New approaches to convert carbohydrate-rich by-products (whey and milk permeate) into high added value products and contribute to the sustainability of the dairy industry

Duration: 2019-2022

Highlights

- World production of whey is estimated around 200 million tons per year with an increase rate of about 2%/per year. Implementing chemical and enzymatic transformations as a platform of whey conversion into added value by-products is expected to conciliate the needs of product diversification with the sustainable development.
- This research activity focuses on the development of the scientific and technological bases of the new approaches to value the lactose rich by-products (whey permeate and milk permeate) in products with high value, including the hydroxymethylfurfural (HMF), 2,5-furandicarboxylic acid (FDCA) lactosucrose and lactobionic acid.
- The US Department of Energy has listed 2,5-furandicarboxylic acid (FDCA) amongst the top-12 molecules with the potential to replace petrochemical monomers. The main challenges in the economical and sustainable production of FDCA are the selection of suitable substrates, and the development of an efficient catalytic-solvent system for its conversion via the 5-hydroxymethylfurfural (HMF) route.
- To address these issues, this research project intends to replace high value sugars such as fructose and glucose with whey, a dairy industry byproduct. In the first step, we analyzed different concentrations of whey permeate for HMF production.
- Lactosucrose demand has been on the rise due to its prebiotic and technofunctional properties. The most effective biocatalysts for targeted bioconversion of lactose into lactosucrose were identified. Our biocatalytic process has led to more than 87% wt% conversion of lactose in whey permeate to lactosucrose.
- Lactobionic acid is a high value-added lactose derivative which has recently emerged as a promising substance with countless applications in the food, pharmaceutical, cosmetic, medicine, and chemical industries. Different biocatalytic systems were developed for a complete conversion of lactose in whey permeate and milk permeate into lactobionic acid.

Objectives

Development of the scientific and technological basis of new approaches to enhance carbohydrate-rich by-products (lactose, whey) into high-value products and contribute to the sustainability of the dairy industry. Two main approaches are investigated:

A) Conversion of lactose whey into value added fine chemicals (HMF, FDCA, FDCA-aliphatic acid co-polyesters) through chemical conversion pathways.

B) Biotransformation of lactose whey into added value ingredients, Lactosucrose and Lactobionic acid, using enzymatic processes.

Results and potential benefits

This research activity is part of an overall approach for the recovery of food processing residues to protect the environment and preserve our resources. It is known that the worldwide whey production is estimated at 180-190 x 106 ton/year, out of which only 50% is further processed. The dairy industry is currently dealing with the whey permeate surplus by selling it as dry permeate powder, through incorporation into animal feed, or simply disposing it as waste. However, the disposal of surplus whey requires extensive pretreatments due to its high biological oxygen demand (30 to 50 g/L), which incur additional operating costs to the dairy industries. The dairy industry by-products represent tremendous potential as they can be converted into furanic compounds or high value-added ingredients.

Results and potential benefits, suite

Synthesis of biobased 2,5-furandicarboxylic acid (FDCA) monomers and their corresponding copolyesters for food packaging

- Lactose was studied as the model carbohydrate, which afforded 59 mol% HMF yield at the optimum conditions (130 °C, 100 min, and 0.21 mol/L $AlCl_3 \cdot 6H_2O$). With whey permeate powder, 74 mol% HMF yield was obtained in a shorter reaction time (40 min) with the sample weight. The increase in HMF yield for whey permeate powder was attributed to the free amino groups of the proteins present, which concomitantly affected the reaction mechanism for HMF synthesis.
- The next challenge is the development of a base free catalytic system to oxidize HMF to FDCA. Therefore, we have developed a Mn-Fe_3O_4 magnetically recyclable catalysts for the oxidation of HMF to FDCA. To date, we have achieved 40 wt% FDCA yield and 100 wt% HMF conversion. The effect of different base, oxidizing agent, reaction temperature and time will be analyzed to further improve the yield.

Development of economically viable biotransformation technologies that would produce high value-added natural health sweeteners and functional ingredients

The results contribute to the development of the fundamental and technological bases of the targeted processes. Indeed, the most effective biocatalysts or biocatalytic systems for targeted bioconversions were determined. In addition, the important reaction parameters to be controlled and modulated, for a viable yield, were identified. Assessing the limits of these technologies according to their industrial potential will be part of our efforts.

The structural characterization of the biogenerated functional ingredient properties will make it possible to determine their potentials while highlighting their distinctive benefits on the basis of their structures.

Innovative aspects

- The study finds the efficient catalytic system which can transform whey permeate to HMF and FDCA.
- We have developed three different magnetic catalysts for HMF to FDCA oxidation.
- We are also building a one pot reactor where azeotropic mixtures will be used for Whey to HMF conversion.
- We have found out that amino acids play a catalytic role in HMF yield enhancement.
- The most efficient biotransformations for the conversion of whey permeate and milk permeate into lactosucrose and lactobionic acid were determined.

Professionals trained

- **Surabhi Pandey** (Ph.D. Candidate)
  - Surabhi wants to become a university professor. Her interests are between food and chemical engineering, where she is interested in developing practical applications (packaging) for food residues.
  - She is currently learning about green chemistry, catalysis, and polymerization.
- **Elham Chidar** (MSc)
  - Elham completed her experiments (lactobionic production) and she is currently writing her MSc thesis
- **Rami Bahlawan** (MSc)
  - Rami is working on the last part of his MSC that aims at the immobilization of biocatalysts on solid supports to increase their efficiency and reusability.
- **Dr Eugenio Spadoni** (postdoc)

For further information

In the first year, we wrote a review paper titled "Untapped potential of 2,5-furandicarboxylic acid and its copolyesters for food and beverage packaging". This manuscript needs some minor changes and will be submitted soon. The first objective has been completed and has been submitted in Chemical Engineering Journal titled as "Catalytic conversion of whey permeate into 5-hydroxymethylfurfural in a green solvent system". Conferences and talks will be given at different meetings as the Novalait Forum Techno.

Financial contributions

RITA Recherche Innovation Transformation Alimentaire: a consortium mandated by MAPAQ at McGill University in collaboration with CTAQ and MEI. Below is the total budget for the 13 activities of the RITA network.

Total budget: $2,765,828

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