3D printing of *Chlorella vulgaris* healthy snacks

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Introduction

- Extrusion-based 3D Food Printing (3DFP) is a term used to describe a process where food materials are extruded through a nozzle to build up, layer-by-layer, 3D objects [1].
- 3DFP has been widely investigated given its potential for employing alternative food ingredients (e.g. algae), manufacturing personalized/customized foods, targeting specific needs of consumer groups (children, athletes, dysplasia patients, elderly), among others [2].
- Growth of global population has pushed the food and agricultural sector to find more sustainable food sources [3].
- Algae have been considered as a key alternative ingredient as they do not compete with food crops for the use of arable land or freshwater resources present a wide variety of health-promoting ingredients [4].

Figure 1. Foodini printer (Natural Machines).

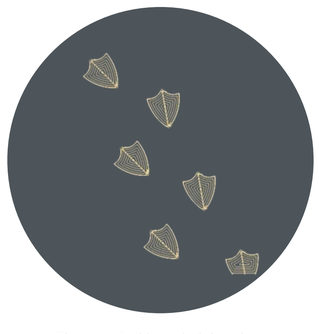

Figure 2. 3D object - duck feet shape design. Source: Natural Machines.

Objectives

Considering 3DFP technology, employment of algae into the production of food products can benefit from the visually appealing 3D structures, boosting the consumption of algae-enriched foods and overcome potential sensory constraints. In this sense, **the aim of the present work was to develop healthy snacks** (Figure 1), a high-demand trending food group, with increasing incorporations (2-12%) of *Chlorella vulgaris* (Cv), a green marine microalga that presents a notorious nutritional composition and has been previously employed in several cereal-based food products such as bread, cookies and pasta [5].

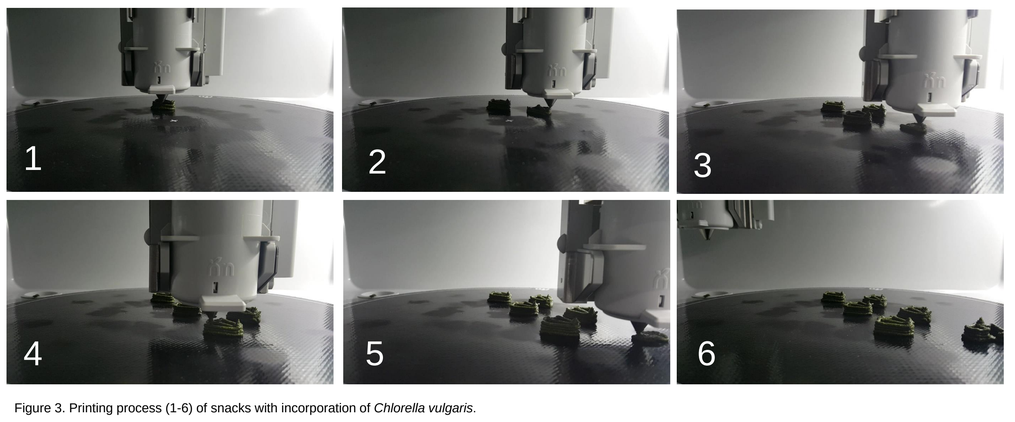

Figure 3. Printing process (1-6) of snacks with incorporation of *Chlorella vulgaris*.

Methods

- A one-bite 3D design (Figure 2) – little ducks' feet – was selected to print snacks, based on a previous 3DFP work [6].
- Dry ingredients (wholegrain oat flour, corn starch, xanthan gum, salt and Cv biomass) were manually pre-mixed, for 5 min, before adding liquid ingredients (distilled water and extra virgin olive oil). Ingredients were blended until a uniform dough was obtained.
- Rheological (viscoelasticity) and texture (firmness) properties were evaluated by performing a frequency sweep, within the linear viscoelastic region, and a Texture Profile Analysis (TPA) of raw doughs, respectively.
- Health impact of baked snacks enriched with Cv was analyzed in terms of pigments content (chlorophyl a and b and total carotenoids), antioxidant activity (FRAP, DPPH and ABTS assays) and content of Total Phenolic Compounds (TPC) (Folin–Ciocalteu assay).

Results

- Rheology (viscoelasticity) and texture (firmness) properties of raw doughs showed an increase in values with increasing incorporations of *Chlorella vulgaris*. Increasing rheology and texture properties indicate a structuring effect of doughs which may affect printability and visual aspect of snacks, thus impacting consumer's acceptance of the final product.

- Content of health promoting bioactive compounds presented a significant increase between control snack and 12% snack:
  - Total Phenolic Compounds (TPC) presented a significant increase of 85%, total chlorophyl presented and increase of 2204% and total carotenoids presented and increase of 269%.
  - Antioxidant activity was also positively impacted: Ascorbic Acid Equivalents(AAE) increased 55% for DPPH, 153% for ABTS and 71% for FRAP assay.

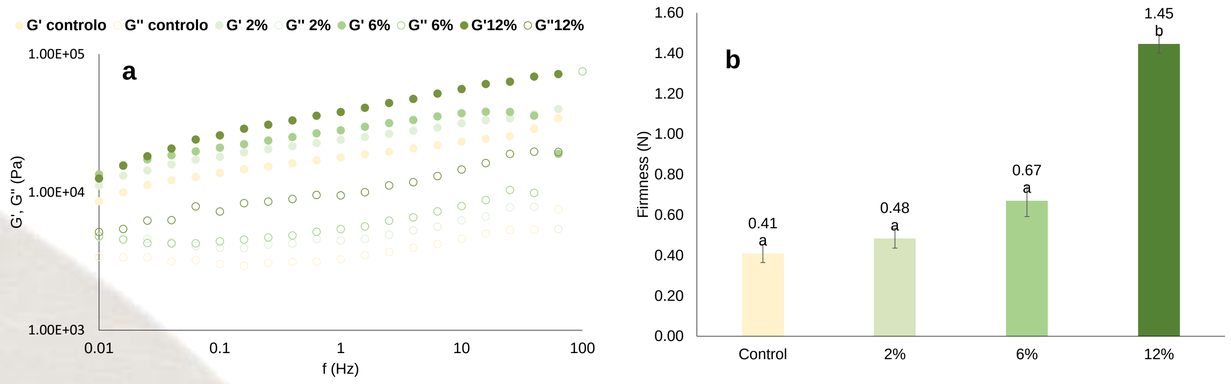

Figure 4. Mechanical spectra (a) and mechanical spectra (b) of raw doughs enriched with Chlorella vulgaris (0-12% incorporation).

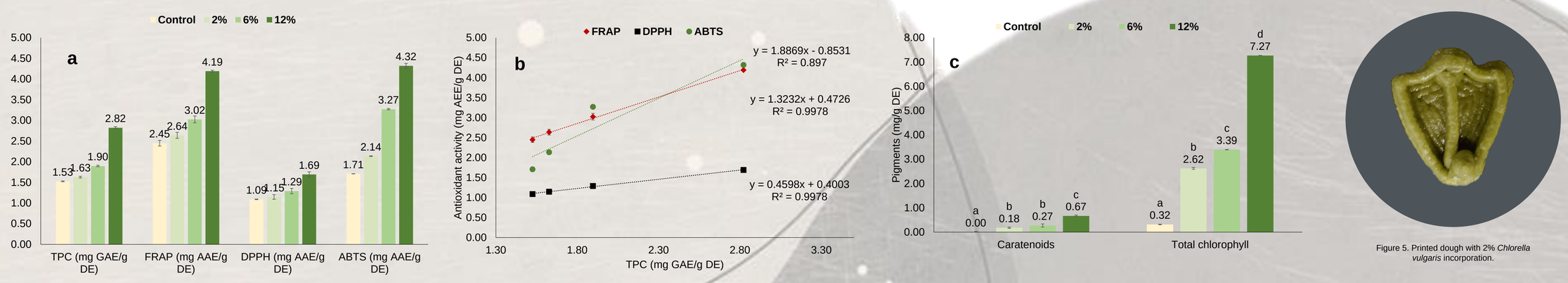

Figure 5. Antioxidant activity and total phenolic compounds (a), correlation between antioxidant assays (b) and pigment content (c) of baked snacks enriched with *Chlorella vulgaris* (0-12% incorporation).

Figure 5. Printed dough with 2% *Chlorella vulgaris* incorporation.

Figure 6. Baked snack with 2% *Chlorella vulgaris* incorporation.

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