PhD DISSERTATION PROJECTS

**Ingredients with high nutraceutical value obtained by food by-products and environmental friendly packaging systems to increase the shelf life and reduce the waste of bakery products**

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This PhD project involves the study of innovative ways of reusing food by-product, to obtain alternative baked goods, containing a high quantity of functional ingredients, and thus having better characteristics in terms of texture and shelf life than the original recipe. Attention will be focused on all phases of the production process, i.e. leavening, cooking and cooling and, finally, storage. In particular, through the adoption and development of innovative on-site and on-time sensors developed by INFN and CERN, the thermal profile and the migration of water will be monitored and then be used as a reliable marker of the changes that occur in the various stages of preparation and storage of baked goods. Furthermore, storage tests will be carried out using modified atmospheres and innovative packaging methods. Products will be analyzed over a long period of storage to observe the effect of the changes as a function of their formulation, and to define the best storage conditions increasing the shelf life and guaranteeing logistical benefits from an industrial point of view.

**Impiego di ingredienti ad elevato valore nutraceutico ottenuti da scarti di filiere alimentari e sistemi di confezionamento innovativi che non prevedono l'uso di additivi chimici per prolungare la conservabilità e ridurre lo scarto dei prodotti da forno**

Questo progetto di dottorato prevede lo studio di modalità innovative di riutilizzo dei sottoprodotti alimentari, per ottenere prodotti da forno alternativi, contenenti un'elevata quantità di ingredienti funzionali, e quindi con caratteristiche migliori in termini di consistenza e conservabilità rispetto alla ricetta originale. L'attenzione sarà rivolta a tutte le fasi del processo produttivo, ovvero lievitazione, cottura e raffreddamento e, infine, conservazione. In particolare, attraverso l'adozione e lo sviluppo di innovativi sensori on-site e on-time sviluppati dall'INFN e dal CERN, il profilo termico e la migrazione dell'acqua saranno monitorati per poi essere utilizzati come marcatori affidabili dei cambiamenti che avvengono nelle varie fasi di preparazione e conservazione dei prodotti da forno. Inoltre, verranno effettuati test di conservazione utilizzando atmosfere modificate e metodi di confezionamento innovativi. I prodotti saranno analizzati per un lungo periodo di conservazione per osservare l'effetto dei cambiamenti in funzione della loro formulazione e per definire le migliori condizioni di conservazione che ne aumentino la durata e garantiscano vantaggi logistici dal punto di vista industriale.

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

The shelf-life of a food is defined as the period of time under certain storage conditions, after manufacturing or packaging, during which a food product remains safe and suitable for consumption (Tebben et al., 2018). Therefore, during this period the product should retain the desired organoleptic, chemical, physical, functional or microbiological characteristics and comply with any labelling claims relating to nutritional information, if stored under the recommended conditions. Every food product has in principle, and should be recognized as having, a microbiological shelf-life, a chemical shelf-life, a functional shelf-life and an organoleptic shelf-life, because all foods deteriorate, often in different ways and at different rates. In addition, the shelf life of a food product is intended to reflect the overall effect of these different aspects, ideally in a series of specified storage conditions (Man, 2015). Baked goods are dynamic systems undergoing physical (staling, moisture redistribution), chemical (rancidity, changes in nutritional value) and microbiological (yeast, mold and bacterial spoilage) modifications which limit their shelf life (Taglieri et al., 2020). Physical staling appears mainly determined by the degree and rate of the interactions (crystallization/association) of the starch fractions, mainly amylopectin. As the aggregation amylose-amylopectin seems to be inhibited by the interaction among starch polymers, lipids and ﬂour proteins, their content, depending on raw material, can influence the staling rate (Taglieri et al., 2020). During bread storage, starch retrogradation is driven by a complex process of moisture redistribution across the loaf followed by moisture loss. Moisture migration in bakery products can indeed result in undesirable physical and chemical changes that negatively affect the quality of the food itself, thus decreasing its shelf life (Talens et al., 2010). Moisture migration occurs when there is a difference in water activity among the food components. The greater is the water activity gradient, the greater is the thermodynamic driving force for moisture migration and equilibration (Labuza et Hyman, 1998). It is widely accepted that the staling kinetics depends on a complex balance of input (dough ingredients, leavening systems and enzymes), process (mixing, proofing, baking and cooling) and storage (humidity, temperature) parameters that contribute in a synergistic manner to crumb firming as a final consequence of starch retrogradation (Taglieri et al., 2020). Beside physical staling, microbiological spoilage is the other main factor limiting the shelf life of the bakery products during post-baking storage, as at high moisture level (aw 0.94–0.99) the growth of almost all bacteria, yeasts and molds is promoted (Taglieri et al., 2020). High-moisture baked goods, whether packaged or unwrapped, are also implicated in foodborne disease outbreaks and, therefore, can pose a food safety concern (Smith et al., 2004). A stable food product can be thus developed by applying different processing techniques and keeping it in appropriate conditions. Extending shelf life and retarding the moisture migration in bakery product is a key goal for the food industry (Barret et al., 2010). Food scientists and bakery industry have been working for a long time to find solutions to maintain the freshness of baked goods and extend their shelf life. To this end, many methods are used to mainly delay microbiological deterioration. Preservatives, such as propionates or organic acids, are common additives used to minimize microbial growth. Modified atmosphere packaging as well as various forms of irradiation can extend the shelf life of products by delaying the development of mold. Controlling the storage temperature is another effective method of preventing microbial alterations over long periods of time (Sargent, 2008). In this regard, some strategies that have proved effective for extending the shelf-life of bread are (i) the addition, within the recipe, of carbohydrates (i.e. trehalose, linear dextrans, maltitol) and hydrocolloids (i.e pectins, guar gum, xhantan, pig-skin gelatin) considering their competition for water between starch; (ii) the chemical acidification of the product to induce the mold inhibition and (iii) the use of modified atmospheres inside the packaging in which the bread is packaged. Considering the prebiotic potential of pectins, together with the evidences that the addition of hydrocolloids effectively improved the technological and sensory quality of bread, reducing also the staling rate, their use in formulation of baked goods could be very interesting. The same goes for organic acids, which combine the acidifying power with interesting nutritional properties. The incorporation of potential functional ingredients in the preparation of baked goods represents thus a further experimental challenge aimed at promoting the nutritional profile and potential health properties of baked foods by using production waste from other agri-food chains (Tebben et al., 2018).

**2. PhD Thesis Objectives and Milestones**

Bakery products are essential for daily nutrition, but they are characterized by a high perishable nature, linked to the staling process and the water migration, which depends on many factors and needs widely research activities to be understood (Fadda et al., 2014¸ O'Connor et al., 2018). According to the bakery industries, a priority is the extension of baked products shelf-life, in order to reduce food waste. This project involves the study of innovative bread formulation and storage, aiming to increase the baked goods shelf life. The main objective of this project is the "Development of technological solutions for advanced manufacturing", as part of the “Intelligent Factory” technological priority. The project will bring important technological innovations to the production line of bakery products. The operator will be indeed supported in process decisions by a DSS (decision supporting system), thanks to the adoption and development of innovative on-site and on-time sensors developed by INFN and CERN. The various steps of the transformative and storage process will be automated by immediate analytical answers, relative to the monitoring of parameters such as temperature, pressure, relative and absolute humidity through the sensors.

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 2:

A1) **Study of innovative ways of reusing food by-product**, to obtain alternative baked goods, containing a high quantity of functional ingredients, and thus having better characteristics in terms of texture and shelf life than the original recipe. Attention will be focused on all phases of the production process, i.e. leavening, cooking and cooling and, finally, storage.

A2) **Adoption and development of innovative on-site and on-time sensors developed by INFN and CERN**, the thermal profile and the migration of water will be monitored and then be used as a reliable marker of the changes that occur in the various stages of preparation and storage of baked goods.

A3) **Storage tests will be carried out using modified atmospheres and innovative packaging methods**, Products will be analyzed over a long period of storage to observe the effect of the changes as a function of their formulation, and to define the best storage conditions increasing the shelf life and guaranteeing logistical benefits from an industrial point of view.

A4) **Writing and Editing** of the PhD thesis, scientific papers and oral and/or poster communications.

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

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
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|  | | **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) | ***Study of innovative ways of reusing food by-product*** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 1) Optimization of production process |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2) Storage and shelf-life |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| A2) | ***Adoption and development of innovative on-site and on-time sensor*** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 1) thermal profile |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
|  | 2) migration of water |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| A3) | ***Storage tests will be carried out using modified atmospheres and innovative packaging methods*** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| A4) | ***PhD thesis editing*** |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |

# **3. Selected References**

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