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Conception of a fresh bacterial biomass based dessert for space traveling cooked in an ohmic oven

Dohogne Dorian[a], De Rijdt Mathieu[a], Coene Céline[b], Demey Dries[b], Bradfer Roxane[a], Codutti Nathan[a], Haubruge Eric[a], Goffin Dorothée[a]

[a] Laboratory of Gastronomic Sciences – Gembloux Agro-Bio Tech, University of Liège, Passage des déportés 2, 5030 Gembloux – Belgium

[b] Redwire – Hogenakkerhoekstraat 9, 9150 Kruibeke – Belgium

Introduction & context

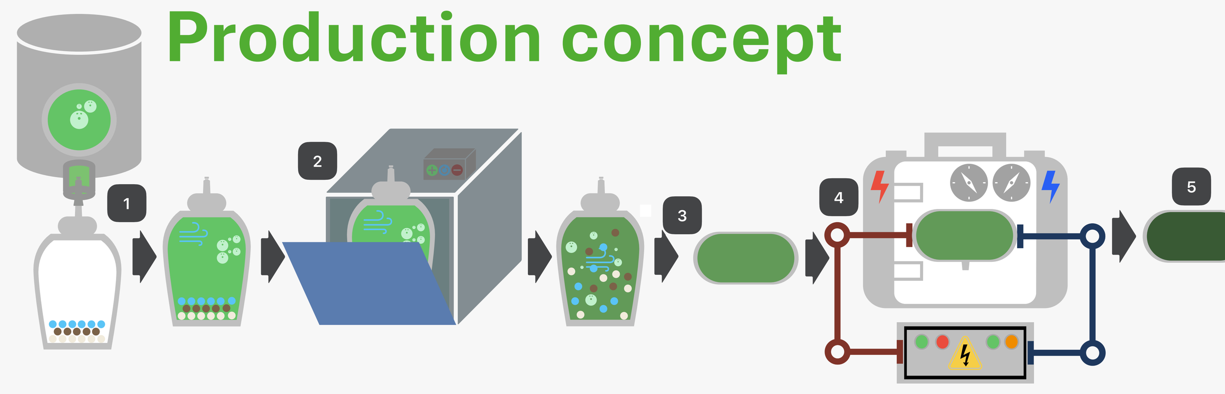
Space exploration poses major challenges for food supply, preservation, and preparation. On the International Space Station (ISS), long-duration missions without resupply require most foods to undergo processing for extended shelf life, while additional constraints such as particle dispersion, minimizing losses (particularly water and energy) and liquid handling is essential. Despite these limitations, meals resembling those on Earth remain essential, as food supports both nutritional needs and psychosocial well-being.

Future missions of greater duration amplify concerns regarding nutrient degradation caused by thermal treatments and the necessity of maintaining astronauts' health and morale. In this context, fresh, nutritious, and enjoyable foods may play a critical role.

To address this challenge, we designed a dessert enriched with freshly cultivated microbial biomass produced in situ within an ISS module. The dessert format was deliberately chosen for its strong social and convivial connotations.

Ohmic heating, a volumetric process based on the Joule effect (Bender et al., 2019), was evaluated against conventional cooking methods. This technique optimizes energy use and is expected to remain effective in microgravity. The integration of microbial biomass and ohmic heating highlights potential pathways for sustainable, high-nutrient food systems in future long-duration space missions.

Production concept



1. Spirulina is added into a vacuum-sealed pouch.
2. The pouch is placed in a mixer/homogenizer.
3. The pouch contents are transferred into a non-stick mold fitted with electrodes.
4. The waffle batter is cooked using ohmic heating.
5. After a short cooling period, the waffle is fully cooked and ready to eat.

Materials & Methods

Sampling Following the production concept, pouches containing the dehydrated ingredient mix were rehydrated (50% water content) either with water → **Dry** or with **Spirulina** (10% dry matter), then cooked using a waffle maker (Waffle Maker SWE/1200/A1, SilverCrest) or a prototype ohmic oven (Emmepiemme Berma, Italy) equipped with a cylindrical cell (h = 7 cm; Ø = 5.35 cm) filled with 80 g of product.

Cooking yield As minimizing water and product loss is an important criterion, three cooking methods were evaluated: waffle iron (n = 21), microwave (n = 21), and ohmic heating (n = 18). The following equation was used to calculate weight loss: $\%\,Weight\ loss = \left(1 - \frac{M_c}{M_i}\right) \times 100$

Ohmic cooking kinetics To evaluate cooking efficiency, three trials were carried out at different voltages (100/150/200 V). Conductivity increased with temperature but decreased as the product solidified, restricting particle movement. Temperature continued to rise until reaching 100 °C, at which point cooking was stopped.

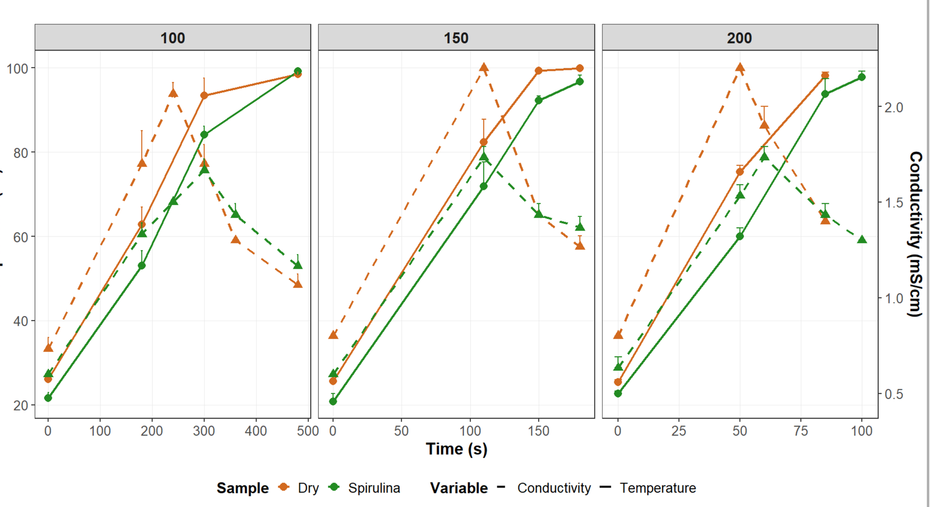
Texture To replicate the cylindrical mold of the ohmic oven, waffles were baked in a conventional oven using a mold of similar dimensions. Samples were analyzed by TPA with a texture analyzer (TA.XTPlus, Ametek TA1 Lloyd). Prior to analysis, samples were cooled to 32–35 °C. A 2.5 cm slice was compressed to 25% of its height with a 3N pre-load. The interval between the two compressions was 10".

Sensory A rapid sensory evaluation was performed during each process on these waffles and compared with a commercial waffle: an ideal score (1–5) and an importance score (1–3) were defined for each organoleptic criterion. For each trial, a rating was given in the following categories: **Appearance**: color, baking of the dough, cooking homogeneity ; **Texture**: tenderness, elasticity, density, friability ; **Taste**: sweet, salty, bitter, flavor notes. Additional scores were assigned for overall impression and product acceptability. The final score was calculated as: " |(*IdealScore–GivenScore*)|×*ImportanceScore* " where lower values indicate better performance. Scores were then summed within each category.

Results

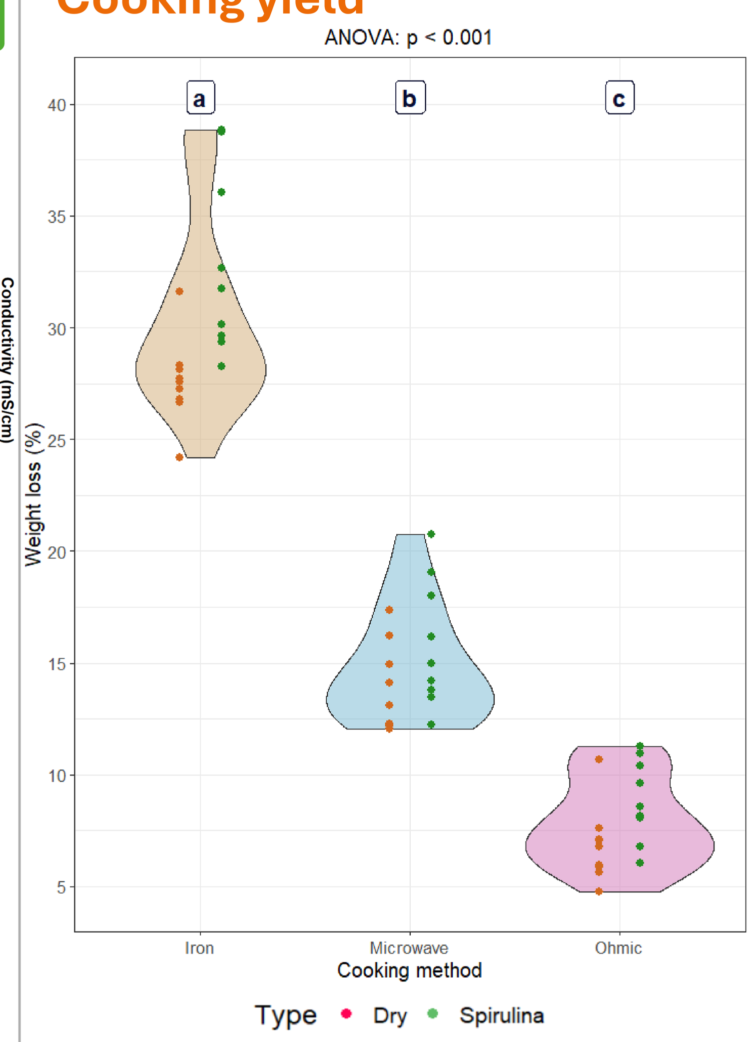
Cooking measures

Ohmic cooking kinetics



Ohmic heating significantly reduces cooking time depending on the applied voltage, with cooking times decreasing from 8 minutes at 100V to 3 minutes at 150V and only 1 minute 20 seconds at 200V. At the highest voltage of 200V, maximum temperature can be reached in less than 1'30'', making this setting the most efficient and rapid option. Kinetic data suggest that the drop in conductivity observed during heating is associated with product solidification, which limits current flow over time. Spirulina appears to enhance the conductivity of the product, allowing it to achieve maximum temperature more quickly. This property demonstrates an additional advantage for energy efficiency. Given that cooking at 200V proves to be faster and more effective than lower voltages, all subsequent ohmic heating tests were conducted at 200V to optimize the process.

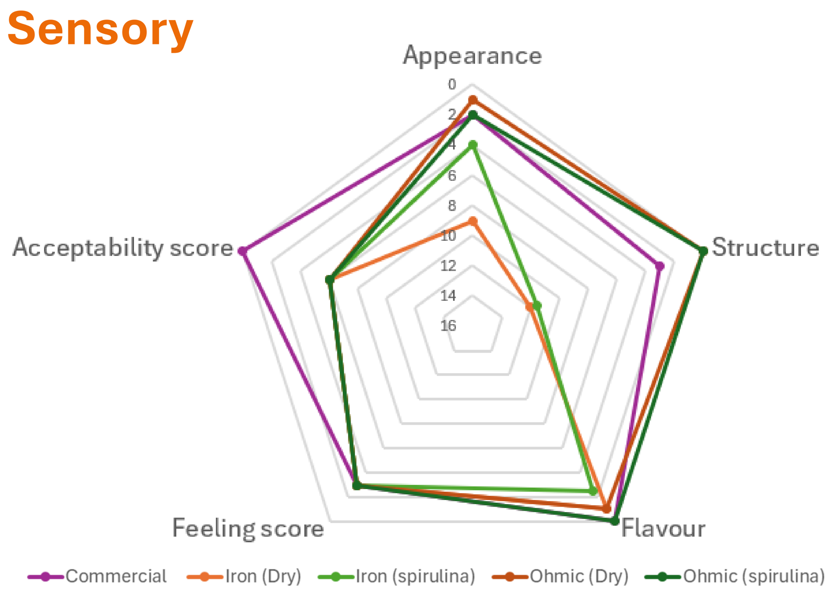
Cooking yield



The results show no difference in cooking yield between the classic samples and those with spirulina. A clear distinction was observed between heat-transfer cooking and the two volumetric methods. Among the latter, ohmic heating proved to be even more efficient, further reducing losses (particularly water) which is a major advantage in space environments. As a result, the final product was more hydrated.

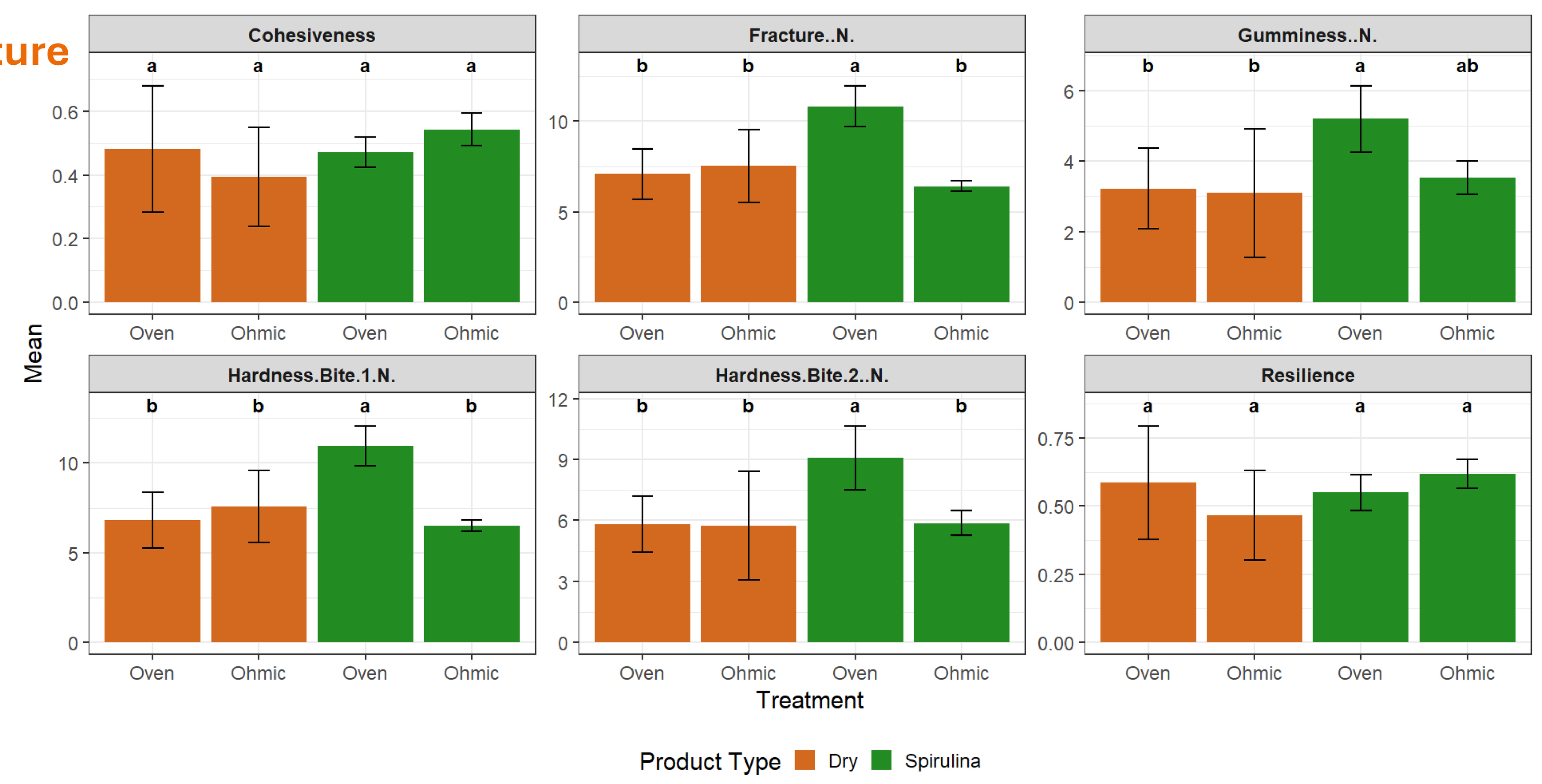
Product results

Sensory



This rapid sensory test was conducted during the formulation phases to evaluate whether each formulation was promising and to compare them over spaced intervals. The organoleptic properties of waffles with and without spirulina were relatively similar, with differences mainly observed in cooking homogeneity and structure. Waffles baked in a waffle iron produced more crumbs, resulting in higher sensory scores compared to ohmic cooking.

Texture



Spirulina slightly alters the product's texture when cooked in a traditional oven. However, this difference disappears when the sample is cooked using ohmic heating, showing identical texture parameters to products rehydrated with water, regardless of whether they are cooked with ohmic or traditional heating methods.

Conclusions & perspectives

Ohmic heating emerges as a promising technology for space applications due to its time efficiency, reduced energy requirements, and ability to limit water and product losses. It preserves a texture comparable to conventional oven baking while offering the advantage of faster cooking and improved product hydration.

The incorporation of spirulina at 10% dry matter had only a limited impact on the organoleptic qualities of the waffles. When increased to 20% dry matter, spirulina-enriched waffles could provide up to 2.5 times more protein, covering approximately 25% of the protein requirements of a meal per portion, along with a substantial iron contribution reaching up to 60% of daily needs, supporting both astronaut health and the psychological benefits of a comforting dessert (Bychkov et al., 2021 ; Smith et al., 2009).

The developed product demonstrated organoleptic properties similar to those of commercial waffles. However, larger-scale trials are required to confirm these preliminary results, as consumer acceptance could be influenced by visual aspects such as color.

Despite its potential, several challenges remain, notably regarding oven and cell design, as well as operational safety and practicality. Overall, ohmic heating shows considerable promise for space food production thanks to its energy efficiency, capacity to structure complex food matrices, and ability to deliver direct volumetric heating without intermediaries.

References

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Contact

For further information,
Please contact **Dorian Dohogne**.
Correspondence :
Dorian.dohogne@uliege.be
Tel.: +32-495308395