**Development of vegetarian and vegan foods from lentil by-products for a healthy and sustainable diet**

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The research project is developed within the “Partenariato Esteso” ON Foods Spoke 2 which aims to develop new foods through the use of innovative ingredients derived from agri-food by-products/wastes. This PhD program aims to characterise, design and develop high-value baked goods based on hull flour from red and green lentils with specific health and technological attributes. Physicochemical, nutritional, structural, and technological properties will be investigated to optimize the tailored foods for specific consumer populations.

Sviluppo di nuovi alimenti vegetariani e vegani da sottoprodotti della lenticchia per una dieta salutare e sostenibile

Questo progetto di ricerca, rientrante nell’ambito dello Spoke 2 Partenariato Esteso ON Foods, mira a sviluppare nuovi alimenti attraverso l'uso di ingredienti innovativi derivanti da sottoprodotti/rifiuti agroalimentari. In particolare, i principali obiettivi del progetto di dottorato sono la caratterizzazione e lo sviluppo di prodotti da forno ad alto valore aggiunto per specifiche popolazioni di consumatori. A tale scopo saranno dapprima testate le cuticole di lenticchie sia rosse che verdi poiché normalmente sono considerate uno scarto alimentare nonostante il loro interessante profilo alimentare. Lo studio della struttura e delle proprietà fisico-chimiche, termiche, funzionali e nutrizionali saranno effettuate per l’ottimizzazione dei prodotti finali.

# **1. State-of-the-Art**

In the human diet, meat still serves as a significant protein source as in 2021, world meat production was estimated at 339 Mt, rising to 5% (OECD and FAO, 2022). Nevertheless, reducing meat consumption is advised due to increasing apprehensions about the environmental consequences of livestock production and the health hazards associated with excessive meat intake. Consequently, there is a growing requirement for plant-based diets and more efficient methods of food processing to address these concerns (Monnet *et al*., 2019; Young and Pellett, 1994). Legumes are consumed worldwide and are desired for their high protein quality and quantity. In particular, lentils (*Lens culinaris Medikus*) are a pulse crop belonging to the Fabaceae family and are grown in more than 70 countries, ranking fourth in the global grain legumes production after bean (*Phaseolus vulgaris L*.), pea (*Pisum sativum L*.) and chickpea (*Cicer arietinum L*.) (Kumar and Pandey, 2020). Lentil cotyledon is lens-shaped and may have a wide range of colours (yellow, orange, red or green), even though the most traded classes are red and green (Romano *et al*., 2021). Lentils are nutritionally beneficial to all, including vegetarian and vegan diets. Lentils are usually used for consumption in the form of cooked whole seeds, split cotyledons or processed into various ingredients (e.g., flour) for use in different food applications (Romano *et al*., 2021). Due to consumer preferences, dehulling is a common procedure for most lentil market classes. Pulse seed hulls are primarily used as low-value animal feed, with limited applications in human foods such as high-fibre bread and meat products. This by-product poses a disposal problem for millers, while it could potentially be a source of novel, nutritious, and health-promoting food ingredients. (Sherasia *et al*., 2017). Indeed, hulls are rich in phenolic compounds, dietary fibre, and phytochemicals that have anti-inflammatory, antioxidant, lower blood pressure, cholesterol and blood sugar properties (Dueñas *et al*., 2006). Hence, it would be ideal to recover the hulls, as they have a technological and nutritional potential, which would otherwise be lost as they are considered a waste product of food industries. They could be studied for application in various product formulations, including bakery (bread, cake, crackers) and extruded (pasta, snacks). However, there are various anti-nutritional factors (ANFs) in lentil hulls including lectins, α-amylase inhibitors, protease inhibitors, phytic acid and tannins that limit their extensive usage in food industries. Thankfully, various post-harvest operations and processing techniques have been shown to reduce ANFs. These include heat treatments such as wet and dry heating, steaming, boiling, and extrusion (Sharma *et al*., 2022).

Among the seven thematic spokes of the PNRR ON FOODS project lies the valorisation of waste and by-products from the food industry. In particular, Spoke 2 aims to improve the sustainability of food systems through circular economy processes for the recovery of by-products to obtain high-added value products.

Hence this PhD project aspires to investigate the safety, nutritional value and properties of a new food enriched with flour obtained from red and green lentil hulls. This new ingredient will be characterized using physicochemical and innovative spectroscopic analyses (e.g., NIR, NMR). The potential use of lentil hulls as an ingredient in bakery products will be tested. To optimize the products and processes, the structure (macro and micro), physicochemical, functional and nutritional (e.g., ANFs and glycemic index) properties of trials made will be studied. Once the new foods have been characterised, the aim would be to evaluate the in vitro gastrointestinal digestion of the new products and the behaviour of certain constituents with high biological activity once inside the human body.

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

Within the overall objective mentioned above this PhD thesis project can be subdivided into the following activities according to the Gantt diagram given in Table 1:

A1) **Evaluation of microstructure and physicochemical, functional, thermal and nutritional properties of lentil hulls.**

A2) **Evaluation of the most suitable spectroscopic technique (e.g., NIR, NMR) for characterising the lentil hull ingredient**.

A3) **Evaluation of potential application in the food industry**.

A4) **Characterization of the properties of the dough.** The doughs obtained with different percentages of flour samples will be subjected to analysis for determination of physicochemical and rheological properties.

A5) **Evaluation of the impact of hull flour on baked products.** The influence of flour on the formulations of bakery products will be studied by analysing their properties and *in vitro* digestibility.

A6) **Writing and Editing of the PhD thesis, scientific papers and oral and/or poster communications.**

***Table 1***Gantt diagram for this PhD thesis project.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Activity 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** |
| A1)  | ***Evaluation of properties of lentil hulls*** |    |    |    |   |   |   |   |    |    |   |   |   |   |    |   |   |   |   |    |    |   |   |   |   |
|   | Microstructure  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|   | Physicochemical, nutritional, thermal and functional analyses  |    |   |    |   |   |   |   |    |    |   |   |   |   |    |   |   |   |   |    |    |   |   |   |   |
| A2)  | ***Evaluation of the most suitable spectroscopic technique for characterising the lentil hulls ingredient*** |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
|   | Spectroscopic analyses (NIR, NMR) |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| A3)  | ***Evaluation of potential application in the food industry*** |    |    |    |   |   |   |   |    |    |   |   |   |   |    |    |    |   |    |    |    |   |   |   |   |
|   | Literature analysis  |    |    |    |   |   |   |   |    |    |   |   |   |   |    |    |   |   |   |    |    |   |   |   |   |
| A4)  | ***Characterization of the properties of the dough*** |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| A5)  | ***Evaluation of the impact of hulls flour on baked products***  |    |   |    |    |    |    |   |    |    |    |    |    |   |    |   |   |   |   |    |    |    |    |    |   |
|   | Microstructure (SEM and CLMS) and macrostructure (Image Analysis protocol) |    |   |    |    |    |   |   |    |    |    |    |   |   |    |   |   |   |   |    |    |    |    |   |   |
|   | Physicochemical, functional, nutritional and rheological properties |   |   |   |   |   |   |   |   |   |  |  |  |  |  |  |  |  |  |  |  |  |  |  |   |
|   | *In vitro* digestibility |    |   |    |   |   |    |   |    |    |   |   |    |   |    |   |   |   |   |    |    |   |   |    |   |
| A6)  | ***Thesis and Paper Preparation*** |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |   |    |    |    |    |    |    |    |

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