

## CURRENT TRENDS ON FORTIFICATION AND ADDITION OF PLANT BIO-BASED INGREDIENTS IN THE BAKERY MANUFACTURING PROCESS

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### Abstract

*Bioactive food compounds represent the foundation of functional foods, playing a key role in supporting human health. This paper provides a comprehensive analysis of natural sources of bioingredients, advanced techniques for the identification of bioactive compounds, and their use in the fortification of bakery products. The study highlights current trends in the integration of plant-based ingredients—such as tubers, legumes, pseudocereals, and fruits—as well as pure compounds including vitamins, minerals, fibers, and proteins into bread and biscuits. The aim is to improve their nutritional profile and to address global nutritional deficiencies.*

*Based on a literature review covering the period 2016–2025, the effects of fortification on dough rheology, fermentation processes, final product structure, and shelf stability are evaluated. The paper emphasizes the beneficial effects of functional compounds (e.g., ascorbic acid) on gluten gas retention capacity, alongside technological challenges such as crumb structure alteration, reduced dough extensibility, and the potential impact on product shelf life. A broader overview of the complex interaction between bioingredients and baking processes is presented, stressing the need for adapted technological strategies like microencapsulation and recipe optimization.*

*The conclusions support bakery product fortification as a strategic direction in the development of functional foods, offering significant nutritional and functional benefits to public health.*

*Keywords: antioxidants, bioingredients, fortified bakery products, functional foods.*

### 1. INTRODUCTION

Bioactive compounds in foods are the foundation of all functional foods and originate from a variety of sources, including plants, fungi, and animal-based raw materials. Although further research is needed on specific food bioactive compounds, their presence represents a first step toward the legitimization of functional foods containing added bioactive ingredients.

Several steps are required in order to set criteria for defining a fortified product, which are illustrated in Figure 1.

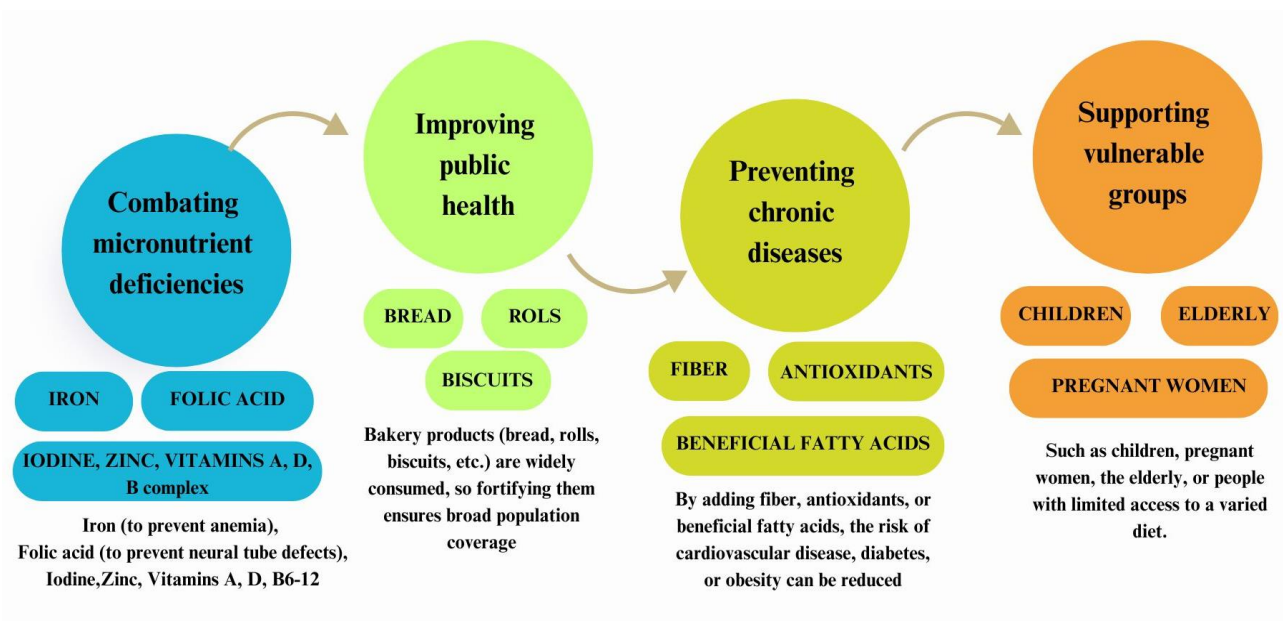
The fortification of bakery products represents an important strategy mainly to combat global nutritional deficiencies. Fortified bakery products are products that have been enriched with additional nutrients in order to prevent nutritional deficiencies in the diet. The classification of fortified bakery products can be made based on the type of nutrients added and to the purpose of fortification. The discovery of new FBCs (functional bioactive compounds) with physiological

activity is an important element in the classification of functional foods. The isolation of FBCs from plants and other sources remains challenging, as they often contain a mixture of several bioactive compounds or phytochemicals (Martirosyan et al., 2022).



**Figure 1. Steps in Establishing Criteria for Defining a Fortified Product**

*Adapted from "Food Research Lab – June 2023, Regulation (EC) No 1925/2006 of the European Parliament"*



**Figure 2. The purpose of fortifying bakery products**

Nowadays, the purpose of bakery product fortification addresses at least four fundamental directions, such as combating micronutrient deficiencies, improving population health, preventing chronic diseases, and, not least, supporting vulnerable groups - elements illustrated in Figure 2.

The objective of this paper is to describe the current state of research in the field of manufacturing bakery products through processes that involve addition of various bioactive ingredients from natural sources or individual micronutrients, and their impact on nutritional quality, and consumer acceptability.

## 1. FORTIFICATION OF BAKERY PRODUCTS

Bakery products are among the most marketed and consumed foods, serving as staple foods for diverse population groups. These are often fortified to enhance their nutritional and bioactive properties. Bread fortification with bioactive ingredients is achieved by incorporating a variety of nutritional components, such as flours from alternative cereals (including rye, rice, barley, oats, and corn), pseudocereals (such as buckwheat and millet), potatoes, seeds, fruits (fresh or powdered), mushrooms, bran, or by-products from malt production, or by addition of vitamins and minerals (Martins et al., 2017).

Legumes have gained increasing interest in baking formulations due to their high nutritional value and low environmental impact in terms of water usage and carbon emissions. Their inclusion, as well as that of their by-products, contributes to improving the amino acid profile and increasing protein intake, thus supporting a balanced diet (Boukid et al., 2019). They are a good source of slow-release carbohydrates and of proteins, typically consumed after thermal processing, which enhances nutrient bioavailability by inactivating antinutritional compounds.

Starch, the main biopolymer component in legumes, undergoes partial transformation during processing into resistant starch (RS), a functional dietary fiber that plays a significant role in the production of high-quality food products. The slow and reduced digestibility of legume starch is primarily due to its high amylose content, which is highly branched and of high molecular weight. Additionally, legumes are rich in various dietary fibers, particularly in the seed hulls, which contribute to positive therapeutic effects (Mahadevamma & Tharanathan, 2004).

Protein fortification of bread can be achieved by adding soy flour (Shao et al., 2009), soy milk flour (Nilufer-Erdil et al., 2012), defatted sunflower seed flour, legumes (Kohajdová et al., 2013), and protein derivatives from the dairy industry (Iuga et al., 2000). Legume seeds in powdered form are an excellent source of proteins, carbohydrates, dietary fiber, vitamins, minerals, and phytochemicals (phenolic acids, anthocyanins). Legume seeds undergo several primary and secondary processes such as dehulling, soaking, milling, and splitting before being used in various food products. Among different technologies, radiofrequency, microwave, irradiation, and high-pressure processing have found potential applications for storage and processing of legume seeds. Besides protein content, legumes also contribute to a significant fiber content (polysaccharides, oligosaccharides, lignin, and associated plant substances). (Siminiuc et al., 2021).

Dietary fiber is important not only because it reduces the caloric intake of foods, but also because the short-chain free fatty acids resulting from its fermentation promote intestinal gluconeogenesis, the formation of gastrointestinal hormones, and, subsequently, satiety. (Gautier et al., 2024)

Dietary fiber intake is associated with overall metabolic health (through key pathways including insulin sensitivity) and with prevention of various other pathologies such as cardiovascular disease, colon health, intestinal motility, and colorectal cancer risk. The gut microbiota functions as an

important mediator of the beneficial effects of dietary fiber, including regulation of appetite, metabolic processes, and chronic inflammatory pathways.

### 1.1. Fortification of bakery products with micronutrients

Food fortification with micronutrients cannot be viewed as a simple mechanical administration of fortificants. During fortification, preparation, and food storage, a series of physical-chemical and enzymatic processes occur, which can significantly influence the biological value of these fortified products. Thus, the development of technological processes for manufacturing fortified food products must be based on a thorough study of the evolution of these micronutrients throughout the technological pathway as well as during the consumption stage. (Vlaic et al., 2019).

In global practice, a priority direction for reducing micronutrient deficiencies, such as calcium deficiency, is the fortification of foods accessible to most of the population, especially flour and bakery products. (Allen et al., 2006) The application of calcium salt to bakery products is encountered in the U.S., Canada, European countries, and Japan. (Ayoub Al Jawaldeh et al., 2018) Additionally, iodine deficiency, which can lead to thyroid dysfunction, necessitates the fortification of common and inexpensive food items as distribution vectors that are accessible to the population. The iodine content of the fortified food, guaranteed by the producer and declared on the packaging (label), must be sufficient to meet at least 20–30% of the average daily intake for this micronutrient at typical consumption levels of the food. (Allen et al, 2021)

In Figure 3, several natural sources of iodine for potential applications in the development of fortified bakery products, are presented.

Natural sources rich in iodine	Example of technological application	Iodine content
seaweed (Kelp, Wakame, Spirulina, Chlorella)	seaweed powder added to the dough (0.2-0.5%).	200–1000 µg/100g (kelp).
Iodine-enriched yeast obtained by culturing yeast on I-rich media	seaweed powder added to the dough (0.2-0.5%).	200–1000 µg/100g (kelp).
Milk and milk products (milk powder)	Milk and dairy products (powdered milk) added to dough for texture and taste.	10–30 µg/100ml milk
Eggs (especially the yolk)	addition to dough in the form of dehydrated powder (egg yolk)	15–20 µg/medium egg

Figure 3. Natural sources of iodine for potential applications in bakery products

Other minerals (iron, zinc, selenium, and calcium) and vitamins A, D<sub>3</sub>, B<sub>6</sub>, B<sub>9</sub>, as well, have been added to bakery products. These micronutrients are presented in Table 1, along with their bioavailability and therapeutic values, according to data provided by WHO/FAO (2004), in the guide "Vitamin and Mineral Requirements in Human Nutrition - 2nd ed."

**Table 1 – Biological and therapeutic value of micronutrients WHO/FAO, 2004, used for bakery products fortification**

Micronutrient	Biological Value (absorption / bioavailability)	Therapeutic Value (physiological / clinical role)
<b>Vitamin B6</b> (Pyridoxine)	~70–80% from food; lower in alcoholism and liver diseases	Cofactor in over 100 enzymes; amino acid metabolism, central nervous system (CNS), neurotransmitter synthesis
<b>Vitamin B9</b> (Folic Acid)	~50% from food; >85% from supplements (monoglutamate form)	Prevention of neural tube defects, DNA synthesis, cell division, hematopoiesis
<b>Vitamin D3</b> (Cholecalciferol)	~80% absorbed with lipids; activated in liver and kidneys to 1,25(OH) <sub>2</sub> D	Regulation of calcium/phosphorus, calcium absorption, bone health, immunomodulation, anti-inflammatory
<b>Vitamin A</b> (Retinol)	70–90% from retinol; 5–15% from beta-carotene (influenced by genetics and lipids)	Night vision, immunity, cellular differentiation, epithelial tissue health
<b>Iron (Fe)</b>	5–15% (non-heme), 20–30% (heme); improved with vitamin C	Oxygen transport (via hemoglobin), mitochondrial function, anemia prevention
<b>Zinc (Zn)</b>	~20–40%; decreased by phytates, increased by animal proteins	Immune function, antioxidant activity, DNA synthesis, wound healing
<b>Selenium (Se)</b>	~80–95% (selenium-methionine > selenite/selenate)	Antioxidant (via glutathione peroxidase), thyroid function, antiviral protection
<b>Calcium (Ca)</b>	~30% (optimal with vitamin D); inhibited by oxalates/phytates	Bone formation, muscle contraction, blood coagulation, nerve transmission
<b>Iodine (I)</b>	~90% intestinal absorption (from iodate/iodide forms)	Synthesis of thyroid hormones (T3, T4), neurological development, energy metabolism

**Table 2 – Daily requirements of micronutrients for an adult (19–64 years)**

Micronutrient	Recommended Daily Intake (RDI)	Common Forms of Fortification in Bakery Products
<b>Vitamin A</b>	700–900 µg RE	Retinyl acetate, β-carotene
<b>Vitamin D3</b>	15–20 µg	Cholecalciferol
<b>Vitamin B6</b>	1.3–1.7 mg	Pyridoxine hydrochloride
<b>Vitamin B9</b>	330–400 µg	Folic acid
<b>Calcium (Ca)</b>	1000–1200 mg	Calcium carbonate, calcium lactate
<b>Iron (Fe)</b>	8–18 mg	Ferrous sulfate, ferrous fumarate, NaFeEDTA
<b>Iodine (I)</b>	150 µg	Potassium iodide, potassium iodate
<b>Zinc (Zn)</b>	8–11 mg	Zinc oxide, zinc sulfate
<b>Selenium (Se)</b>	55 µg	Sodium selenite, selenomethionine

The daily requirement of micronutrients such as vitamin A, D<sub>3</sub>, B<sub>6</sub>, B<sub>9</sub> (folic acid), calcium (Ca), iron (Fe), iodine (I), zinc (Zn), and selenium (Se) for an adult is established by health authorities, including EFSA (European Food Safety Authority) and IOM (Institute of Medicine, USA). Table 2 presents the recommended values and common forms of fortification in bakery products, in accordance with the sources mentioned above.

To ensure resistance to high temperatures and long-term storage, micronutrients are added in stable and bioavailable forms. In bakery product fortification, these micronutrients are typically introduced as well-dosed, stable premixes incorporated into flour either during the milling process or during dough preparation (Kampehl L., 2018).

The thermal stability of vitamin D<sub>3</sub> during baking can be significantly improved through microencapsulation. This technique protects the vitamin from thermal degradation and ensures uniform distribution in the fortified food matrix (Navab et al., 2024). Vitamin B<sub>6</sub> has also been studied for its thermal resistance. A study evaluated the stability of vitamin B<sub>6</sub> during the baking and storage of fortified bread, reporting that losses during baking did not exceed 15%, thereby indicating satisfactory thermal stability for bakery applications (Leklem et al., 1980). Similarly, folic acid has been shown to exhibit high thermal stability. A study demonstrated that folic acid remained highly stable at 100 °C, 120 °C, and 140 °C in model liquid food systems, with minimal loss of activity (Day et al., 2006).

Iron, another key micronutrient, interacts with B-group vitamins (B<sub>1</sub>, B<sub>2</sub>, B<sub>6</sub>, B<sub>9</sub>, and PP), which play roles in its absorption and metabolism. Common iron sources used in flour fortification include: Ferrous sulfate (FeSO<sub>4</sub>·H<sub>2</sub>O), Ferrous fumarate (Fe(C<sub>4</sub>H<sub>2</sub>O<sub>4</sub>)), elemental iron (Bilal R. et al., 2002).

Regarding zinc, Wang et al., (2019) demonstrated that zinc, particularly in the form of sulfate or oxide, remains stable at standard baking temperatures (180–220°C), with negligible losses during processing, supporting its effective use in cereal and bakery fortification.

For calcium fortification, the most frequently used salts worldwide include calcium carbonate, sulfate, chloride, gluconate, and bone meal. The quantity used must align with physiological requirements, daily consumption patterns, and the endogenous calcium content of flour. WHO recommends 800–1200 mg/day of calcium for adults. Considering average daily bread consumption (200–250 g/day) and endogenous calcium content (18–53 mg/100 g), fortified products should contribute 30–50% of daily calcium needs. In practice, calcium fortification in baked goods typically falls within 660–1600 mg Ca/kg of product (Cormick et al., 2021).

Studies have shown that calcium carbonate-fortified bread provides calcium with bioavailability comparable to dairy sources without adversely affecting bread quality (Ranhotra et al., 2000). Further, Rossi et al., (2020) found that wheat breads fortified with calcium salts, including calcium lactate, exhibited significantly increased levels of bioavailable calcium.

Martin et al., (2002) reported that calcium sulfate-fortified bread delivered calcium absorption rates comparable to milk. Calcium chloride is also used to enhance texture and stability in bakery products and may replace part of the sodium chloride content. Basset et al. (2013) investigated a 50:50 blend of CaCl<sub>2</sub> and CaCO<sub>3</sub> as a NaCl substitute, noting changes in dough extensibility and sensory attributes.

Calcium gluconate, known for its good solubility and neutral taste, is suitable for diverse applications. Codina et al. (2018) examined the effects of calcium ions from gluconate and lactate on the rheological properties of refined wheat flour dough, noting improvements in dough structure.

Bioactive additives like mineral salts (iron, calcium, zinc) and microencapsulated vitamins can influence the gluten network, altering dough hydration and development. Ferrous sulfate, for example, may interact with sulfhydryl groups in gluten proteins when added in excess, reducing extensibility and mixing tolerance.

Mineral salt fortification may also impact yeast enzymatic activity and fermentation dynamics. Depending on form and dose, zinc and iron may affect CO<sub>2</sub> production, potentially reducing specific bread volume if the formula is not properly adjusted (Flander et al., 2007). Furthermore, B vitamins, sensitive to temperature and pH may degrade during prolonged fermentation or baking.

Recent findings suggest that soluble forms of iodine or selenium can intensify Maillard reactions, which may alter the color and aroma of baked products (Zhang et al., 2023).

Certain fortificants may act as pro-oxidants. For instance, sodium ferrate may accelerate lipid oxidation in the presence of oxygen and heat, shortening shelf life. Hence, the choice of fortificant form and incorporation method (e.g., microencapsulation or compression) is crucial (Hurrell, 2002). Some micronutrients also pose formulation challenges. Calcium, for example, can affect texture and absorption, requiring moderate addition levels. Iodine is light- and heat-sensitive, which may cause losses during processing. However, potassium iodate and iodide, commonly used in fortification, display good stability under typical baking conditions. Potassium iodate, in particular, shows superior stability under high heat and humidity, making it preferable in tropical climates (Ekott et al., 2025).

NaFeEDTA is recommended for wholemeal flour fortification due to its stability and reduced interaction with phytates, which otherwise inhibit iron absorption. Studies have shown that NaFeEDTA is more effective than ferrous sulfate in phytate-rich environments. For instance, Muthayya S., et al., (2012) demonstrated that NaFeEDTA fortification significantly reduced iron deficiency and improved cognitive performance in study participants.

In accordance with WHO/FAO fortification guidelines, the recommended addition per 100 kg of wheat flour includes 3000 mg of iron in the form of ferrous fumarate - a chemically stable compound with minimal impact on organoleptic properties; 20,000 to 30,000 mg of calcium as calcium carbonate, selected for its high bioavailability and neutral sensory characteristics; and 20 to 40 mg of iodine as potassium iodate (KIO<sub>3</sub>), typically incorporated through standardized premixes or, alternatively, via iodized salt as part of the formulation matrix

## **1.2 Fortification of bakery products with fibers and nutritive ingredients (proteins, essential fatty acids)**

Fortifying bakery products with proteins, fibers, and essential fatty acids is an effective strategy for improving their nutritional profile, meeting consumer demand for healthier food options. Proteins from legumes such as pea, chickpea, lentil (Shimeles et al., 2024), from pseudocereals like quinoa, amaranth (Miranda-Ramos et al., 2020), from nuts and seeds: almonds, flaxseeds, chia seeds (Blicharz-Kania et al., 2023, Syarmila et al., 2025), from edible insects such as cricket powder – *Acheta domesticus* (Mafu et al., 2022), mealworm larvae powder - *Tenebrio molitor* (Gautner et al., 2022), and fish - salmon powder (Ajay S. Desai et al., 2018) can be added in the form of flours, protein concentrates, protein isolates, or protein hydrolysates.

Adding proteins may affect the dough's rheology, reducing its extensibility and elasticity. Non-gluten proteins may interfere with the gluten network, negatively influencing the bread's volume and texture. To maintain sensory quality, processes such as sourdough fermentation or ingredient germination are recommended. A study published by Mafu A. et al., (2022) analyzed the

replacement of whole wheat flour with cricket powder at 5%, 10%, and 15%. Fortified bread showed high protein content (18.97–25.94%), fat (10.91–15.07%), and ash (2.09–2.33%). Bread with 20% cricket powder received the highest consumer acceptability score (77%).

Table 3 summarizes main protein sources and technological issues regarding their addition to bakery products.

**Table 3 – Fortification of bakery products with different forms of proteins, and their technological impact**

Protein Form Added to Bakery Product	Protein Source	Applicable Product Type	Recommended Proportion Relative to Wheat Flour	Technological Observations	Ref.
Legume Flour	Peas, Chickpeas, Lentils, Soy	Bread, Biscuits, Pasta	5–20%	Enhances nutritional value; may affect texture and taste due to dilution of gluten and changes in dough rheology.	Bojňanská, T., et al., (2021)
Whey Protein Isolate (WPI)	Milk (Whey)	Bread, Biscuits, Snacks	5–15%	May reduce product volume, requires hydration adjustments	Komerowski M.R. et al., (2023)
Soy Protein Concentrate	Soy	Bread, Biscuits	10–20%	Good solubility; potential bitter taste that may require masking strategies.	Statsenko E.S. et al., (2023)
Seed Flour	Flax, Chia, Pumpkin	Bread, Biscuits, Wholegrain Products	5–10%	Adds fiber and fatty acids; may affect texture and reduce loaf volume.	Miranda-Ramos K. et al., (2020)
Algae/Microalgae Powder	Spirulina, Chlorella	Bread, Pasta, Biscuits	1–3%	High protein content; color and taste may influence product acceptability.	Achour Y. et al., (2014)
Insect Protein Powder	Crickets ( <i>Acheta domestica</i> ), Mealworms ( <i>Tenebrio molitor</i> )	Bread, Biscuits, Crackers	5–10%	Rich in protein; sensory acceptance varies among consumers.	Amoah I, et al., (2023)
Dried Fish Flour	Salmon, Sardine	Bread, Biscuits, Ethnic Products	5–8%	Provides omega-3 fatty acids; strong flavor and odor may affect product acceptability.	Adeleke R.O., et al., (2010)

According to Amina D., et al., (2022), An example formulation for producing bread enriched with whey protein isolate (WPI), based on 100 kg of flour, may include 10 kg of WPI, 60–65 liters of water, 1.5–2 kg of yeast, 1.5–2 kg of salt, 1–2 kg of sugar (optional), and 1–2 kg of vegetable fat (optional). From a technological perspective, the incorporation of WPI may reduce the dough's extensibility and result in a lower final bread volume. Therefore, it is recommended to adjust the water content and kneading time to counterbalance the changes in the rheological properties of the dough. (Amina et al., 2022).

Another recipe from Kohajdová, Zlatica & Cova, J.K. & Magala, M., (2013) is as follows for biscuits fortified with pea flour: pea flour: 15 kg, wheat flour: 85 kg, sugar: 20–25 kg, vegetable fat: 20–25 kg, eggs: 5–10 kg, water: 10–15 liters, leavening agents: 2 kg. As technological observations, pea flour improves the protein profile and gives the biscuits a crispier texture, but it is important to adjust the hydration level to achieve the desired dough consistency. (Kohajdová et al., 2013).

Cercel et al. (2017), proposed a recipe for producing bread fortified with lyophilized myofibrillar protein concentrate. The advantages of the mentioned processes are as follows: protein balanced bread ensured by adding wet myofibrillar protein concentrate or lyophilized myofibrillar protein concentrate; myofibrillar protein concentrate can be obtained from various muscle tissue sources (poultry, fish, pork, beef), having approximately the same concentration of extracted myofibrillar proteins. Myofibrillar proteins have neither a specific taste nor smell, and there are no differences in sensory properties depending on the myofibrillar protein source; bread made with myofibrillar proteins has good rheological behavior, with technological and sensory properties similar to traditional bread; the use of lyophilized myofibrillar protein concentrates can ensure the continuous operation of an industrial process, rather than a seasonal one; the mentioned process can be immediately applied industrially, as it does not require changes to the production lines; myofibrillar protein extraction processes are multiple and efficient. The technical challenge was to create protein bread within parameters comparable to traditional bread, that is, bread made from flour, yeast, water, and salt, without other additives. (Cercel et al., 2017).

Plant proteins and dietary fibers used as vectors for bioactive ingredients can modify the density and porosity of the crumb. For example, the use of legume flours or the addition of protein isolates leads to an increase in crumb consistency and a potential negative impact on elasticity and volume (Nyyssölä et al., 2020).

The addition of fibers in bakery products has a significant impact on the dough's rheology - during processing, fermentation, and baking. The most important influences are summarized in Table 4.

Dosages usually vary between 2–10% of the weight of the flour, depending on the type of fiber and the final product (bread, biscuits, pasta). Soluble fibers are preferred for soft or moist products (bread), while insoluble fibers are more commonly used in crunchy products (biscuits, crackers). It is important to adjust the water content and mixing/baking times to compensate for the rheological changes. Table 5 presents the technological effects of soluble and insoluble fibers based on the type of fiber and the form in which they are added to the fortified bakery product, as well as their nutritional functionality.

**Table 4 – The Influence of Fibers on Dough Rheology by Rosell et al., (2001), Sudha et al., (2007), Collar et al., (2007)**

Technological Aspect	Influence of Fibers	Types of Fibers Involved	Consequences on the Product
<b>Water Absorption</b>	Fibers increase the water absorption capacity	Insoluble (bran, cellulose)	Requires adjustment of water quantity; risk of dry dough if not corrected
<b>Elasticity and Viscosity of Dough</b>	Fibers negatively affect the extensibility and homogeneity of the gluten network	Mainly insoluble	Firmer dough with affected gluten network
<b>Product Volume</b>	May decrease due to poor gas retention	All types (depending on dosage)	Denser bread with smaller volume
<b>Texture and Internal Structure</b>	Soluble fibers can improve texture by forming gels	Inulin, beta-glucans	Moist and soft texture, extended shelf life
<b>Fermentation</b>	Fibers can limit the availability of sugars for yeast	Various (depending on composition)	Slower fermentation, may require adjustment of proofing times
<b>Nutritional Value and Satiety</b>	Adding fibers increases fiber content and induces satiety	Soluble and insoluble	Significant nutritional benefit, healthier product

**Table 5 – Different types of fibers used in fortifying bakery products and technological effects**

Fiber Type	Example	Solubility	Form of Addition	Nutritional Functionality	Technological Effects	Ref.
<b>Inulin</b>	Extracted from chicory, agave	Soluble	Powder	Prebiotic, stimulates gut flora	Improves texture, increases moisture, reduces calories	Niness, K. R. et al., (1999)
<b>Beta-glucans</b>	Oats, barley, wheat bran	Soluble	Concentrate or extract	Lowers cholesterol, improves blood sugar	Increases dough viscosity, may affect extensibility	Lazaridou A. et al., (2007)
<b>Guar gum</b>	Guar gum	Soluble	Technological aid (hydrocolloid)	Regulates digestion, slows glucose absorption	High absorption capacity, may hinder processing	Rosell et al., (2001)
<b>Lignin</b>	Dried apple pulp, wheat bran	Insoluble	Powder or paste	Polyphenols + fiber, antioxidant	May affect color and taste, reduces elasticity	Sudha et al., (2007)
<b>Cellulose and hemicellulose</b>	Bamboo fiber, apple, wheat bran	Insoluble	Powder	Texturizer, increases satiety	Improves biscuit texture, but may make bread rigid	Wang et al., (2020)
<b>Pectin</b>	Apples, citrus fruits	Soluble	Powder added as gelling agent	Prebiotic, beneficial for gut health	May improve water retention, but affects fermentation	Elleuch et al., (2011)

Fortifying bakery products can be performed also with amino acids as an effective strategy for improving the nutritional value of these products, especially in the context of protein imbalances in cereals, such as the low lysine content in wheat. Additions of essential amino acids can correct these deficiencies, contributing to a more complete and balanced diet, particularly in diets predominantly based on cereals. Amino acids can be added in purified form, through extracts from natural sources

(soy, milk, whey, legumes), or through fermentation processes. The selection of the type of amino acid, its source, and the form of addition must be done carefully, as they can influence not only the nutritional composition but also the technological properties of the dough, such as elasticity, hydration capacity, and the texture of the final product. (Joye et al., (2019), Wang et al., (2007).

### 1.3 Fortification of bakery products with cereals, pseudocereals or tubers

Bread and bakery products can also be produced from other cereals, different from wheat. Multigrain bread is rich in seeds and cereals, containing varying amounts of flour or grits from cereals, such as: rice, oat, corn, barley, rye. Spelt wheat (*Triticum spelta*) is an ancient variety of wheat cultivated for thousands of years and considered an "ancient wheat." It is related to common wheat (*Triticum aestivum*), but has distinct botanical and nutritional characteristics. Ruibal-Mendieta, N. L. et al., (2005), described the nutritional value and rheological properties of dough containing spelt wheat, noting that it is less elastic but makes flavorful bread with a denser texture, weaker structure, and is more easily digestible than modern wheat.

The scientific literature contains numerous studies on the addition of pseudocereal flour in bread, such as buckwheat flour, sorghum flour, millet flour, amaranth flour. Pseudocereals do not contain gluten, so the final dough has different rheological properties – usually less elasticity and cohesion. They may require adjustments in hydration and/or combination with natural additives (e.g., gluten, xanthan gum) to maintain the bread volume and texture. The addition of pseudocereals improves the nutritional density of the baked product, making it more valuable for special diets (e.g., vegetarian, gluten-free – if wheat-free dough is used).

Table 6 describes the nutritional value of bread supplemented with different pseudocereals, as well as their influence on its rheology.

Various flours obtained from potato, cassava, yam, sweet potato, and Jerusalem artichoke tubers have been used to fortify bread (Barktiene et al., 2013). Table 7 shows the main effects of adding tubers to the dough, namely, the increase in dough hydration capacity (especially with Jerusalem artichoke and sweet potatoes), but also the decrease in the final bread volume, especially at higher proportions (>20%) of substitution.

In baking, tubers are most commonly incorporated as dry flour, puree, or rehydrated flakes. Since most of these plant sources are gluten-free, their use in traditional bread recipes typically requires blending with wheat flour or adding binding agents (such as xanthan gum, soy, or egg proteins) to maintain dough structure. While these ingredients can enhance the nutritional profile by increasing fiber, vitamins, resistant starch, and antioxidants, using them in high proportions (over 30%) may negatively impact bread texture. Furthermore, the higher content of fiber and bioactive compounds (such as inulin and polyphenols) may require adjustments in proofing time due to variations in enzymatic activity.

Apea-Bah et al., (2011) reported that the cassava varieties they studied had low crude protein levels, ranging from 0.2% to 1.7%, but their starch and fiber content can enrich the nutritional value of baked products that include them.

**Table 6 – Influence of pseudocereal addition on the nutritional value and rheology of the dough**

Pseudocereal	Form of addition	Method of addition	Influence on dough rheology	Added nutritional value	Ref.
<b>Quinoa</b>	Flour, ground seeds	Partial substitution (5–20%)	Reduces extensibility, increases water absorption, affects gluten network	Complete proteins, fiber, iron, magnesium, B vitamins	Alvarez-Jubete et al., (2010);
<b>Amaranth</b>	Whole flour	Partial substitution (5–15%)	Decreases dough elasticity, increases viscosity	High-quality protein, calcium, iron, magnesium, saponins	Shukla & Srivastava, 2011; Alvarez-Jubete et al., (2010)
<b>Buckwheat</b>	Flour	Partial substitution (5–30%)	Negatively affects dough structure due to lack of gluten, increases density	Antioxidants (rutin), proteins, fiber	Wijngaard & Arendt, 2006
<b>Chia</b>	Flour or ground seeds	Direct addition (5–10%)	Increases viscosity due to mucilage, improves water retention, affects texture	Ω-3 fatty acids, soluble fiber, proteins	Ixtaina et al., (2011)
<b>Teff</b>	Whole flour	Partial substitution (5–25%)	Decreases elasticity and fermentation capacity, but improves color and aroma	Iron, calcium, fiber, proteins	Hager et al., 2012;
<b>Canihua (Kañiwa)</b>	Flour	Direct addition or partial substitution (5–15%)	Reduces extensibility, may increase density	Proteins, calcium, zinc, fiber	Repo-Carrasco et al., (2003)
<b>Chenopodium (alternate quinoa)</b>	Flour	Partial substitution (5–20%)	Reduces formation of the rheological structure, may require hydration adjustments	Essential proteins, amino acids, minerals	Vega-Gálvez et al., (2010)
<b>Sorghum</b>	Whole or white flour	Partial substitution (5–25%)	No gluten, high viscosity, may lead to denser dough, compact structure, requires adjustments (xanthan gum or natural emulsifiers)	Polyphenols, insoluble fiber, iron, proteins	Rooney & Serna-Saldivar, (2000); Schober et al., (2005); Dlamini et al., (2007)
<b>Millet</b>	Millet flour	Partial substitution (5–20%)	Does not form gluten network, requires adjustments for binding, dough may become crumbly	Iron, magnesium, silicon, fiber, low allergen content	Saleh et al., (2013); Singh et al., (2022);

Meng et al. (2022) conducted a study on the partial substitution of wheat flour with potato flour (PF) and sweet potato flour (SPF) at levels of 10%–30%. The study evaluated flour and dough properties, total polyphenol content (TPC), and carotenoids (TCC) in the final bread, along with their correlation to bread texture and starch digestibility. The inclusion of PF and SPF led to reductions in peak, breakdown, and setback viscosities, as well as decreased dough development and stability times. Bread hardness was also reduced. The specific volume of the bread depended on the percentage of PF and SPF used, with the best results—lowest hardness and highest volume—obtained at 15% substitution. TPC and TCC levels, influenced by the flour type, were found to reduce specific volume while enhancing resistant starch (RS) content. The rheological and textural changes varied according to the type and amount of flour added.

**Table 7 – Comparative effects of adding different types of tubers on technological parameters and on dough rheology**

Tubers	Form of Addition	Influence on Dough Rheology	Added Nutritional Value	Technological / Sensory Implications	Ref.
<b>Potato</b> ( <i>Solanum tuberosum</i> )	Potato flour, flakes, paste	Increases water absorption, reduces gluten elasticity, dough is softer and stickier	Vitamin C, B6, potassium, resistant starch	Soft texture, smaller volume, thinner crust, moist crumb	Sabanis & Tzia, (2011)
<b>Cassava</b> ( <i>Manihot esculenta</i> )	Cassava flour, starch	Gluten-free – decreases dough cohesion, requires binding agents (xanthan gum, proteins), reduces elasticity	Starch, easily digestible carbohydrates, low protein content	Crumbly bread if not mixed with other flours, neutral taste, porous texture	Apea-Bah et al., (2011)
<b>Yam</b> ( <i>Dioscorea spp.</i> )	Yam flour or puree	Reduces extensibility, increases dough viscosity, denser and more compact dough	Fiber, potassium, vitamin C, resistant starch	Heavier texture, slightly yellow color, slow fermentation	Li QM, et al., (2020)
<b>Sweet Potato</b> ( <i>Ipomoea batatas</i> )	Flour or puree	Increases water retention, reduces elasticity, may hinder proofing	Beta-carotene (provitamin A), fiber, polyphenols, complex carbohydrates	Orange color in the crumb, pleasant sweet taste, natural antioxidants	Wu, Kun-Lun & Sung, et al., (2009)
<b>Jerusalem Artichoke</b> ( <i>Helianthus tuberosus</i> )	Flour, puree	Contains inulin → increases viscosity and water retention capacity, may soften dough	Prebiotic fiber (inulin), potassium, iron, B vitamins	More moist texture, slightly sweet taste, prebiotic effect, more active fermentation in the presence of yeast	Kryzhska, Tetiana & Danylenko, et al., (2020) Chirsanova A., et al., (2021)

Banti et al., (2025) examined the partial replacement of wheat flour with yam flour up to 40% and its impact on flour and bread quality. The study found that the functional characteristics of the composite flour were suitable for baking. Moisture content in fresh bread ranged from 21.07% to 24.02%, while protein and fat contents decreased as yam flour inclusion increased. Fiber content rose from 1.71% to 2.76%. Substituting wheat with yam flour also enhanced the bread's mineral content, particularly Na, Ca, Mg, and Fe. Sensory evaluation showed no significant difference from the control bread at substitution levels up to 20%. Overall, the study concluded that replacing up to 30% of wheat flour with yam flour can result in acceptable and nutritionally improved bread products.

Chirsanova et al., (2021) investigated the potential of Jerusalem artichoke flour to diversify bread offerings. The research explored the effects of incorporating 2.5%, 5%, 7.5%, and 10% Jerusalem artichoke flour into wheat bread on its sensory and physical-chemical characteristics. This flour is high in dry matter and rich in essential amino acids such as histidine, isoleucine, methionine, phenylalanine, and valine. Findings indicated that using 5% Jerusalem artichoke flour yielded a product with improved organoleptic properties, a longer shelf life, and a higher content of micro- and macronutrients, positively contributing to human health.

#### 1.4 Fortification of Bakery Products with Fruits

Fruits have traditionally been included in bread recipes, but recent research has increasingly focused on the effects of incorporating both fresh-cut and dried fruits, as well as fruit by-products like peels and powders, on the technological, nutritional, and sensory attributes of baked goods. Examples include pomelo (fresh and dried), fibers from pear, apple, and dates, as well as powders derived from apples, bananas, chestnuts, green coffee beans, pumpkin, carob seeds, and more (Reshmi et al., 2017; Bchir et al., 2014; Lauková et al., 2016; Dall'Asta et al., 2013; Ho et al., 2013; Jakubczyk et al., 2018; Rakcejeva et al., 2011; Papakonstantinou et al., 2018).

For instance, apple powder, rich in dietary fiber indicating high water-binding capacity was shown to enhance dough hydration, increase development time, and improve dough stability when used at levels of 5%–15%.

Kaur et al., (2022) explored the effect of apple peel powder on muffin dough, highlighting improvements in texture, nutrition, and sensory appeal. Similarly, Sudha et al., (2007) tested varying amounts of apple powder (5%, 10%, and 15%) in bread and cookies. Their findings confirmed that moderate additions (up to 10%) significantly elevated fiber and antioxidant content without negatively impacting taste or texture. Products also retained moisture better and had a softer crumb in early storage days, with the 10% level striking a good balance between functionality and consumer preference.

Chestnut flour has also been examined for its use in gluten-free bread. Marciniak-Łukasiak et al., (2022) tested its inclusion at 5%–20% substitution for corn starch, revealing better elasticity and crumb softness. The 5% and 10% levels were especially well-received in sensory tests due to improved flavor and aroma, while 10% addition also led to increased loaf volume.

Sttanciu I. et al., (2023) emphasized the nutritional benefits of sea buckthorn powder, which is rich in vitamins C and E, essential fatty acids, and antioxidants. Adding it at 2%–6% enhanced the nutritional quality of bread without negatively affecting taste or appearance. However, more research is needed to determine how these beneficial compounds behave during baking.

Apricot powder, as studied by Nisar et al., (2021), was added to cookies at a 25% level, resulting in a notable increase in fiber content and antioxidant activity.

Parafati L., et al., (2020) demonstrated that using prickly pear peel flour (PPPF) in bread (5%–20%) increased polyphenol and flavonoid levels, particularly at 10–15%. Even a 5% substitution significantly boosted antioxidant potential.

She et al., (2024) assessed the impact of partially replacing wheat flour with kiwi starch (10%–20%). While the addition improved water absorption and dough structure through stronger gel formation, it also compromised the gluten network, causing firmer bread and changes to the crumb. This substitution also led to enhanced Maillard reaction effects, decreased starch digestibility, a lower predicted glycemic index, and longer shelf life due to reduced mold growth at room temperature.

#### 4. CONCLUSIONS

The fortification of bakery products with bioactive compounds and ingredients emerges as a scientifically well-founded and technologically feasible strategy for improving nutritional quality and combating micronutrient deficiencies on a global scale. The integration of essential micronutrients (vitamins, minerals, dietary fiber) and plant-based ingredients, such as legumes, tubers, cereals and pseudocereals, fruits, contributes not only to the functional value of the final product but also to meeting current consumer demands for healthy foods.

The results of the reviewed literature show that, although fortification brings significant nutritional benefits, it also involves technological challenges, such as altering dough rheology, decreasing extensibility, and changes in bread crumb structure. However, technological advances – such as microencapsulation, controlled fermentation processes, and recipe optimization – can counteract these effects and maintain the desired quality characteristics.

From a public health perspective, functional bakery products fortified with bioingredients can become accessible vehicles for delivering essential nutrients with the daily diet. This approach supports both preventive nutrition and sustainability goals by valorizing underutilized plant resources.

Therefore, continued interdisciplinary research is needed to connect food technology, nutritional science, and consumer behavior to ensure the development, acceptance, and efficient scaling of fortified functional bakery products.

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