Technological strategies for by-products valorisation   
and innovative food developments

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This PhD project aims to propose technological strategies to improve the reuse and recycle of by-products as alternative sources of nutrients. Food loss and waste (FLW) represent a good candidate for the requirements of a better sustainable food system. Their transformation and reuse for innovative food products development would contribute to reduce the current environmental impact. Some FLWs will be selected based on their nutritional and functional characteristics, also evaluating local by-products. They will be utilised as alternative ingredients for designing and developing innovative end-products with high nutritional and sensorial properties, also employing emerging technologies, such as 3D food printing.

Strategie tecnologiche per la valorizzazione di scarti alimentari e lo sviluppo di prodotti innovativi

Questo progetto di dottorato propone di incentivare, attraverso strategie tecnologiche, il recupero e il reimpiego di scarti e sottoprodotti alimentari come fonti alternative di nutrienti, rappresentando una strada percorribile per rispondere alla richiesta di una maggiore sostenibilità del sistema alimentare. La loro trasformazione e riutilizzo contribuirebbero a ridurre l’impatto ambientale dell’attuale modello produttivo. Alcuni scarti e sottoprodotti saranno selezionati per il loro contenuto nutrizionale e caratteristiche funzionali, anche considerando sottoprodotti locali, i quali saranno utilizzati come ingredienti innovativi per progettare e sviluppare prodotti finiti, ad elevato valore nutrizionale e apprezzabile qualità sensoriale, anche impiegando tecnologie emergenti come la stampa 3D.

**1. State of the art**

Global food waste has been estimated at around 1,3 billion tons a year. This matter has been reported as a social, environmental, and economic challenge by FAO (2019). Indeed, such a waste of food represents a paradox if we consider that, in the world, around 800 million are malnourished and this data is destined to increase up to 100% within 2050. The increasing food demand is compelling the agro-food industry to exert unsustainable pressure on natural resources, such as soil, air, water, and biodiversity. The global incidence of agriculture and farms is estimated to account for up to 30% of gas emissions and up to 70% for use of water. In this context, and considering the growth of the population, using resources more efficiently and reducing gas emitted will be paramount in meeting increasing demand in a sustainable way. Moreover, among the main nutritional deficiencies registered, there are proteins. In some parts of the world, it is arduous to supply protein sources, such as meat and fish, considering the production cost and not availability of farms and sea; so as for some population targets, like low-income and elderly people (FAO, 2018). For these reasons it is necessary to explore the possibility of exploiting alternative vegetable protein sources, which could represent a cheaper alternative, especially if derived from waste and by-products. In this scenario, new food production technologies need to be investigated and optimised, implementing the circular economy. Currently, the most utilised recycling technologies are based on the extraction of functional compounds, such as phenols, and proteins (Munialo et. al., 2022). These methods require the application of chemical reagents or microwaves, that imply high costs and energy expenditure and do not represent an effectively sustainable solution. Consequently, more suitable technologies need to be investigated and suggested, following an eco-friendly perspective. In view of the previously mentioned challenges, the research of new sources of nutrients, especially those with a high protein content, sustainable and healthy, is among the main priorities of European strategies (Horizon Europe, 2021-2027). For these reasons, in recent years, researchers have focused attention on by-products and food waste as nutrient sources. In Table 1 are reported some examples of vegetable wastes and derived innovative products, selected based on their functional and nutritional properties, local availability, sustainability, and amount of waste produced.

***Table 1*** *Some applications of selected by-products and waste in food products*

|  |  |  |  |
| --- | --- | --- | --- |
| Vegetables waste/ byproduct | Main nutrients and functional molecules | Developed products | References |
| Almond skins | Phenolic compounds,  fibres | Bread | Gaglio et al., 2023 |
| Artichoke (stems, leaves, external bracts) | Fibres (inulin),  minerals,  phenolic compounds | Fortified spreadable cheese | Soares Mateus et al., 2023 |
| Okara | Proteins, fibres | Biscuits | Shan Lee et al., 2020 |
| Canola (oil extraction residual) | Proteins | Meat analogues, bakery products, snacks | Chmielewska et al., 2020 |

# **2. PhD Thesis Objectives and Milestones**

Considering the aforementioned challenges, the present Phd project has the main objective to study and employ alternative sources of proteins and other nutrients, also deriving from waste of the food industry, in order to create innovative food products with high nutritional and healthy value, with sensory properties widely appreciated by consumers. It can be divided into the following specific objectives and activities according to the Gantt diagram given in Table 2:

OS1) Development of **by-product-based novel food ingredients** in different forms (e.g., powder,

viscous liquids, paste, etc.) with nutritional and technological properties tailored for the targeted end-products.

T1.1) Data analysis from different available databases to identify the most important technological properties affecting the development of targeted food products (e.g., bread, biscuits, fruit juice, etc.).

T1.2) Novel ingredients development in form of powders or viscous liquid: by testing and optimising technological methodologies - e.g., different dehydration techniques, grinding methods and conditions, homogenization, and stabilisation processes.

T1.3) Technological, nutritional, and sensorial characterization of the obtained ingredients and their mixing tailored for the target food products consumer’s demands.

OS2) **Design, development, and test of novel nutritionally enhanced food products by** using traditional and innovative techniques.

T.2.1 - Traditional techniques: study of mixing, leavening, and cooking steps with enriched bakery products.

T.2.2 - Innovative techniques: use of the 3D printing technology, optimization of digital model design and printing parameters.

T.2.3 - Nutritional and sensory analysis.

OS3) **Writing and Editing** of the PhD thesis, scientific papers, oral and poster communications.

***Table 2*** *Gantt diagram for this PhD thesis project.*

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Activities Months | | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| OS1) | **Ingredients realisation** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | T1.1) Data analysis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | T1.2) Ingredients development |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | T1.3) Qualities determination |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OS2) | **Products development** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | T2.1) Traditional techniques |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | T2.2) Innovative techniques |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | T2.3) Qualities analysis |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| OS3) | **Thesis and Papers writing** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

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