were investigated, and results showed that UV-C crosslinking for up to 13 min significantly improved film strength, permeability, and solubility. However, film elongation decreased, indicating a more compact and stiff structure due to the crosslinking process. Based on FTIR analysis, UV-C crosslinking caused an observable shift of absorption to higher wavenumbers of the Amide A, B, I and III bands indicating a significant crosslinking effect on the conformational change of the GT. The solubility and WVP were significantly ($p \leq 0.05$) reduced by 11 and 67% respectively, for all UVC-treated films compared to the control film (without exposure to UV-C light). Film tensile modulus (TM) and tensile strength (TS) were also enhanced significantly ($p \leq 0.05$), thus showing excellent mechanical properties. Release studies revealed that the GT-RF-1% AF film had the highest controlling effect on the diffusion and release rate of EO, indicating Fickian diffusion behavior. The crosslinked films showed excellent antibacterial activity against spoilage bacteria in the vapor diffusion assay. Finally, the application of the crosslinked antimicrobial films on meat extended the shelf-life from 12 to 20 days, demonstrating their potential application in meat preservation.

3. Fabrication of Sustainable & Robust Cellulose-based Hydrogels from Waste Cotton Fabrics as High-performance Food Coolants

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Ideal temperature condition is one of the essential determinants that critically impact the quality and safety of food products. Conventional methods of employing water-based ice cubes present challenges from meltwater being the breeding ground for microorganisms and heightening the risk for cross-contamination. Hereby, the presented cellulose and cellulose/alginate hydrogels crosslinked by epichlorohydrin were dip-coated with alginate/calcium chloride to form a core-shell structure for achieving the critical benchmarks of an ideal food coolant with limited meltwater production, high-water retention capacity, and high mechanical strength. The structure and properties of the hydrogels before and after freeze-thaw cycles were characterized by scanning electron microscopy, compressive test, water retention test, and differential scanning calorimetry. All the formulated hydrogels demonstrated promising compressive strength, latent heat of fusion, and water retention property. Notably, 100%- Cellulose hydrogel dip-coated with 2%- alginate and 10%- calcium chloride exhibited a maximum compressive modulus of 144.71 KPa and a high latent heat of fusion of 272.47 J/g, which were better than the previously reported sustainable hydrogel coolant. Furthermore, comparison studies revealed that the obtained hydrogels demonstrated similar thawing pattern to conventional ice cubes but without the generation of any meltwater. The temperature of blueberries could be cooled down from 22°C to 3.9°C in32 minutes by the hydrogels and in 26 minutes by ice cubes, respectively.

Systèmes alimentaires personnalisés & nutrition
Personalized Food Systems & Nutrition

1. Assessing Clostridium-induced Cheese Spoilage: Insights from Slurry Models & Bacteriocin Intervention

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The spoilage of cheese due to gas production and alterations in quality attributes poses significant economic challenges to the dairy industry. In this study, we investigated the potential of various Clostridium strains in inducing cheese spoilage and late-blowing using a novel approach termed "cheese slurry" models. We also examined the sensitivity of these strains to different Gram positive bacteriocins as a potential approach for their control during cheese ripening. Cheese slurries simulating Cheddar cheese composition were prepared and used to determine the effect of strains. They were inoculated with different Clostridium species and incubated to ripen. The results of our experiments revealed a pronounced impact of these bacterial strains on cheese quality and spoilage dynamics. We have also shown that Clostridium species other than C. tyrobutyricum are able to instigate significant spoilage of cheese through gas production, texture defects, cracks and holes and rancid odor. Moreover, significant alterations in cheese quality attributes, including protein, fat, salt, and moisture content were observed. Protein content was decreased, probably because of proteins breakdown because of bacterial enzymatic activity. Blowing defect primarily affects the moisture content and texture of the cheese rather than its salt and fat composition therefore the alteration in salt and fat contents were not significant. Using different inhibition assays, we have demonstrated that most of the Clostridium isolates were sensitive, at various extents to three antimicrobial peptides namely Nisin, Enterocin and Brevibacillin with MIC values ranging from 12.5 to less than 0.19 µg/ml. Future work will be dedicated to demonstrating this anti-Clostridium activity in a Cheddar cheese model. In conclusion, this study sheds light on the intricate interplay between Clostridium strains and cheese quality, highlighting their potential as key determinants of cheese spoilage regardless of the Clostridium species involved. It also provides preliminary evidence on the potential of certain bacteriocins as a natural approach for the control of Clostridium in a cheese matrix and consequently the prevention of spoilage during cheese ripening. Moving forward, continued investigation into the mechanisms underlying cheese spoilage will be essential for enhancing product shelf life and ensuring consumer satisfaction within the dairy sector.

2. Nanoencapsulating β-Carotene Improved its Delivery & Anti-inflammatory Potency in IBD Patient Derived Organoids & Caco-2 Cell Monolayers

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Inflammation suppression plays a crucial role in predicting outcomes and serves as the primary objective in treating inflammatory bowel disease (IBD). β-Carotene (BC) is a widely recognized bioactive compound known for its antioxidant, anticancer, and anti-inflammatory properties. However, its insolubility in water, limited bioavailability, and the challenging conditions it faces in the stomach and mucus layer penetration within the intestine hinder its effectiveness as an oral medication. This study aimed to tackle these challenges by encapsulating BC using a core-shell nanoencapsulation approach. Zein was utilized as the core material, while pectin and polyethylene glycol (PEG) served as the shell polymers. The process of nanoencapsulation, carried out through antisolvent precipitation and polymer deposition, resulted in an BC encapsulation efficiency of 75 %. Additionally, the core-shell spherical structure of nanoencapsulated BC (nBC) was confirmed through transmission electron microscopy (TEM) analysis. nBC showed enhanced BC radical scavenging ability, stability, protection against simulated gastric conditions, and demonstrated sustained release profiles in simulated intestinal conditions. The polymeric shell also offered improved mucoadhesive and mucopenetrative properties, as evidenced by a 7.3-fold increase in penetration through an artificial mucus (AM) model. When exposed to inflammatory models of lipopolysaccharide (LPS) and dextran sulfate sodium (DSS)-induced inflammation in Caco-2 cells and IBD patient-derived organoids, nBC displayed improved delivery and enhanced the anti-inflammatory activity of BC, in a dose-dependent manner. These findings revealed the promising potential of the protein-polymer nanoencapsulation platform in delivering therapeutic agents for suppressing inflammation in patient derived organoids.

Acceptabilité sociale & aspects réglementaires

Social Acceptability & Regulatory Aspects

1. Rapid Infrared Spectroscopy Methods to Detect & Maintain the Quality of Northern Shrimp

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Shrimp is one of the most consumed seafood worldwide due to its exceptional delicious taste and healthy benefits. However, instant freshness monitoring is challenging for the seafood and aquaculture industries due to their highly susceptibility to post-harvest quality loss following their post-mortem metabolism. Therefore, a reliable, expeditious, and non-invasive technique to estimate shrimp quality is in high demand.

Hyperspectral imaging (HSI) technique combined with chemometrics algorithm was investigated for discriminating the freshness of Nordic shrimp in the short-wave infrared region 986-2560 nm based on their total volatile basic nitrogen (TVB-N) contents and total viable count (TVC) of the shrimp.

A quantitative prediction model using partial lease square regression (PLSR) was constructed for TVB-N content and TVC of the shrimp by collecting 986-2560 nm hyperspectral data and TVB-N content of samples of Nordic shrimp during five consecutive days. The prediction effect of PLSR model yielded a correlation coefficient (R) of the validation set reaching 0.9893. PLSR achieved satisfactory total classification accuracy of 100% and 96% for freshness grade of shrimp in calibration (25 samples) and prediction (25 samples) sets, respectively. In addition, principal component analysis (PCA) algorithm was used for classification of the samples. The combination of wavelengths 1204, 1277, 1327 and 1482 nm selected from the PLS loadings achieved satisfactory total classification accuracy of 100% for the discrimination between fresh and stale Nordic shrimp that starts spoiled only the second day of storage.

An image visualizing classification map of freshness grade confirmed the possibility of rapid and non-destructive detecting freshness grade of Nordic shrimp by the combination of HSI and chemometrics.

L'intelligence artificielle dans l'industrie alimentaire

Artificial Intelligence in the Food Industry

1. Botanical Discrimination Model for Buckwheat Honey Based on Liquid Chromatography Coupled with High Resolution Mass Spectrometry

S. Bilamjian, L. Tian, D. Cuthbertson, L. De Leoz, T. Anumol & S. Bayen

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Relatively higher market price and consumer demand for monofloral honeys have attracted the attention of fraudsters, and the adulteration and/or the mislabeling of the botanical origin of honeys have been recorded. Honey fraud is a threat for both consumers and the honey industry. The interest for monofloral buckwheat honey is growing in recent years as buckwheat honey is one of the most valued honeys owning to its nutrients. A non-targeted workflow was developed in the present study to record honey fingerprints and a discrimination model was developed for buckwheat honey authentication using 262 honeys collected in 2021. Honeys were analyzed using a "dilute and shoot" method based on liquid chromatography coupled with high resolution mass spectrometry (LC-HRMS). The method performance is satisfactory with the analyte recoveries ranged from 95% to 105% for all the spiked chemicals and an inter-day RSDs lower than 11%. A PLSDA model was built to distinguish buckwheat honeys from 13 other types of honeys and the model had good sensitivity (100%) and accuracy (97.7%). The prediction accuracy of the developed model is 95.7% for new honeys collected in 2023 (n=92), which indicates the applicability and robustness of the developed model to discriminate buckwheat honeys.

2. An Embedded AI System Utilizing a Multiplex Microfluidic «Lab-on-the-Chip» for AMR surveillance of Foodborne Pathogens

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The farm-to-fork continuum represents a fundamental pathway for the spread of antimicrobial resistance (AMR) of foodborne pathogens. To address this crisis, we recently developed a real-time surveillance system to monitor the rise of AMR bacteria in food chain using microfluidic "lab-on-a-chip" for antibiotic susceptibility testing and image recognition. However, this surveillance system only monitors one antimicrobial each time and requires costly GPU to run a model on desktop computer, which limits its potential applications in agri-foods.

This study aims to enhance the efficiency of AMR surveillance of foodborne pathogens by developing a portable, cost-effective embedded AI system.

As an embedded device, Orange Pi 5B was utilized to simultaneously control various components of a portable incubator, including a heater for temperature control, a micro gas pump for managing CO2 level, and assorted sensors that monitor the bacterial cultivation conditions. Additionally, a camera linked to the Orange Pi could record the colorimetric reaction on multiplex microfluidic chip. An onboard light object detection model was then applied to automatically detect antimicrobial resistance and upload the findings to the cloud. Four typical foodborne pathogens were selected for testing and verification, including Campylobacter jejuni, Campylobacter coli, Salmonella enterica serovar Enteritidis, and Salmonella enterica serovar Typhimurium.

This embedded AI system was empowered with a finely tuned lightweight YOLO V5 object detection model and could achieve a processing speed exceeding 30 frames per second and 99% precision in classification of bacterial growth/inhibition. It costed approximately $150 excluding the incubator. The collected data could be automatically uploaded to the cloud server, facilitating instantaneous, large-scale analysis of spatial and temporal AMR trends.

This advanced embedded AI system with multiplexing capabilities holds significant potential for AMR surveillance as it enlarges the scope of surveillance and extends the capacity to concurrently monitor disparate antimicrobials. The affordable and compact AI node with powerful processing capabilities might revolutionize AMR detection across the global food supply chain.

3. Non-targeted Analysis to Detect Unknown Contaminants from Food Packaging – An Application to Thermal Labels

G. Leung, Z. Xu, L. Liu, C. Goodyer & S. Bayen

McGill University

Non-targeted analysis is a novel technique to identify unknown compounds in the samples. In this study, a non-targeted screening workflow was applied to identify unknown flame-retardant compounds in plastic food packaging materials. These flame retardants, including organophosphate esters (OPEs) are often used as plasticizers in food packaging. Since they are not bonded to the materials, they could potentially migrate from the packaging materials to the food in contact. Recently, a study reported that the maximum level of OPEs in polymer packaging materials was up to 4,000 ng/g, and the level was 50 times higher than that in the fresh food samples. This has created food safety concerns as some of these OPEs were found to be endocrine disruptors. In the methodology, a non-targeted screening workflow was applied, with an in-house screening library of 140 compounds. The workflow also included applying a machine-learning software, SIRIUS, which correlates MS/MS spectra for structural predictions, resulting in more accurate identifications of unknown compounds in the samples. The results showed the detection of tris(2-butoxyethyl) phosphate (TBOEP), triethyl phosphate (TEP) and melamine from thermal label samples. This showed that these additives in food packaging could potentially lead to additional exposure to OPEs by humans via diet. This study shows that using a non-targeted approach will provide a novel angle to assess the total flame-retardant exposure from food.

4. Data Mining the Honey LC-MS Spectra for Botanical Origin Authenticity Markers

A. Roginski, S. Chahal, L. Tian, S. Bilamjian & S. Bayen

McGill University

Honey is a highly valued natural food product which is renowned for its superior nutritive value compared to other sweeteners. In particular, the market price of honey is largely determined by its botanical origin, making it a prime target for fraudulent practices. Current strategies for authenticating the botanical origin of honey (e.g., pollen analysis) are often time-consuming or provide ambiguous results given the diversity of floral origins from which bees can obtain nectar. This work explored multi-targeted and non-targeted analysis, utilizing high-resolution mass spectrometry coupled with advanced data mining tools, to rapidly identify markers for authenticating the botanical origin of honey. A multi-targeted analysis of 34 selected phenolic compounds in over 450 honeys from 36 different botanical origins collected from the Canadian market was analyzed using a simple 'dilute-injection' LC-QTOF-MS method. This marks the first study to examine and compare the phenolic profile of such many Canadian honey samples. This investigation revealed the effectiveness of phenolic compounds in distinguishing buckwheat honey from other botanical origins. Specifically, it was identified that p-hydroxybenzoic acid serves as a promising single-marker for assessing the authenticity of buckwheat honey, with a quantitative threshold level established. Furthermore, a non-targeted analysis of 262 monofloral honeys from 25 different botanical origins was performed. Novel algorithms were designed to systematically data mine thousands of features to find a variety of marker types to authenticate blueberry honey. This pipeline led to the discovery of niacin as a blueberry honey authenticity marker. Moreover, a rapid algorithm was developed to evaluate every unique ratio of two features to determine if such ratio-features could be used to authenticate blueberry honey. The resulting method performed as well as a brute-force search, but reduced machine learning classifier training time from days down to only minutes. This innovative approach holds significant potential for honey authenticity testing and marker discovery, with findings suggesting that the rich chemical fingerprint of honey obtained by LC-QTOF-MS contains chemical markers which can be used as a powerful tool for combatting honey-related authentication challenges in the food industry.

5. High Throughput Multi-parameter Assessment of Pea-derived Products Using Hyperspectral Imaging & Machine Learning

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Conseil national de recherches Canada (CNRC)

This study aims to develop rapid and non-invasive methods based on hyperspectral imaging for predicting moisture, protein, ash, total starch, and insoluble fiber from the same spectral data. Hyperspectral imaging was used to acquire images from pea processing streams, namely pea flour (PF), pea protein concentrate (PPC), and pea protein isolate (PPI). Partial least squares (PLS), support vector machines (SVM), and convolution neural networks (CNN) were used to develop prediction models from the spectral and reference data. Prediction results in terms of root mean square errors showed the optimum moisture content was provided by SVM (0.29%), protein by PLS (2.07%), and insoluble fiber by SVM (2.14%). Ash and total starch content showed 0.34% and 1.47% errors, respectively, by CNN. The accurate prediction achieved by hyperspectral imaging highlights its suitability for rapid multi-parameter quality control of pea-derived products. This is particularly important given their increasing market demand.

6. Rapid Assessment of Pea Product Functionalities Using FTIR Spectroscopy

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This study aimed to assess the feasibility of Fourier-transform infrared (FTIR) spectroscopy as a rapid and non-destructive method for predicting the quality attributes of pea products. A total of 62 pea samples were provided by Aquatic and Crop Resource Development Center of National Research Council (NRC) Canada in Saskatoon, along with the wet chemistry data, particle size, and functionality results. An ATR-FTIR spectrometer was used to obtain the FTIR spectral data of all pea samples, including 12 pea flour samples, 20 pea protein concentrate samples and 30 pea protein isolate samples. Different spectral pre-processing techniques such as SNV, MSC, 1^{st} derivative and 2^{nd} derivative were used to calibrate FTIR data. Prediction models were developed based on the calibrated data using PLS regression for different quality attributes. Results showed high prediction accuracies were obtained for a range of quality parameters including moisture content (rc=0.81; rp=0.70), protein content (rc=0.99; rp=0.97), starch content (rc=1.00; rp=0.92), bulk density (rc=0.91; rp=0.85), particle size (rc=0.97; rp=0.86), water holding capacity (rc=0.98; rp=0.88), oil holding capacity (rc=0.96; rp=0.84), least gelation concentration (rc=0.97; rp=0.91), and solubility (rc=0.96; rp=0.95). This suggests a significant potential for the application of FTIR spectroscopy as a promising tool for the rapid and non-destructive assessment and quality control of pea-based food products.