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Recent developments in functional bakery products and the impact of baking on active ingredients

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Abstract (100 words)
Active ingredients can be supplemented into a bakery product to produce functional food. However, the preservation of the functionality of these active ingredients during baking remains a challenge for food industry. A deeper understanding of the underlying interactions between functionality and baking is highly desired for developing innovative functional bakery products with significant health benefits and high product quality. In this work, recent advances in the development of functional bakery products are reviewed. The interactions between the baking process and the functionality of the supplemented active ingredients are discussed and the perspective of future research is addressed.

Keywords: *baking; active ingredients; probiotics; inactivation kinetics; functional food*

1. Introduction

A functional food can be defined as a modified food or food ingredient that may provide a health benefit to the consumer beyond its basic nutrients. Bakery products can be fortified with health-promoting active ingredients to produce non-dairy-based functional food. The viability of the active ingredients such as probiotics in the final products should be sufficient to confer beneficial influence on consumer health. However, for baking process it is a challenge to maintain the functionality of these heat-sensitive active ingredients as high temperatures are involved.

This review aims to illustrate recent advances and challenges in the development of functional bakery products. The interactions between the baking process and the funcationality of the active ingredients are discussed, as well as new technologies such as microencapsulation to preserve the active ingredients during baking. Manufacturing of functional bakery products of good quality and sufficient health-promoting properties leads to interesting research questions and the perspective of future research is addressed.

2. Recent advances in the development of fuctional bakery products

The father of modern medicine Hippocrates declared 2500 years ago that food intake may be beneficial to health: "*Let food be thy medicine and medicine be thy food.*" In modern food industry, a new food category called "functional foods" emerged as a result of the increasing awareness of the link between personal health & well-being and diet. To date, there is no unitary accepted definition for functional foods, nevertheless three main concepts are involved in most of the proposed definitions in literature, i.e., health benefits, nutritional functions and technological processes [1]. Among these concepts, 'technological processes' refer to i) the development of functional foods by optimizing traditional food processing technologies, e.g. fortification of foods with dietary fibre; ii) technologies designed to prevent the deterioration of active ingredients, e.g. microencapsulation; iii) technologies aimed to design personalized functional foods, e.g. application of nutrigenomics; 3D food printing. To simplify, functional foods can be defined as modified food or food ingredients that can provide health benefits to the consumers beyond its basic nutrients.

Functional foods introduced into the market include for example beverages, dairy products, confectionery products, bakery products and breakfast cereals [2]. The category of functional bakery products is newer and received increasing attention in scientific studies. Bakery products are not only nutritious plant-based foods containing macronutrients (e.g. starch and dietary fibre) and micronutrients (e.g. antioxidants and minerals), the transportation and storage of bakery products is also less demanding compared to liquid-form products such as yoghurt. In addition, the worldwide consumption of baked goods on a daily basis makes these products interesting to serve as potential vehicles to deliver health-promoting ingredients to the human diet.

Table 1 lists some recent studies of functional bakery products with a special focus on bread which is one of the most-consumed staple foods. The main active ingredients supplemented to bakery goods include probiotics and prebiotics (dietary fibres), antioxidants and phenolic compounds [3]. Other functional ingredients are oils and lipids, minerals and salts, and vitamins [2]. Among these ingredients, probiotics and prebiotics are important in human nutrition because of their influences on the gastrointestinal (GI) microbiota. Probiotics are defined as 'live microorganisms which confer a health benefit on the host when administered in adequate amounts' [4]. Prebiotics are short chain carbohydrates which are non-digestible by digestive enzymes in the upper GI tract of humans, but are 'consumed' selectively by some types of bacteria (typically bifidobacteria and/or lactobacilli). Prebiotics can therefore enhance the activity of those beneficial bacteria [5]. The alleged health-promoting benefits of the aforementioned functional bakery products are diverse, e.g. reducing serum cholesterol and blood pressure, reducing the risk of coronary heart diseases, lowering the glycaemic response after food consumption, treating human intestinal barrier dysfunctions [6–10].

Table 1. ***An overview of scientific studies focusing on functional bakery products.***

Ingredient	**Product**	**Incorporation strategy**	**Baking condition**	**Functionality**
Probiotics				
Lactobacillus rhamnosus R011 [11]	biscuit	mix microentrapped cells in whey protein isolate into dough	baked at 280 °C for 5 min	4.5×10^5 CFU/g (initial viability 1.3×10^7 CFU/g)
Lactobacillus acidophilus [12]	bread	apply edible coating layers onto the surface of part-baked bread	baked off at 180 °C for 16 min	~7 log CFU/70 g bread
Lactobacillus reuteri DSM 17938 [13]	chocolate Soufflé	supplement cells microcapsules into dough	70 g dough; frozen at -18 °C; 2 h; baked at 180 °C; 10 min	~3-6 log CFU/g sample from core
Bifidobacterium lactis Bb12 [14]	bread	mix cell suspension into dough	60 g dough; baked at 165, 185 or 205 °C for 12 min	~2-3 log CFU/g (initial viable counts in dough 2.1×10^6 CFU/g)
Lactobacillus rhamnosus GG [15]	bread	apply probiotic containing film solution on the surface	air dry the prebaked bread at 60 °C; 10 min or	7.6-9.0 log CFU/30-40 g bread slice

		of prebaked pan bread	180 °C; 2 min	

(Continued)

Bacillus coagulans MTCC 5856 [16]	muffin	mix spray-dried bacteria powder into batter	baked at 205 °C for 20-25 min	7.14 log CFU/g (initial viable counts in batter 6.99 log CFU/g)
Prebiotics				
carob fibre/inulin/pea fibre [17]	bread	add 3% fibre to dough	100 g dough; baked at 190 °C for 20 min	total dietary fibre in bread: carob fibre 5.06 %; inulin 5.14 %; pea fibre 5.38 %;
β-glucans & arabinoxylans [18]	flat bread	substitute wheat flour with 20 % barley fibre-rich-fractions	diameter of circular dough sheet 20 cm; baked at 540 °C for 70 s	total β-glucans 3.0 g, arabinoxylans 4.2 g per flat bread
hemicellulose B [19]	bread	add hemicellulose B to dough	baked at 200 °C, baking time N/A	3.87 % dm dietary fibre in baked bread
bacterial nanocellulose (BNC) [20]	bread	disperse BNC gel in water and mix with other ingredients	70 g dough; baked at 195 °C for 23 min	N/A
Others				
tea catechins [21]	bread	mix green tea extract into dough	baked at 215 °C for 11 min	tea catechins content: 0.53 mg/g bread
phenolic antioxidants [22]	bread	substitute wheat flour with fruit phenolic extracts	baked at 155 °C for 60 min	the phenolic recovery ranged from 9 % to 39 %; total antioxidant activity increased
anthocyanin [23]	bread	mix anthocyanin-rich black rice extract powder into dough	50 g dough; baked at 200 °C for 8 min	79 % of cyanidin-3-glucoside was retained in bread crumb after baking

3. Bread baking process

Bread is one of the most-consumed staple foods worldwide. Bread making is a complex process involving dough mixing, proofing (i.e., fermentation), baking and cooling. Among these steps, baking is of great importance because heat and mass transfer occurs simultaneously and interdependently inside the dough during baking, along with a series of physical and chemical changes, e.g. water evaporation, gas cell expansion, starch gelatinization, protein coagulation, dough-crumb transition and crust formation [24]. These changes are dominated by heat and mass transfer mechanisms inside the oven chamber as well as in the product, and interact in a complex manner, which significantly influence the product quality. A deeper understanding of the bread baking process is necessary to better control the quality of the final products.

During baking, the heat transport in the dough is dominated by the classic 'evaporation-condensation' mechanism [25]. Hence, the temperature in the crumb reaches a plateau of 100 °C while the moisture content remains similar to that of the dough (40 w/w%); the temperature in the crust keeps increasing to the oven temperature (if the baking time is long enough) and the moisture content reduces more significantly (to 20 w/w%) compared to the crumb [26]. These distinct temperature and moisture content histories in the inner part and the outer layer of the dough result in bread with unique macroscopic features, i.e., soft and porous crumb and crispy and dense crust. In addition, the brown colour of the crust and the flavour/aroma of the bread are formed during baking due to the Maillard reactions.

4. Factors influence the functionality of active ingredients

The development of functional bread is challenging for the food industry because active ingredients may fully or partly lose their bioactivity or bioavailability during manufacturing due to either the high baking temperature or their interaction with other ingredients, e.g. decreased bioavailability of water-extractable arabinoxylan in bread due to ferulic acid-protein cross-links [27]. Therefore, it is important to investigate the interactions between the bread making process and the addition of active ingredients.

On the one hand, the baking process can influence the bioactivity of heat-sensitive ingredients supplemented to bread e.g. probiotics [14]. Although certain probiotic strains (i.e., *Bacillus coagulans*) may show high heat resistance due to their ability to form spores (see Table 1) [16], several strategies have been investigated to preserve other probiotic strains (i.e., lactic acid bacteria) under stressful conditions, e.g. micro-entrapment or encapsulation, edible film, coatings, and micro-beads [28–30]. However, application of these technologies may alter quality-attributes of bread. For example, starch based coatings containing probiotics changed the crispness of the bread crust [12]. Nevertheless, data available for the wide application of microencapsulation of active compounds in thermal-processed foods are still rare [31]. Furthermore, a recent study on the inactivation kinetics of *Lactobacillus plantarum* showed that the moisture content of the bread matrix influenced the survial of the embedded bacteria [26]. The survival of this bacterium after baking appeared higher in the crust compared to the crumb for certain balking conditions, which was attributed to the lower moisture content and denser matrix structure in the crust. New strategies to enhance survival of probiotics during baking could therefore benefit by lowering moisture content of the close environment in which the cells are embedded, e.g. via encapsulation or embedded in a thin dried film at the surface of the bread.

On the other hand, incorporation of active ingredients into bread can influence the product quality in either a positive or a negative manner. For example, sourdough fermentation can produce bread with increased specific volume and softer crumb, and some of the added lactic acid bacteria (LAB) produce metabolites with antimicrobial activity, which prolong the shelf-life of bread [32–34]. However, supplementation of some other active ingredients can compromise the organoleptic properties of the products, therefore the modern food industry is seeking for techniques to resolve this problem [35]. For example, encapsulation technology is employed to reduce off-flavours caused by the incorporation of omega-3 fatty acids [36]. Another example is that the substitution of wheat flour with fibre-rich-fractions negatively influences the aesthetic properties of the bread (e.g. dark discolouration, harder crumb with lower loaf volume) [37], which consequently lowers the acceptance of the fortified bread by consumers [38]. In this context, enzymatic pre-treatment of the fibre-rich-fractions might be done to modify their baking properties [39].

5. Conclusion and future perspectives

To develop functional bread that contains sufficient active ingredients without compromising product quality, systematic study on the interactions between the functional ingredients and the baking process is of great importance. Several questions for furture research are identified: i) develop kinetic models for the inactivation of active ingredients during baking based on experimental data, which can be coupled to heat & mass transfer models of baking. The combined model may be used to optimize the baking process to better retain the functionality of active ingredients; ii) further explore the encapsulation of the active ingredients to enhance their resistance against moist-heat during baking; iii) investigate the functionality of the active ingredients during digestion, and the health-promoting properties of those ingredients in clinical trials.

5. References

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