Chapter 9
Functional Cereal-Based Bakery Products, Breakfast Cereals, and Pasta Products

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9.1 Introduction

Consumers' interest in consuming functional foods is increasing and food industry has been developing new products that are healthier and more diversified (Nicole et al., 2021; Punia, Sandhu, & Kaur, 2020; Punia, Dhull, et al., 2020). Among the different legislations and definitions on functional foods, the common denominator is that they are those foods able to provide beneficial effects beyond the provision of nutrients. They are not medicines, and they should be an integral part of the eating habits of the population. Bakery products and pasta are a staple food in many parts of the world, representing an ideal matrix to be functionalized. This chapter will explore recent trends in the functionalization of bakery goods, breakfast cereals, and pasta through various ingredients from those traditional to more innovative ones (Fig. 9.1). Before going into the topic it follows a general overview of the products covered in the chapter and their potential to be functional foods.

Bread is one of the most ancient food products and the art of baking has been passed from generations (Nehra et al., 2021). Flour, yeast, salt and water are the main ingredients used for bread making. It is a source of carbohydrates, protein, vitamins, mainly B group, and minerals. Bread was originally produced from barley (*Hordeum vulgare* L.) and emmer wheat *(Triticum dicoccum* L.). However, nowadays several other ingredients and innovative preparation methods are used to fulfil consumers' preference or to take account of environmental and health issues (de Pinho Ferreira Guiné & dos Reis Correia, 2013; Miskelly, 2017). Bread is one of the most consumed cereal-based products worldwide, it is convenient as food carrier

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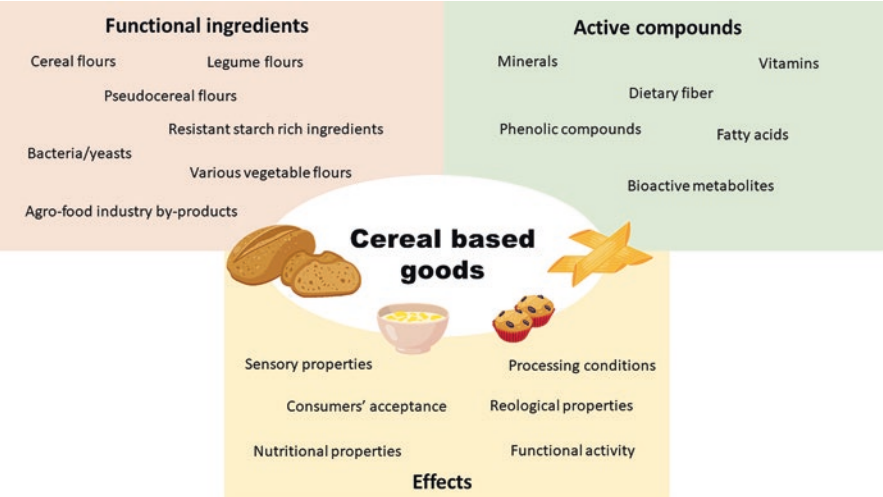

Fig. 9.1 Functional ingredients used in cereal based goods, the active compounds contained and their effects. (Images designed by pch.vector/Freepik)

since its economic, well-known and easy to implement process, due to its large daily intake and its acceptable sensory properties. For this reason, bread is well suited for the incorporation of bioactive compounds in order to improve the nutritional value of the product and to develop a functional bread (Betoret & Rosell, 2020).

Biscuits are cereal based products, baked to a moisture content lower than 5% (Manley, 2000) which allows to have a long shelf life. Biscuit main ingredients are wheat flour (*Triticum aestivum* L.), fats and sugars to which a variety of other ingredients may be added, often including eggs. Dough piece formation can be obtained through different technologies, but biscuit production process is quite simple in outline. Indeed, gluten network development is not as fundamental as in bread, biological leavened products, and pasta (Schober et al., 2003); hence, the addition of new ingredients in replacement of, or in addition to, wheat flour is possible without affecting excessively the technological properties of the dough and the texture of the biscuits. However, the fact remains that it is important to prepare a dough with the ideal characteristics for the dough piece formation technology to be used, otherwise the dough could not be workable and the final quality of the biscuits could result impaired. Biscuits are generally appreciated by most of the population, they are affordable, and have a long shelf life when properly stored. For these reasons, biscuits represent an ideal matrix to be reformulated in the view of producing new functional products.

The enrichment of baked goods other than bread and biscuits with functional ingredients may be an effective way to prompt people's health. Many attempts are being made to improve the nutritional value and functionality of snacks by modifying their nutritive composition. Such effects are very often achieved by increasing the nutrient density in basic recipes (Ainsworth et al., 2007; Sun-Waterhouse et al., 2010). These baked goods can be both sweet and savory, ranging from cakes to muffins, crackers, and breadsticks. All of them are appealing for consumers and eaten quite often even if dietary guidelines suggest to have a moderate consumption of some of them due to their richness in sugars and fats. Since they are widely consumed, they are suitable to be functionalized (Marchetti et al., 2018) also in the view of enhancing their nutritional profile.

Besides baked goods, breakfast cereals represent another vast food industry sector based on cereals. It is in constant evolution and its global market value was 55 billion dollars in 2020 (Wunsch, 2020). These products are defined as processed grains for human consumption and they are mostly made of wheat, corn, rice, barley and oats (Caldwell et al., 2004). Data collected through numerous surveys conducted by the International Breakfast Initiative found that breakfasts containing ready-to-eat cereals, oats, and/or muesli in association with milk exhibited better nutritional profiles and were classified as having higher diet quality scores (Gibney et al., 2018). This has been proven for all age categories, sex groups, and culturally different diet patterns. Regular consumption of ready-to-eat breakfast cereals was also associated with higher diet quality. In addition, it was also shown that those who chose this category of products were less likely to skip breakfast, a parameter that contributed to a better overall nutrient intake (Michels et al., 2016). The chemical composition of breakfast cereals is characterized by a wide presence of phytochemicals, such as phenolic acids, flavones, phytic acid, flavanoids, coumarins, and terpenes (Sidhu et al., 2007). On the other hand, these products have certain limitations from a nutritious point of view, especially linked to the small amount and amino acid profile of their proteins, the swelling of the starch during heating process and the limited bioavailability of their mineral component due to the presence of some anti-nutritional factors (e.g. phytic acid) (Nout, 2009). These limitations can be the starting point for an improvement in the nutritional quality of breakfast cereals and the achievement of functional foods.

Pasta has a primary role in human nutrition, and it is included at the base of the food pyramid since daily consumption is strongly recommended in the Mediterranean diet. Conventional durum wheat (*Triticum turgidum* L. var. *durum*) semolina is the most suitable cereal for high–quality pasta because of its sensorial and cooking properties (Simonato et al., 2019). Pasta made with durum semolina is considered a good source of carbohydrates (74–78% DM) but lacks in proteins (11–15% DM) and is deficient in lysine and threonine as well as most cereal products (Abdel-Aal & Hucl, 2002). Moreover, pasta has low fat and sodium levels and shows large acceptability by the population for its palatability, long shelf life, and low cost. All these characteristics give a reason to consider pasta as an appropriate carrier of different bioactive compounds, increasing nutritional and functional properties (Simonato et al., 2019). In addition, pasta production technology easily allows its functionalization.

9.2 Bread

Each bread making step causes physicochemical, sensory and nutritional changes: raw materials, mixing, fermentation, baking, and storage conditions affect final bread quality. Refining process during milling reduces nutritional value of grains. Indeed, the majority of bioactive compounds are present in the outer layers of the kernels such as arabinoxylans or β-glucans and dietary fiber. In addition, phenolic compounds are not uniformly distributed in wheat kernel but mainly located in its outer layer. During milling process, it is separated from endosperm causing a loss of these bioactive compounds. Therefore, the use of wholegrain is recommended by dietary guidelines (Angelino et al., 2017; Ciudad-Mulero et al., 2020). Also β-glucans, useful in promoting the reduction of blood cholesterol, undergo changes according to mixing and fermentation time of the dough (de Pinho Ferreira Guiné and dos Reis Correia, 2013). Thermal process during baking has a significant impact on nutritional value of bread. For example, a reduction in lysine content and consequently in the protein quality of the final product occurs due to heat destruction (Lindenmeier & Hofmann, 2004). Moreover, high temperatures negatively affect thermolabile compounds with health effect, such as polyphenols and vitamins.

Considering the growing consumers' demand for healthier foods, several studies focused on incorporation of bioactive ingredients in bread, for example legumes (Stamataki et al., 2016), prebiotics (Mollakhalili-Meybodi et al., 2021), fruit and vegetables (Betoret & Rosell, 2020) in order to develop functional bread, taking into account physicochemical and sensory properties of final product.

Dietary fiber consists in carbohydrates such as hemicellulose, inulin, resistant starch and other polysaccharides and oligosaccharides. They have technological influence on bread making, influencing rheological parameters. Their positive health benefits are well-know: dietary fiber is not digested nor absorbed promoting a better gastrointestinal motility, controlling blood cholesterol and glucose content, preventing diabetes, cancers and weight gain (Kurek & Wyrwisz, 2015). Taking into account these aspects, the supplementation of fiber in bread has been explored in the recent years. Rice bran is a good source of fiber, but also of B-vitamins, minerals and polyunsaturated fatty acids. For this reason, it was added in wheat bread to enhance its nutritional profile. As reported by Ameh et al. (2013), the supplementation of increased levels of rice bran in wheat bread resulted in a significant increase in minerals, protein and fiber content. As regards the physical properties, there was a significant reduction of bread weight and volume. Different sensory properties in terms of texture, crumb and crust color, aroma, and overall liking were highlighted. Control sample scored higher than bread supplemented with rice bran, 7.95 and 7.20, respectively. Anyway, the incorporation of rice bran resulted in a product with enhanced nutritional aspect, consequential it may be considered a potential functional bread. Hu et al. (2009) stated that the addition of defatted rice bran in bread enhance hemicellulose and insoluble fiber content. The final product had acceptable sensory properties despite a significant increase in firmness. Punia Bangar et al. (2021) and Punia, Kumar, et al. (2021, Punia, Sandhu, et al. (2021)) reported that fermented barley and rice bran may improve the bioactive profile of various food products. Nehra et al. (2021) evaluated the effect of pearl millet addition on nutritional and sensory properties of bread. It is observed that after the addition of pearl millet flour nutritional and antioxidant properties of bread improved.

Another challenge for the market is the re-use of agro-food by-products in order to reduce food waste. Most of them contains bioactive compounds, thus their incorporation in foodstuffs meets aspects related both to the circular economy and the consumers' requirements for functional foods (Martins et al., 2017). Brewers spent grains (BSG) are the main by-products from brewery industry. They contains dietary fiber, mainly β-glucans and resistant starch, but are also source of essential amino acids, minerals and polyphenols. The addition of 5% of BSG resulted in two-fold increase of the fiber content of the bread and five-fold when 20% of BSG were added in bread formulation. In this way the BSG enriched bread allowed to respect the recommended daily intake of fiber required for healthy nutrition (about 30 g per day) (Fărcaş et al., 2014). Volatile profile of bread containing BSG showed a higher content of volatile compound groups such as alcohols and aldehydes, generally associated to "malty" flavour, compared to 100% wheat bread suggesting that there was a difference in aroma profile between samples. As regards the sensory acceptability, the ideal amount of BSG in order to not adversely affect the sensory acceptability of the enriched product was 10%. Taste and texture were the main sensory attributes influencing the liking of final product: increased levels of BSG corresponded to a reduction in the texture score, the hardness of the crumb was higher, due to the crosslink between fiber and gluten proteins. In addition, incorporation of BSG resulted in a darker color of the crust and crumb of the bread (Fărcaş et al., 2014). Significant changes in rheological properties were also shown by Amoriello et al. (2020), who reported a decreased volume of bread loaves and a higher water absorption and dough strength as BSG % in the formulation increased. The second major by-product of brewery industry is the dry spent yeast, low in fat, carbohydrates and sodium but with an appreciable content in β-glucans. It was added in a homemade bread causing an increase in β-glucans content from 65 to 125 mg in 50 g of bread without affecting sensory attributes. Fruit and vegetables by-products such as banana (Eshak, 2016), cupuassu (*Theobroma grandiflorum*) (Salgado et al., 2011), orange (Stoll et al., 2015) and pineapple (Wu & Shiau, 2015) peels, apple pomace (Pyanikova et al., 2021), sweet potato leaf and stem (Liu et al., 2007), pea and broad bean pods (Belghith Fendri et al., 2016) were frequently used in supplementation of bread to uplift their nutritional value. All of these studies stated that consumption of bread enriched with 5–10% of by-products from fruit and vegetables industry allowed to increase the daily intake of dietary fiber without affecting overall acceptability (Stoll et al., 2015).

Chicory-inulin enriched bread showed altered rheological properties in terms of dough machinability due to the interactions among protein, inulin and starch. Furthermore, loaf volume and crust color were significantly influenced by inulin addition. Five percent inulin was considered the ideal concentration in order to not drastically influence the bread quality. More studies are needed to confirm whether addition level of maximum 5% inulin allows to make bread "functional" since that inulin beneficial effects are due to a daily recommended intake of at least 10–15 g (Sirbu and Arghire, 2017).

Phenolic compounds have a crucial role in preventing inflammation, oxidative stress and they have cardio protective effects (Sandhu & Punia, 2017; Punia, Sandhu, et al., 2019). There is a correlation between consumption of phenols-rich foods and reduction of chronic disease suggesting antioxidant properties (Angelino et al., 2017). As reported by Pathak et al. (2016), incorporation of ripe mango peels showed a significant increase in total phenolic content (from 220 to 756 mgGAE/100 gm) compared to control sample and also for antioxidant capacity based on DPPH and FRAP assay results. For these reasons, ripe mango peel could be considered a potential health-promoting ingredient. However, rheological properties of bread, in terms of loaf height, weight loss percentages and specific volume, were negatively correlated with the amount of ripe mango peels added. On the other hand, an increase in hardness, cohesiveness and springiness was observed in enriched bread. Five percent was considered the optimum amount of ripe mango peels to incorporate in bread, without excessively affecting rheological and sensory properties, and to improve at the same time the antioxidant capacity. The same occurred when grape (*Vitis Vinifera* L.) pomace was added in bread improving its functional properties in terms of total polyphenols content (from 35 mgGAE/100 g in control sample to 89 mgGAE/100 g in bread with 10% of grape pomace) and anti-radical activity. The incorporation significantly influenced color parameters of crust and crumb. Anyway, overall liking was not influenced by 2–5% addition of grape pomace (Hayta et al., 2014). This is in agreement with Walker et al. (2014) who reported significant increase in total phenolic content and DPPH radical scavenging activity in white bread enriched with spearmint (*Mentha spicata*) aqueous extract. The spearmint extract could be a proper functional ingredient but further studies will be useful in optimization of sensory aspects of the final product (Shori et al., 2021).

Seaweeds is related to beneficial health effects due to its composition in bioactive compounds such as polysaccharides, vitamins, phenols. Its addition in bread resulted in product with an increased phenolic compound and antioxidant activity. Color of crumb and crust was highly influenced with enhanced darkness and green coordinates (Amoriello et al., 2021).

Different *in vitro* studies examined the bio accessibility of the phenol compounds present in enriched bread. Incorporation of ground flaxseed hulls in bread increased phenolic content and, as consequence, antioxidant capacity. Flaxseed by-products are good source of lignans, functional compounds with beneficial effect on human health helping in the prevention of cancers, diabetes and cardiovascular disease. Phenols resulted bio accessible according to digestion *in vitro* (Sęczyk et al., 2017; Wirkijowska et al., 2020). Artichoke stem powder is rich in polyphenols, mainly cynaropicrin. *In vitro* simulated gastrointestinal digestion showed a high bio accessibility of polyphenols (82%) from artichoke heads used in the formulation of unconventional breads suggesting this ingredient as a promising functional compound in order to exert an intestinal protective action but also able to modulate glucose metabolism (Colantuono et al., 2018).

Vitamins and minerals in cereal-based products undergo significant changes during bread making. Milling of grains causes a depletion of vitamin B and minerals content. Even if fermentation could increase vitamin B levels, different studies aimed at overcoming the depletion of vitamins and minerals during baking (Batifoulier et al., 2005). The addition of rice bran could be one of the strategies to improve vitamins and minerals content in bread. Ameh et al. (2013) showed a significant increase in vitamin B1 and B2 content in comparison with control bread sample. Both "contribute to normal psychological function" and to "normal energy-yielding metabolism" (European Commission, 2012). Bread supplemented with rice bran contained significant higher levels of iron, potassium, calcium and magnesium than 100% wheat bread showing a successful nutritional profile.

Red bell pepper contains a high amount of carotenoids and the incorporation of its powder in bread was performed with the aim to enhance carotenoids content and make bread a functional product with high antioxidant capacity (Kaur et al., 2020). Also pumpkins by-products are rich in carotenes. Kampuse et al. (2015) showed that the addition of pumpkin pomace resulted in five-fold increase in carotenoids content against an increase of 13 times higher when pumpkin powder was used as supplementation of bread. Moreover, as regards sensory aspects, addition of 50% of pumpkin pomace scored the highest in terms of overall acceptability.

Bread enriched with 5–15% of pomegranate whole fruit bagasse proved to be "high in Cu" (Bhol et al., 2016) showing increased antioxidant properties than control bread since significant amount of copper "contributes to the protection of cells from oxidative stress" (European Commission, 2012). However, this supplementation negatively affected sensory attributes of enriched bread imparting a gritty mouthfeel.

Calcium is a vital nutrient contributing to neurotransmission and to the right formation of bones. This is the reason for the development of calcium-enriched bread. As reported by Agrahar-Murugkar and Dixit-Bajpai (2020), different ingredients were added for this purpose such as malted finger millet, sesame seeds, moringa leaves and cumin seeds. Also Weisstaub et al. (2018) developed a functional bread with resistant starch, garlic and calcium citrate showing an increased calcium bioavailability.

Polyunsaturated fatty acids (PUFA), mainly eicosapentaenoic acid (EPA C20:5) and docosahexaenoic acid (DHA C22:6) have an important role in the prevention of cardiovascular disease, "contributing to the normal function of the heart if daily consumption is above 250 mg of EPA and DHA" (European Commission, 2012). Rice bran oil is unique among edible vegetable oils because of its unique fatty acid composition, phenolic compound (γ-oryzanol, ferulic acid) and vitamin E (tocopherol and tocotrienol) (Punia, Sandhu, & Kaur, 2020; Punia, Dhull, et al., 2020). Fish oil is one of the main dietary source of PUFA and it was used to produce a functional bread (Kolanowski & Laufenberg, 2006). No significant differences emerged in sensory profile of control and enriched breads. The latter scored above six in a nine-point hedonic scale suggesting an acceptable overall liking of final product despite the increase in hardness (Sridhar et al., 2021). γ-Aminobutyric acid (GABA), a non-proteinogenic amino acid considered as bioactive compound due to its health functions such as reduction of hypertension, depression and anxiety, prevention of diabetes, cancer and chronic disease. Few studies reported its incorporation in bread. Unconventional flours, made of buckwheat, amaranth, chickpea, quinoa, were selected for bread making and fermented by *Lactobacillus plantarum* C48 (now reclassified as *Lactiplantibacillus plantarum*) in order to synthetize GABA. Sourdough fermentation allowed to enhance phenolic compounds and antioxidant activity of bread. From sensorial point of view, an enhanced perception of acidity and acid flavour was observed. Nevertheless, final product had an acceptable taste suggesting that bread enriched with GABA could be a suitable functional food (Coda et al., 2010).

Pseudocereals are also used in gluten-free bread both for their compliance with "gluten-free" statement and their nutritional composition. Gluten-free bread made from pseudocereals flour demonstrated higher protein, fat, fibers and minerals (Alvarez-Jubete et al., 2009), total polyphenols content and increased antioxidant activity (Ibrahim et al., 2015).

9.3 Biscuits

New trends involvethe production of functional biscuits, which if inserted into a healthy diet plan, could help to provide physiological benefits other than purely nutritional effects. In recent years, we witnessed to the changes that many producers made to their product portfolio by the addition of healthy biscuits. On the other hand, also the academic world is working on the development and characterization of functional biscuits realized with varied raw materials and new combinations of ingredients.

Biscuits can be "functional" thanks to the flours used, but also to the addition of other functional ingredients into the recipe both from unconventional food ingredients and from by-products of agro-food industry. One of the simplest approach to realize functional biscuits is the use of flours richer in phytochemical and fiber to totally or partially replace wheat flour. Pasqualone et al. (2015) used purple wheat line CItr 14,629 (*Triticum turgidum* ssp. *durum* (Desf.) Husnot) to make functional biscuits. The quality characteristic of biscuits resulted impaired by the use of purple wheat; nevertheless, purple biscuits had higher values of total anthocyanins, phenolic content, and antioxidant activity. For example, purple biscuits had 13.86 mg/kg Cy-3-Glu which was not detected in conventional biscuits. The sensory profile of conventional and purple biscuits was similar, except for friability and color. Nevertheless, no information was reported about the liking of the products. Inyang et al. (2018) studied biscuits made with acha (*Digitaris exilis* (Kippist) Stapf), a typical West African crop, and kidney bean (*Phaseolus vulgaris* L.). The use of the combination of these flours allowed obtaining biscuits with an increased fiber content and a higher amount of some minerals, mainly calcium and magnesium compared to control biscuit made with wheat flour. Sensory analysis showed that the use of acha and kidney beans did not lower overall acceptability of the biscuits. This result should be confirmed with further test since the panel employed to collect this data was quite small.

Always with a view to fulfil the needs of consumers looking for healthy baked goods together with the requirement of a target group of population with specific dietary needs, gluten-free biscuits with underexploited flours have been developed. Di Cairano, Condelli, Caruso, et al. (2021) formulated gluten-free biscuits with pseudocereal, legume and cereal flour other than rice and maize. The aim of the researchers was the reduction of the glycemic index of the products. Nowadays, there is a growing attention to the glycemic index of cereal-based product since a high glycemic index diet could favor the onset of some metabolic diseases, even if this topic is controversial (Livesey et al., 2019; Vega-López et al., 2018). The estimation of the glycemic index in biscuits made with combinations of buckwheat, sorghum, millet lentil and chickpea flours, showed a reduction of this parameter when experimental samples were compared to a wheat based control and two commercial gluten-free biscuits. All the biscuits had a good acceptance score, except for the formulation containing millet that gave a bitter taste to biscuits, lowering its liking score. The use of more nutrient dense flours, could potentially lead to healthier biscuits, as also observed by Pellegrini and Agostoni (2015), Thejasri et al. (2017) and Molinari et al. (2018).

The flours used in the production of functional biscuits could also be obtained by plant matrices other than grains. For example, Dyshlyuk et al. (2017) evaluated the effect of the addition of pumpkin flour to biscuits on hypocholesterolemic, antioxidant, hepatoprotective and prebiotic properties of laboratory animals. Pumpkin contains a range of compounds such as fiber, antioxidants, fatty acids and vitamins that are able to confer it a wide spectrum of biological activity (Yadav et al., 2010). Milled biscuits were added to animal feed in order to evaluate the effect of biscuits on the health parameters mentioned above. The functional properties were actually proved by the study; indeed after 6 weeks there was a decrease in hypocholesterolemic values in serum of laboratory animals and there was a reduction of pathogenic and growth of lactic- and bifidobacteria in the gastrointestinal tract of the studied groups of animals. Nevertheless, there was any insight on technological or sensory properties of the biscuits.

Banana flour thanks to its composition, richness in resistant starch and minerals (Agama-Acevedo et al., 2012) is gaining more and more attention as functional ingredients in different cereal-based products. Mabogo et al. (2021) used unripe banana flour to partially replace wheat flour in biscuits. Experimental biscuits had less crispy/crunchy texture as compared to control biscuits. In addition, the replacement lead to biscuits with a higher content of phenolic compounds and antioxidant activity. A higher amount of phenolic compounds was also recorded by Mahloko et al. (2019) who used banana flour to replace part of wheat flour in biscuits. In this case, banana flour was obtained by the peel and not from the pulp and it was used alone or in combination with prickly pear (*Opuntia ficus-indica* (L.) Mill) peel flour. They also measured crude fiber content, which increased in biscuits with banana and prickly pear peel flours, alone or in combination. Specifically, the use of banana flour, mainly the one obtained from unripe bananas, is able to enrich the content of resistant starch of the finished product. Resistant starch, is the fraction of the starch that is not digested and act as a fiber at gastrointestinal level (Lockyer & Nugent, 2017). García-Solís et al. (2018) used plantain flour, a type of banana, to reduce starch digestibility and increase fiber in gluten-free cookies. Results showed a higher fiber content and a reduced glycemic index for experimental biscuits. Unfortunately, no indication on the liking of these product based on banana flours product were reported. The use of ingredients rich in resistant starch represent a strategy to obtain biscuits with potential health benefits. In this regard, Cervini et al. (2021) used a novel resistant starch ingredient obtained from annealed white sorghum starch to make biscuits. The highest total dietary fiber and resistant starch content was measured in biscuits with the highest replacement level (45%), and consequently the starch hydrolysis index decreased at increasing replacement levels. The use of resistant starch increased hardness of the biscuits. This result is in contrast with data from Pourmohammadi et al. (2019) and Di Cairano et al. (Di Cairano, Caruso, Galgano, et al., 2021) reporting lower hardness values for biscuits with added resistant starch, but this was probably due to a different measurement method. Cervini et al. (2021) found lower acceptability scores due to the addition of resistant starch, but the values were still above the acceptability threshold. Di Cairano et al. (2022) used a commercial RS2-type of resistant starch to partially replace flour in gluten-free biscuits based on buckwheat, sorghum and lentil flours with a view to reduce their glycemic index. In addition, maltitol and inulin were used as sucrose replacers. In spite of what previously reported, the use of resistant starch did not have any effect on *in vitro* glucose release and consequently on glycemic index, as opposed to using sucrose replacers. Thanks to the very composition of the flours, these biscuits also had a higher protein and fiber content. Moreover, this work actually demonstrated the feasibility of producing potentially functional gluten-free biscuits on large scale, since biscuits were made at an industrial plant. Consumer test showed a general appreciation for the biscuits; anyway, the liking of the product was strictly related to eating habits of the consumers.

Sahin et al. (2021) to compensate quality loss due to addition of fiber rich ingredients adopted an innovative strategy to produce functional biscuits. Indeed, they used the lactic acid bacterium strain *Leuconostoc citreum* TR116 to ferment oat and wheat bran prior to their use in biscuit making. Fermentation increased biscuit spreading, influenced biscuit snap force, enhanced crunchiness and color formation, and lowered the predicted glycemic index. There results were mainly related to the acidification of bran and the higher presence of monosaccharides.

Moringa oleifera is getting high attention as food fortificant (Oyeyinka and Oyeyinka, 2018) thanks to its richness in protein, fiber and mineral. Hedhili et al. (2021) added dried moringa leaf to biscuits, obtaining a higher protein and iron content for supplemented biscuits, but the protein digestion was incomplete. The incomplete digestion of the proteins, together with a lower palatability when high substation levels were employed, suggest adding cautiously moringa to food products. Other authors (Giuberti et al., 2021), used moringa leaf powder to improve nutritional quality of gluten-free biscuits obtaining a higher dietary fiber content, even at low replacement level, and an enhanced protein, resistant starch content, and reduced hydrolysis index.

In recent years, environmental sustainability is under the spotlight, explaining why agro-food by-products are widely being studied to become new food ingredients to valorize food "waste" and minimize environmental impact. This trend involves also research about biscuits. For example, Castaldo et al. (2021) added spent coffee ground to biscuits. Spent coffee grounds are rich in melanoidins, chlorogenic acid and caffeine, which are compounds with good antioxidant activity. It was simulated a gastrointestinal digestion to evaluate the phenolic compound release, results showed that the highest bio accessibility is after the colonic stage, with potential advantages for human health. Vázquez-Sánchez et al. (2018) tried to valorize spent coffee grains by extracting antioxidant dietary fiber from spent coffee grounds and adding it to biscuits. They stated that anti diabetic compounds might be released during the digestion with beneficial effects on the regulation of sugar metabolism of diabetic people. Spent coffee grounds from instant coffee were also used to make biscuits without sucrose (Martinez-Saez et al., 2017). A good number of research report the use of coffee by-products in biscuit recipes; hence, wondering about their safety is legit. A first answer was given by Martinez-Saez et al. (2017) who evaluated the food safety of spent coffee ground through microbiological analyses and measuring the amount of acrylamide and hydroxymethylfurfural, reporting values not causing concerns. Garcia-Serna et al. (2014) did not find any trace of acrylamide in the digests of biscuits enriched with coffee silver skin, suggesting that it is not bio accessible in coffee digests. Nevertheless, they also reported that no chlorogenic acid was found in the digests casting doubts on its bioavailability. In this case, coffee silver skin was added to improve the color of sucrose free biscuits and enrich them with dietary fiber; both the goals were achieved, however no clue on the sensory acceptability of the biscuits is reported in the paper.

Fruit peels are a residual of fruit processing which can reach up to 50% of fresh product; they represent a source of valuable compounds, generally polyphenols and dietary fiber, which can be used to enrich biscuits. For example, pomegranate peel (Colantuono et al., 2016), orange peel (Obafaye & Omoba, 2018), prickly pear peel (Bouazizi et al., 2020), passion fruit peel (Weng et al., 2021), banana, carrot and apple (Rahman et al., 2020), watermelon rinds and orange pomace (Ogo et al., 2021) were all used in biscuits recipes. They were useful to enhance fiber and bioactive compounds content. However, when dealing with the employ of food by-products in baked goods, the intention of consumers to buy them should not be taken for granted. An interesting study by Grasso and Asioli (2020) illustrates consumer preferences for upcycled ingredients. Three groups of consumers were identified: traditionalist, price sensitive and environmentalist. The latter, was the group more interested carbon trust label, and had the strongest preference for biscuits made with upcycled ingredients.

9.4 Baked Snacks

Different baked foods both savory and sweet exist beside bread and biscuits. They range from cakes, to muffins, croissants, crackers, breadsticks etc. All of them are appealing for consumers and eaten quite often even if dietary guidelines suggest to have a moderate consumption of some of them due to their richness in sugars and fats. Since they are widely consumed, they are suitable to be functionalized (Marchetti et al., 2018) also in the view of enhancing their nutritional profile. Many attempts are being made to improve the nutritional value and functionality of snacks by modifying their nutritive composition. Such effects are often achieved by increasing the nutrient density in basic recipes (Ainsworth et al., 2007; Sun-Waterhouse et al., 2010). Additionally, a very important aspect of food functionality is its antioxidant capacity since there is much scientific evidence indicating the important role of food antioxidants in the prevention of different types of cancer and coronary heart diseases (Marlett et al., 2001).

Among snack foods, crackers are a versatile food consumed on a frequent basis due to the appealing taste, long shelf life and relatively low cost. Functional crackers are now gaining more and more popularity (Ahmed & Abozed, 2015).

Polat et al. (2020) produced functional crackers with the enrichment of germinated lentil extract (GLE). Legumes are suitable for producing functional foods due to their rich phenolic content, antioxidant activity and fiber, moreover when germination the nutritional value of legumes results enriched (Polat et al., 2020). In particular, lentils (*Lens culinaris* L.) have the highest phenolic content and antioxidant activity compared to other legume species (Singh et al., 2017). They are rich in proteins, carbohydrates, fibers, minerals, and vitamins (Ajila et al., 2008; Amarowicz et al., 2010). Germination is an economical and effective method to improve the quality of legumes. It has been suggested as an effective way to increase total antioxidant activity. However, the antioxidant properties, which are often related to phenolic content, depend on the type of legume and germination conditions (Dueñas et al., 2015). Polat et al. (2020) showed that crackers could be enriched with GLE for increasing the nutritional value of the product. The GLE addition increased the total protein content (from 1.68% to 2.43%), total phenolic content (from 0.78 to 3.33 mg GAE/g) and antioxidant activity (from 0.34 to 0.84 μmol trolox/mg) of the crackers. Sensory analysis proved that 5%-enriched crackers could be accepted by consumers. Crackers enriched with GLE can be considered as a food with better beneficial and functional properties as compared to conventional crackers, which are poor in phenolic compounds. Hence, they would be appealing functional food thanks to the retention of sensory properties.

Functional crackers were also produced and characterized by Nicole et al. (2021). Crackers were based on fermented soybean (tempeh) paste to which wheat flour and soy protein isolate (SPI) were incorporated to enhance the global quality of the crackers.

Fermented soybean is often regarded as an alternative to meat as it is a complete source of protein and contains vitamin B12 (Erkan et al., 2020). Tempeh have many properties such as antioxidant, antimicrobial, anticancer, antihypertensive, anti-thrombotic and hypocholesterolaemic effects, which are known to be beneficial to human health (Sanjukta & Rai, 2016). SPI is a food additive derived from separating and extracting dehulled and defatted soybean meal. SPI normally contains around 90% protein and it is regarded as a high-quality protein that is nutritionally balanced and is relatively low in cost. In its application, it can be used alone or in a combination with other protein sources such as wheat proteins. Soy proteins are widely used in the industries due to its hydrating capacity, solubility, colloidal stability, gelation, emulsification, foaming and adhesion properties (Martins & Netto, 2006). However, these properties are strongly influenced by processing methods, treatment parameters and the interactions of soy protein with other food components (Zhao et al., 2020). Nicole et al. (2021) incorporated various proportions of wheat flour and SPI into tempeh paste crackers, the results showed that the addition of wheat and SPI affected the physicochemical properties of crackers. The incorporation of SPI was successful in boosting the protein content of crackers and did not affect the color and the moisture content, together with other textural and physicochemical properties. The findings supported the potential of crackers with tempeh paste to be considered as a good high protein plant-based product.

Ahmed and Abozed (2015) investigated the possibility of improving the quality of wheat flour based cracker by supplementing the basic recipe with different amount of *Hibiscus sabdariffa* calyxes residue (HRS) to enhance their dietary fiber and antioxidant content.

Hibiscus sabdariffa L. is one of the most common flower plants grown worldwide and is used to make jellies, jams and beverages. Recently, it has gained importance as a soft drink material in many parts of the world. It is a good source of phytochemicals and has antioxidant compounds activity (Mahadevan & Kamboj, 2009; Chen et al., 2003). Ahmed and Abozed (2015) showed that *Hibiscus sabdariffa* calyxes remaining after drink preparation are characterized by high dietary fiber content, low fat content and considerable proportion of other biologically active compounds, mainly polyphenols. Crackers prepared with HSR exhibited lower protein, fat content and higher content of dietary fiber compared to commercial crackers. At increasing amounts of HSR weight, height, specific volume, moisture, and pH of crackers decreased. Lower moisture as well as pH favors improved shelf life of the crackers. Phenolic content had also a positive contribution on nutritional excellence of the developed cracker. Sensory ratings for crackers containing 1.25% and 2.50% HSR replacement of wheat flour were positive. Specifically, taste, crispness odor and overall acceptability ratings for these crackers were superior compared to commercial cracker. HSR is a potential functional food ingredient high in fiber content and antioxidants activity that may be processed into flour and used in food applications, such as baked goods. Still in the field of savory bakery goods, recently, Rainero et al. (2022) formulated breadsticks with red grape pomace, a by-product obtained by wine industry, and evaluated their physico-chemical and sensory properties. The addition of grape pomace, reduced hardness and fracturability of the breadsticks, antioxidant activity and total phenolic content increased for increasing replacement level of wheat flour with grape pomace. Sensory profile slightly changed due to the addition of the pomace; however, the acceptability was above the acceptance threshold.

Sweet bakery products represent an important part of baked goods. These products are usually considered poorly healthy and they should be consumed sparingly. This is one of the reasons why enhancing their nutritional quality and conferring functional properties could be relevant. Salehi and Aghajanzadeh (2020) studied the effects of the addition of dried fruit and vegetable powder in cake formulations. These powders are good source of different vitamins, natural colorants, minerals, fibers and antioxidants. Their use affected the appearance, physicochemical, textural and sensorial properties of the cakes. The presence of fiber increased the moisture content of the cakes due to its ability to absorb water. In most cases, replacing wheat flour with fruit and vegetable powders reduced the gluten content of the batter and lead to cake with a lower volume and firmer texture. The color of the cakes resulted darker, and it was found a relationship between color and sensory acceptability.

Dyshlyuk et al. (2017) studied *in vivo*, on lab animals, the hypocholesterolemic, antioxidant, hepatoprotective and prebiotic properties of muffins with pumpkin flour. The results suggested the effectiveness of the addition on the evaluated parameters. However, no indication about sensory properties of the product were reported. Previous research showed the possibility to obtain bread with good organoleptic properties and texture when pumpkin powder was added to wheat dough (de Escalada Pla et al., 2007; Manjula & Suneetha, 2014; Ptitchkina et al., 1998). Marchetti et al. (2018) evaluated the effect of replacing wheat flour by pecan nut expeller meal in a muffin formulation. Nuts are source of unsaturated fatty acids, proteins, fiber and micronutrients; their consumption had been associated with a lower cardiovascular mortality index due to their healthier lipid profile (Marchetti et al., 2018; Yang et al., 2009). Specifically, pecan nuts are rich in fiber, they are a rich source of γ- and poor source of α- tocopherol and contains complex flavonoid substances that are recognized for their effective inhibition of lipid oxidation in foods and possibly in biological systems (Haddad et al., 2006; Kornsteiner et al., 2006; Pinheiro do Prado et al., 2009). Pecan nut expeller meal incorporated into baked products as muffins in replacement of wheat flour could improve their profile and fiber content, it would also increase mineral content and it could be a good industrial and nutritional alternative to wheat flour in bakery products (Marchetti et al., 2018) (Table 9.1).

9.5 Breakfast Cereals

The global breakfast cereal market is principally segmented by type of products. Actually, breakfast cereals falls in two main categories: hot cereals, which could require further heating or cooking before consumption and cold ready-to-eat cereals (Tribelhorn, 1991). The manufacturing of breakfast cereals involves several methods to produce a wide range of products. A general breakfast cereal process include

Table 9.1 Effects of the use of functional ingredients on nutritional and functional properties of bakery products

	Products	Functional ingredients	Main effects on nutritional and functional properties	References
Cereal, pseudocereal and legume flours	Biscuits (gluten free)	Buckwheat Sorghum Lentil Chickpea	↓ predicted glycaemic index	Di Cairano et al. 2021; Di Cairano, Condelli, Caruso, et al., 2021
	Biscuits	Acha (*Digitaris exilis* (Kippist) Stapf), a typical West African crop, and kidney bean (*Phaseolus vulgaris* L.)	↑ fiber ↑ calcium ↑ magnesium	Inyang et al. (2018)
	Biscuits	Purple wheat	↑ phenolic compounds ↑ antochyanins	Pasqualone et al. (2015)
Other vegetable flours	Bread	Malted finger millet Sesame seeds Moringa leaves Cumin seeds	↑ calcium content	Agrahar-Murugkar and Dixit-Bajpai (2020)
	Bread	Red bell pepper	↑ antioxidant activity ↑ mineral ↑ fiber	Kaur et al. (2020)
	Biscuits (gluten free)	Platain flour	↑ resistant starch ↓ starch digestibility	García-Solís et al. (2018)
	Biscuits (gluten free)	Moringa leaf powder	↑ dietary fiber ↑ protein ↓ starch digestibility	Giuberti et al. (2021)
	Biscuits	Dried moringa leaf	↑ protein content ↑ iron content	Hedhili et al. (2021)
	Biscuits	Unripe banana flour	↑ resistant starch ↑vitamin conten	Mabogo et al. (2021)
	Biscuits	Banana flour and prickly pear (Opuntia ficus-indica (L.) Mill) peel flour	↑ resistant starch ↑ antioxidant activity ↑ total phenolic content ↑ flavonoids	Mahloko et al. (2019)
	Biscuits	Pumpkin powder	↑ fiber ↑ antioxidants ↑ fatty acids ↑ vitamins content	Yadav et al. (2010)
	Muffins	Pumpkin flour	Positive effects on the hypocholesterolemic, antioxidant, hepatoprotective and prebiotic properties of lab animals	Dyshlyuk et al. (2017)

(continued)

Table 9.1 (continued)

	Products	Functional ingredients	Main effects on nutritional and functional properties	References
Agro food by-products	Bread	Seaweeds	↑ phenolic compounds ↑ pigments ↑ antioxidant activity	Amoriello et al. (2021)
	Bread	Pomegranate whole fruit bagasse	↑ antioxidative potential, ↑ mineral content, especially copper	Bhol et al., 2016
	Bread	Artichoke stem powder	↑ in vitro bioaccessibility of polyphenols	Colantuono et al. (2018)
	Bread	Brewer spent grains	↑ dietary fiber ↑ protein content ↑ fat content ↑ minerals	Fărcaș et al. (2014)
	Bread	Pea and broad bean pods	↑ dietary fiber	Fendri et al. (2016)
	Bread	Grape pomace	↑ phenols, ↑ antioxidative activity ↑ dietary fiber	Hayta et al. (2014) Walker et al. (2014)
	Bread	Grape seed flour	↑ total phenolic content	Hoye and Ross (2011)
	Wheat bread	Pumpkin by-products	↑ carotenoids	Kampuse et al. (2015)
	Home made bread	Dry spent yeast	↑ beta-glucans	Martins et al. (2015)
	Whole wheat bread	Ripe mango peels	↑ phenols, ↑ antioxidative activity ↑ dietary fiber	Pathak et al. (2016)
	Whole bread	Cupassu peel (*Theobroma grandiflorum*)	↑ dietary fiber	Salgado et al. (2011)
	Bread	Ground flaxseed hulls	↑ total phenolic content ↑ antioxidant activity ↓ protein digestibility – no effect on in vitro starch digestibility	Sęczyk et al. (2017)
	Bread	Tomato seed meal	↑ protein quality and content	Sogi et al. (2002)
	Loaf bread (fat free)	Orange peel fiber (+ α-amylase)	Successfully obtained fat free bread with fiber	Stoll et al. (2015)
	Bread	Barley rootlets	↑ beta-glucans	Waters et al. (2013)
	Steamed bread	Pineapple peels	↑ dietary fiber	Wu and Shiau (2015)
	Biscuits	Spent coffee ground	↑ melanoidins	Castaldo et al. (2021)

(continued)

Table 9.1 (continued)

	Products	Functional ingredients	Main effects on nutritional and functional properties	References
	Biscuits	Various fruit peels (pomegranate, orange, prickly pear, passion fruit, banana, carrot, apple, watermelon rinds, orange pomace)	↑ fiber ↑ bioactive compounds	Obafaye and Omoba (2018), Bouazizi et al. (2020), Weng et al. (2021), Rahman et al. (2020), Ogo et al. (2021)
	Biscuits	Antioxidant dietary fiber from spent coffee grounds	Possible release of anti-diabetic compounds	Vázquez-Sánchez et al. (2018)
	Crackers	Hibiscus sabdariffa calyxes residue	↑ dietary fiber ↑ phenols ↑ antioxidant activity ↓ protein ↓ fats	Ahmed and Abozed (2015)
	Breadsticks	Red grape pomace	↑ phenolic content ↑ antioxidant activity	Rainero et al. (2022)
Other ingredients	Bread	Rice bran	↑ minerals, ↑ B-group vitamins, ↑ dietary fiber	Ameh et al. (2013)
	Bread	Dried olive pomace	↑ phenols	Cecchi et al. (2022)
	Bread	Spearmint aqueous extract	↑ phenols ↑ antioxidant activity	Shori et al. (2021)
	Romanian wheat flour half white bread	Commercial inulin	↑ phenols ↑ antioxidant activity	Sirbu and Arghire (2017)
	Biscuits	Annealed white sorghum starch	↑ dietary fiber ↓ starch hydrolysis	Cervini et al. (2021)
	Biscuits	*Leuconostoc citreum* TR116 to ferment oat and wheat bran prior to their use in biscuit making	↓ predicted glycemic index	Sahin et al. (2021)
	Crackers	Fermented soybean paste Soy protein isolate	↑ protein content	Nicole et al. (2021)
	Crackers	Germinated lentils extract	↑ protein content ↑ total phenolic content ↑ antioxidant activity	Polat et al. (2020)

the following operations: mixing, cooking, forming, drying, equilibration, texturizing, fortification, finish drying/toasting, packaging. Various production methods exist, but the ingredients utilized are similar and consist in grains or flours mixed with other secondary components such us water, sugar, salts, oil, additives (e.g. flavor agents) and fortificants. As noted above, the manufacture of functional food represents a great opportunity to introduce in the consumers' diet additional beneficial functions over than purely nutritional properties. This can be achieved by applying technological or biotechnological media to increase the concentration, remove, add or modify a specific compound and increase its bioavailability, provided that the actual bio functionality of the compound is demonstrated (Roberfroid, 1999). Breakfast cereals could be promising carriers of these benefits since they are used worldwide as staple foods, consumed daily and representing a considerable daily source of nutrients.

In recent years, many attempts have been made to obtain functional breakfasts cereals, taking into account the operating conditions of the production process. The strategies adopted for the functionalization of this category of products are essentially two: the partial substitution of traditional raw materials and the enrichment with bioactive and functional substances. As regard the first strategy, many efforts from the scientific community were made to improve the nutritional quality of breakfast cereals by replacing basic raw materials with others that can provide nutrients which are known to be deficient in traditional ingredients. For example, Ukeyima et al. (2021) replaced traditional flours with maize grits, partially defatted peanut flour and beetroot flour to produce functional flakes. The results showed an increase in vitamin content and *in vitro*protein digestibility of the functional flakes over control ones, as well as a favorable sensory evaluation. In a similar study, Okafor and Usman (2014) evaluated the physical and functional properties of breakfast cereals made with maize, African yam bean (*Sphenostylis stenocarpa*), defatted coconut cake and sorghum malt extract. It was obtained an increase of *in vitro* protein digestibility given specifically by the addition of defatted coconut fiber in the formulations. Lemmens et al. (2021) characterized breakfast flakes made with sprouted wheat. Sprouted wheat was used with the aim of increasing the mineral bio accessibility and providing intrinsic sweetness The resulting flakes had a darker color and a higher density, but their textural properties had a good overall acceptance. Oliveira et al. (2018), tested the replacement of traditional flours in the production of extruded breakfast cereals with whole grain wheat flour and jabuticaba (*Myrciaria cauliflora*) peel, obtaining an hardness and crispness decrease for all the experimental formulations evaluated after soaking in milk, but also acceptable results in regards of their general crispness. Color parameters, density and hardness were the parameters able to discriminate experimental samples from control sample.

Lots of research was also made based on the assumption that improvements of the nutritional and technological properties of breakfast cereals could occur by adding ingredients with proven functional properties (e.g. dietary fibers, proteins, antioxidants). In this regards, Ferreira et al. (2021) reported the incorporation of inulin, a dietary fiber, in order to improve the technological and nutritional properties of breakfast cereals made with corn grits. Different operating conditions were tested (e.g. the moisture of the 'corn grits and inulin' mixture, the amount of inulin added) and the results demonstrated that the addition of inulin did not damage the physical properties of breakfast cereals, such as density, expansion ratio, instrumental force and color. In addition, inulin did not affect the overall acceptance of products, and had a positive impact on them. Extrudates with this fiber presented also a high fiber level and moderate glycemic load, in contrast to the control products that presented low fiber level and high glycemic load.

However, the enrichment of breakfast cereals represents a challenge of considerable difficulty when taking into account the operations needed for their production. Actually, the basic problem related to the addition of bioactive compounds in processed foods is the sensitivity of the compound to changes in different parameters such as pH, temperature, light exposure, oxygen and mechanical stress during processing. One of the unit operations that affects most breakfast cereals – especially ready to eat cereals – is the extrusion. The high pressure/temperature conditions of extrusion can strongly damage a large variety of bioactive compounds, such as vitamins, carotenoids, polyphenols, and prebiotics. There are several approaches explored in literature to overcome this issue. Specifically, in regards to the incorporation of carotenoids, taking into account their great solubilization in non-polar solvents, they can be included into organic solutions in order to increase their bioavailability. In addition, this type of protection system also results to have a greater stability to lipid oxidation and the degradation of carotenoids by avoiding the formation of radical species that can react with carotenoids. The dissolution in oil and the addition in the final steps of extrusion is the strategy put in place by Emin et al. (2012) to reduce the loss of β-carotene during the operation. They obtained an increase of the retention of approximately 40%. Other studies demonstrated the effectiveness of heated protein-carbohydrate system, in which carotenoids were mixed before the addition to the process, to guarantee their stability in extruded foods (Ying et al., 2015). The presence of antioxidant substances, such as polyphenols, flavonoids, tocopherols and vitamins (C and E) can also improve the stability of carotenoids during extrusion. This method was evaluated with optimal responses in the retention of carotenoids by Kolniak-Ostek et al. (2017), who formulated extruded corn products made with flour with a high phenolic content (e.g., pumpkin tissue, amaranth seeds). Good responses were also obtained by Obradović et al. (2015) who added ascorbic acid to improve the retention of carotenoids present in pumpkin powder incorporated in an extrusion corn-based formulation. Moreover, microencapsulation, a proper protection technique, has been also reported to improve carotenoid retention during the extrusion operation. The covering of the bioactive compound by layers of protective materials, generally biopolymers, represents the most valuable strategy to obtain the preservation of the molecule itself and its bio-functionality (Tachaprutinun et al., 2009). Favaro-Trindade et al. (2020), tested microencapsulation by complex coacervation as a tool to produce extruded cereals functionalized with proanthocyanidin-rich cinnamon extract, obtaining products with greater protection of the bioactive compound during processing and storage.

Some papers reported effective attempts of functionalization that combines the replacement of traditional flours and the enrichment with nutraceutical ingredients for the production of functional breakfast cereals. For example, Emelike et al. (2020) evaluated the nutritional composition, the functional and organoleptic properties of breakfast cereals processed using as raw materials acha, wheat, cashew (*Anacardium occidentale*) kernel and prawn. Acha grains and cashew kernels were processed into flour and prawn was processed into powder. Acha flour was used as substitute of wheat flour whereas a constant percentage of cashew kernel flour and prawn was used as an enrichment in formulations tasted. The produced breakfast cereals resulted to be rich in protein, fat, carbohydrates and ash contents demonstrating an appropriate combination of raw materials. In addition, the observed decrease in moisture content at increasing replacement levels of acha flour suggests another favorable characteristics of this functional product, that is an extended shelf-life, if appropriate embalming is carried out. In another study, carried out by Asmoro and co-workers (Asmoro et al., 2021), the formulation of breakfast cereals was tested using Mocaf cassava flour as a gluten-free substitute of wheat flour and moringa leaves flour as a functional ingredient to add nutritional value to the product. The resulting products showed improved nutritional profiles especially in terms of ash content, but also an increase of fat content – up to 8.2% – a factor that actually does not meet the demand for healthier products.

9.6 Pasta

Improvements of pasta nutritional quality may occur by incorporating ingredients that promote increased protein content and functional properties, such as adding ingredients rich in fiber and/or with high antioxidant activity (Kaur et al., 2021; De Pasquale et al., 2021). Unsurprisingly, numerous efforts to increase the nutritional value of pasta have already been made. Detailed research using different cereals (Montalbano et al., 2016), legumes (Petitot et al., 2010), pseudocereal flours (Lorusso et al., 2017), as well as fish, seafood, and meat products (Liu et al., 2016; Calanche et al., 2019), were published. It is also interesting the possibility to re–use typical agro–industrial by–products such as brewers' spent grain, grape pomace, celery root sugar beet, okara, olive pomace, and tomato skin, as recently reviewed by Bianchi et al. (2021), and the chance to increase the nutritional value of pasta by using edible insects (Çabuk & Yılmaz, 2020). It should also be underlined that the use of flours different from wheat is considered an attractive strategy by the food industry to meet the demand for new products coming from the health–conscious consumers who pay greater attention to the management of available resources (De Pasquale et al., 2021). Detailed, in some pasta products, the replacement of refined durum wheat with other cereals, pseudocereals, or wholegrain cereals has been evaluated. Through this expedient, ingredients rich in phytochemicals and other nutrients are added to pasta (Wang et al., 2021). Carcea et al. (2017) reported that pasta made of pseudocereal species such as emmer, oats, and buckwheat had higher protein, fiber, and polyphenols than cereal products (even whole meal cereal products). Similarly, Schoenlechner et al. (2010) reported a higher concentration of total folate in gluten–free pasta produced from pseudocereals such as amaranth, quinoa, and buckwheat. Different are the health benefits delivered using pseudocereal flour in pasta production. For example, the addition of buckwheat in pasta resulted in a more balanced amino acid content, higher phenolic compounds content, and antioxidant capacity than control pasta. However, the overall quality of cooked spaghetti, evaluated as swelling index and cooking loss, was reduced by the introduction of buckwheat due to a not well–formed gluten network resulting in the leaching out of starch granules during cooking leading to a sticky product (Biney & Beta, 2014). Interesting are the results of a clinical study conducted by Khan et al. (2015) who explored the acute effect of pasta produced with 30% red or white sorghum flour in healthy subjects. The consumption of the experimental pasta samples determined the increase in plasma polyphenols, antioxidant capacity and superoxide dismutase activity with a reduction of the protein carbonyl level was significantly lower in the subject compared to 100% semolina pasta.

Due to the higher amounts of dietary fiber and bioactive micronutrients compared to the corresponding refined cereal, wholegrain cereals are usually used in pasta production (Kristensen et al., 2010). Baiano et al. (2006) used whole durum wheat to replace refined durum flours, found a significant increase in total dietary fiber content. However, as West et al. (2013) reported, the use of wholegrain wheat for pasta production, apart from providing higher fiber, minerals, and antioxidant capacity, could determine changes in the sensory profile. Whole grain pasta tends to be darker in color, rougher, heavier in texture, and prone to developing off–flavors over time. For this purpose, researchers have used extracted soluble and insoluble dietary fiber to create functional pasta (Tudorica et al., 2002). Results show that both the type of dietary fiber influenced the quality of uncooked and cooked pasta in terms of physical, chemical, textural, and nutritional properties. However, it should be noted that the addition of soluble dietary fiber significantly reduced the *in vitro* glucose release from pasta. However, different fiber types may specifically affect the pasta structure and nutritional value. From research conducted by Bustos et al. (2011) emerged that the inclusion of inulin, a soluble fiber, in pasta should be avoided since, because of its cooking loss, it negatively influenced the technological quality of pasta during the boiling process. Instead, the addition of oat bran had a positive effect on the cooking properties of the final products up to 5.0% of substitution and, in the same way, the inclusion of resistant starch resulted in pasta with improved final quality, mild cooking losses, and increased hardness. Thus, the results suggested that using insoluble fiber, the nutritional quality of pasta could be enhanced without negatively affect its sensory properties. Interestingly, prebiotic and probiotic substances may also be introduced in pasta. In this regard, Fares et al. (2015) produced a functional pasta using a durum wheat flour rich in polyphenols, with added barley beta–glucan and *Bacillus coagulans* GBI–30, 6086. The obtained product had a glycemic index, measured in healthy volunteers, of 59.7 and sufficient probiotic strain in cooked pasta (about 9.0 log CFU/100 g). Recently, in a similar product was assessed the effect of a consumption of the synbiotic functional pasta on 41 healthy overweight or obese volunteers during a 12–week single–blind, parallel, randomized, placebo–controlled dietary intervention study. The research demonstrated how the daily consumption of symbiotic pasta could be a valuable strategy to obtain positive effects on the athero–protective function of serum HDL (Favari et al., 2020).

Different chemical compositions and technological properties characterize legumes compared to wheat. They are an excellent source of proteins, with a high amount of essential amino acids, and they contain carbohydrates and appropriate levels of vitamins and minerals (Foschia et al., 2017). Many legumes also contain dietary fiber and resistant starch, which reduces the glycemic response and provides health benefits (Punia, Dhull et al., 2019; Punia, Siroha et al., 2019; Punia, Sandhu, & Kaur, 2020; Punia, Dhull, et al., 2020). Since legumes are a better source of essential amino acids, particularly lysine, the enrichment of cereal flour with pulses can improve the nutritional quality of the resulting product, increasing the protein content and contributing to a better balance in the protein profile (Bouchenak & Lamri-Senhadji, 2013). Food enrichment with pulses, flours, or their proteins has beneficial effects on health, well–being, and potential disease prevention. Petitot et al. (2010) prepared nutritionally enhanced semolina spaghetti enriching flour with high amounts (35%) of legume flour (split pea or fava bean) comparing them with standard semolina spaghetti. Similarly, Laleg et al. (2017) prepared functional pasta partially or completely replacing wheat flour with fava flour to increase the protein content and improve its quality. It was found that the protein content of pasta increased significantly with the increase in fava flour enrichment and, at the same time, a linear increase in the cooking loss was reported. Moreover, enriched pasta is generally high in polyphenol content and antioxidant capacity. Sęczyk et al. (2016) reported that carob flour at 5% significantly increased total phenolic compound and antioxidant activity of the pasta. Unfortunately, the researchers did not report the pasta glycemic index reduction generally observed due to legume flour inclusion. About that, Turco et al. (2019) correlated the low glycemic index observed in pasta produced with different inclusion levels of pea flour, red lentil flour, grass pea and chickpea flour firstly to the higher pasta's protein content and secondarily to the starch composition, fiber and polyphenols content. Goñi and Valentín-Gamazo (2003) confirmed such results also in an in vivo study. It should be underlined that the use of flours different from wheat is considered an attractive strategy by the food industry to meet the demand for new products coming from the health–conscious consumers who pay greater attention to the management of available resources (De Pasquale et al., 2021).

It must be reported that legumes also contain species–specific antinutritional factors such as phytic acid, condensed tannins, and trypsin inhibitors, which can interfere with protein or mineral absorption. Several treatments such as microwave, extrusion, steaming, boiling, and roasting have been proposed to reduce the legumes antinutritional factor. Among the others, selected lactic acid bacteria fermentation was reported to be more efficient. In a recent study, De Pasquale et al. (2021) concluded that fermentation with selected starters might be used to overcome some of the legume flour drawbacks, positively affecting protein digestibility, glycemic index, antinutritional factor degradation, and antioxidant activity. Another major source of protein is fish. Specifically, fish is an excellent source of high–value protein, essential amino acids, and unsaturated fatty acids, especially eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). In addition, fish contains micronutrients such as vitamins (A, D, B6, and B12) and many minerals (iron, zinc, iodine, selenium, potassium, and sodium). Because of this, there are different studies dedicated to increasing the nutritional value of pasta products by adding fish and seafood protein concentrate. Among the others, Desai et al. (2018a) evaluated the effect of semolina replacement with protein powder from fish (*Pseudophycis bachus*) on pasta nutraceutical, nutritional, and physicochemical characteristics. The authors reported that supplementation with 5–20% of fish powder was an effective way to increase the essential amino acid and protein content as well as the phenolic content and the antioxidant activity. In addition, a reduction of the glucose release of enriched pasta was reported. The amount of rapidly digestible starch in pasta supplemented with fish powder was lower than the control. Probably the fish powder may have created a protein network around the starch granules reducing the accessibility of α–amylase to starch and affecting, in this way, the ability of the enzyme to hydrolyze the starch into glucose. The same authors also reported a decrease in the n6:n3 ratio from 19:1 (the control pasta) to 3:1 when the 20% of salmon fish powder was incorporated in pasta (Desai et al., 2018b). Moreover, Ramya et al. (2015) evaluated the influence of freeze-dried shrimp (*Penaeus monodon*) meat at different levels (2.5%, 5%, and 10%; w/w) in pasta processing and Goes et al. (2016) produced noodles with tilapia (*Oreochromis niloticus*). Prabhasankar et al. (2009) produced a functional pasta with different levels of wakame (*Undaria pinnatifida*) seaweed. Different levels of the Japanese seaweed (0–30%; w/w) were substituted to wheat flour, and a significant improvement in the protein, fat, ash, and fiber content in fortified pasta samples were observed. From a sensorial point of view, pasta with 10% of seaweed had a higher acceptance rating by the panelists. Increasing the powder concentration up to the 20%, deep modification in the sensory profile was observed in saltiness and aroma.

Due to the high biological value of protein and the concentration of some micronutrients such as iron, selenium, vitamins A, B12, and folic acid that are needed for good health, the feasibility to use a beef emulsion at three different levels of 15, 30 and 45% (w/w) to develop a pasta with enhanced nutritional profile has been evaluated (Liu et al., 2016). Pasta with added meat had a lower glycemic index compared to the control and enhanced amino acid profile. Specifically, in functional pasta, five essential amino acids (leucine, lysine, methionine, threonine, tryptophan) increased significantly with increasing meat addition.

More and more attention is arousing the possibility of increasing the nutritional quality of pasta by using edible insect flour. In fact, because of the significant content of protein, vitamins, and minerals, the Food and Agriculture Organization of the United Nations (FAO) recommends insect flour consumption. Crickets, silkworms, mealy larvae, and ants are some examples. The incorporation of 5% cricket powder flour into pasta was recently assessed. The authors demonstrated how the introduction of insect proteins into pasta significantly influenced cooking and technological properties. Overall, pasta sensory evaluation showed that the product fortified with cricket flour satisfied consumer expectations, exhibiting no significant difference compared to control–wheat pasta (Duda et al., 2019). Instead, Biró et al. (2019) evaluated silkworm–enriched buckwheat pasta technological and sensory properties. Their results revealed that silkworm powder increased buckwheat pasta nutritional value and that the 5% and 10% enriched pasta had a higher protein content, with reduced energy value. According to technological analyses, silkworm powder reduces optimum cooking time while increasing pasta acidity over storage. The consumer sensory analysis of pasta determined that 10% enriched pasta with silkworm received the highest overall acceptance, while the lowest values were assigned to the control product. According to the reported results, it is possible to define insect powder as a suitable material for enriching pasta producing a healthy alternative (Table 9.2).

Table 9.2 Effects of the use of functional ingredients on nutritional and functional properties of pasta

	Products	Functional ingredients	Main effects on nutritional properties	References
Cereal, pseudocereal and legume flous	Pasta	Emmer Oats Buckwheat	↑ protein, ↑ fiber ↑ polyphenols	Carcea et al. (2017)
	Pasta	Wheat flour rich in polyphenols Beta-glucans *Bacillus coagulans* GBI–30, 6086	Glycemic index: 59.7, probiotic pasta	Fares et al. (2015)
	Pasta	Red and white sorghum	↑ plasma polyphenols, ↑ antioxidant capacity, ↑ superoxide dismutase activity	Khan et al. (2015)
	Pasta	Fava bean	↑ in vitro protein digestion	Laleg et al. (2017)
	Pasta	Barley	↓ starch hydrolysis ↑ antioxidant activity ↑ beta-glucans	Montalbano et al. (2016)
	Pasta	Split pea and fava bean	↑ polyphenol content, ↑ antioxidant capacity	Petitot et al. (2010)
	Pasta (gluten free)	Amaranth Quinoa Buckwheat	↑ folate content	Schoenlechner et al. (2010)
	Pasta	Pea Red lentil Grass pea Chickpea	↓ glycemic index	Turco et al. (2019)
Other vegetable flours	Pasta	Carob	↑ phenolic compounds ↑ antioxidant activity	Sęczyk et al. (2016)

(continued)

Table 9.2 (continued)

	Products	Functional ingredients	Main effects on nutritional properties	References
Other ingredients	Bukwheat pasta	Silkworm powder	↑ protein content	Biró et al. (2019)
	Pasta	Lactic acid bacteria fermentation	Overcoming of some drawbacks related to the use of legume flours	De Pasquale et al. (2021)
	Pasta	Protein powder from fish (*Pseudophycis bachus*)	↑ essential amino acids, ↑ protein content, ↓ glucose release	Desai et al. (2018a)
	Pasta	Salmon fish powder	↓ n6: n3 ratio	Desai et al. (2018b)
	Noodles	Tilapia (*Oreochromis niloticus*) protein concentrate	↑ protein ↑ ash ↑ fat ↑minerals	Goes et al. (2016)
	Pasta	Beef emulsion	↓ glycemic index ↑ amino acids profile	Liu et al. (2016)
	Pasta	Freeze dried shrimp meat	↑ protein content ↓ in vitro protein digestibility ↓ glycemic index	Ramya et al. (2015)

9.7 Conclusion

Functionalization of baked goods, breakfast cereals and pasta is a field of promising developments and challenges. The use of new ingredients alongside with the ones generally contemplated in their recipes could contribute to the obtaining of new functional products. These products functionalized with high added value ingredients could be an excellent carrier of nutrients with beneficial effects on human health thanks to their wide consumption.

Due to the variety of ingredients that can be used it is not easy to always maintain or predict the quality characteristic of the products functionalized with new ingredients. The selection of the raw materials and their amount should be done carefully; it should be always kept in mind that the sensory properties could be impaired. Generally, lower replacement level of wheat flour help to reach a good compromise between liking and functional properties. In light of this, it is crucial to understand the effect of the ingredients on texture and sensorial properties. In principle, the addition of high added value ingredients is promising but it should not be neglected that the bio functionality of the incorporated molecules should be better tested prior to stating that a product is functional. This should be a common goal of all future works dealing with formulation of novel functional foods.

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