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The Importance of Sprouts from Brassicaceae Family in Bakery

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Abstract

This review explores the potential of incorporating sprouts from the Brassicaceae family, including radish (*Raphanus sativus*), broccoli, and kale (derived from *Brassica oleracea*), into bakery products to enhance their nutritional and functional quality. Brassicaceae sprouts are rich in bioactive compounds such as glucosinolates, phenolics, flavonoids, vitamins, minerals, and dietary fiber, which contribute to increased antioxidant capacity and overall health-promoting properties of cereal-based foods. The review also addresses technological and sensory aspects of sprout incorporation, including effects on dough characteristics, texture, color, and flavor. Evidence indicates that appropriate processing and formulation strategies allow sprout addition without compromising product acceptability. Their use aligns with current trends in functional foods, plant-based ingredients, and clean-label product development, meeting consumer demand for nutritionally improved bakery items. Overall, cruciferous sprouts represent promising functional ingredients for innovative bakery applications. Further research is needed to optimize processing conditions, preserve bioactive compounds, and support large-scale industrial implementation and consumer acceptance.

Keywords: radish, broccoli, kale, bakery

1. Introduction

Brassicaceae (Cruciferae) vegetables include numerous essential species cultivated globally and traditionally used in various cultures for both culinary and medicinal purposes [1].

In recent years, increasing consumer awareness regarding nutrition, disease prevention, and overall well-being has stimulated the development of functional foods enriched with bioactive compounds. Bakery products represent one of the most widely consumed food categories worldwide; however, they are often characterized by high carbohydrate content and limited levels of essential micronutrients and phytochemicals. Consequently, improving the nutritional quality of bakery products through the incorporation of natural, plant-based ingredients has become a major research priority in food science and technology [2-4].

Vegetables belonging to the Brassicaceae family, including radish (*Raphanus sativus L.*), broccoli (*Brassica oleracea var. italica*), and kale (*Brassica oleracea var. acephala*), are widely recognized for their exceptional nutritional value and health-promoting properties. These vegetables are rich sources of vitamins, minerals, dietary fiber, polyphenols, and glucosinolates, which contribute to their antioxidant, anti-inflammatory, antimicrobial, and chemoprotective activities [5-8]. Kale has been

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described as a "superfood" due to its high concentration of bioactive compounds [5], while broccoli has been extensively studied for its metabolomic complexity and sulforaphane content [6, 7].

Sprouts and microgreens represent an early developmental stage of plants characterized by intensified metabolic activity and enhanced nutrient accumulation. Compared to mature vegetables, sprouts exhibit higher levels of bioactive compounds, improved mineral bioavailability, and increased antioxidant capacity [2, 7, 9]. Germination activates enzymatic processes that promote the synthesis of phenolic compounds, vitamins, and glucosinolate derivatives, while reducing antinutritional factors such as phytates [10-13]. As a result, sprouts have emerged as promising ingredients for the development of health-oriented food products [3, 14].

Among Brassicaceae sprouts, broccoli, kale, and radish sprouts have attracted considerable scientific interest due to their high content of sulforaphane and other isothiocyanates[15-17]. These compounds have been associated with multiple health benefits, including modulation of inflammatory responses, protection against oxidative stress, improvement of gut health, and potential neuroprotective and anticancer effects. Clinical and experimental studies have demonstrated that sulforaphane-rich broccoli sprouts may reduce inflammatory biomarkers and contribute to the prevention of chronic diseases [18, 19].

In addition to their nutritional and physiological benefits, Brassicaceae sprouts present valuable technological properties for food processing applications. When incorporated into cereal-based systems, sprout powders and extracts may influence dough hydration, viscoelastic behavior, and starch–protein interactions[20-22]. Moderate supplementation levels have been shown to enhance fiber and protein content, improve antioxidant capacity, and extend shelf-life through the inhibition of lipid oxidation and microbial growth. However, excessive addition may negatively affect loaf volume, crumb structure, and sensory acceptability [23].

Recent research has explored various processing techniques to preserve the functional quality of sprouts during food manufacturing. Drying methods, including freeze-drying and low-temperature dehydration, as well as encapsulation strategies, have been applied to improve the stability of heat-sensitive compounds [24, 25].

Therefore, the present study aims to highlight the scientific evidence regarding the nutritional composition, bioactive potential, technological functionality, and application of radish, broccoli, and kale sprouts in bakery products. By integrating current findings from recent literature, this work seeks to contribute to the development of innovative, sustainable, and health-oriented bakery products. Figure 1 illustrates the Brassicaceae sprouts analyzed in this study, namely radish, kale, and broccoli.

a b b

Figure 1: Brassicaceae sprouts: a) radish, b) kale, c) broccoli.

2. Nutritional and functional properties of Brassicaceae sprouts

Table 1 summarizes the nutritional profile of kale, broccoli, and radish sprouts expressed per 100 g fresh weight, using data collected from food composition databases and recent scientific literature [2, 17, 26]. The presented results emphasize the significant biochemical and nutritional modifications induced by the germination process in Brassicaceae species.

All analyzed sprouts exhibited elevated moisture levels, exceeding 88%, which reflects the activation of metabolic pathways and cellular hydration during early plant development [2, 9]. While this high water content enhances palatability and digestibility, it may also increase susceptibility to microbial

spoilage, highlighting the importance of appropriate storage and processing conditions [27].

In terms of macronutrient composition, kale and broccoli sprouts demonstrated higher protein concentrations than radish sprouts, suggesting improved amino acid availability following germination [5, 26, 28]. This increase is associated with enzymatic hydrolysis of storage proteins and subsequent synthesis of functional peptides [2, 14]. Simultaneously, lipid content remained low across all samples, supporting their classification as low-fat functional ingredients suitable for health-oriented food formulations [29].

Dietary fiber content was particularly elevated in kale sprouts, contributing to intestinal health and glycemic regulation [5, 28]. In parallel, carbohydrate levels were reduced due to partial starch degradation into soluble sugars, which may positively influence fermentation processes and flavor development in bakery products [20, 21].

The mineral profile revealed substantial variations among the analyzed sprouts. Kale sprouts exhibited remarkable levels of calcium, potassium, and magnesium, while broccoli sprouts presented balanced concentrations of phosphorus and iron [5, 9]. These minerals play essential roles in metabolic regulation, bone health, and oxygen transport [26]. The enhanced bioavailability of minerals can be attributed to phytate degradation mediated by endogenous phytases activated during germination [12, 13].

Vitamin C content increased markedly in kale and broccoli sprouts, reaching values associated with strong antioxidant protection and immune support [5, 17]. In addition, the accumulation of glucosinolates and sulforaphane, particularly in broccoli and radish sprouts, represents a distinctive characteristic of Brassicaceae species, contributing to their chemoprotective and anti-inflammatory properties [6, 15, 16].

The reduction of antinutritional factors, especially phytates, further improves mineral absorption and digestive tolerance [12, 13]. At the same time, the elevated antioxidant activity reflects the enrichment in phenolic compounds, flavonoids, and isothiocyanates, which collectively enhance oxidative stability and cellular protection [14, 17, 28].

From a technological perspective, the nutritional characteristics presented in Table X indicate favorable conditions for the incorporation of Brassicaceae sprouts into bakery formulations. Their balanced protein–fiber matrix supports water retention and dough stability, while antioxidant compounds may delay lipid oxidation and quality deterioration [20, 21]. Nevertheless, excessive supplementation could modify sensory attributes, underlining the necessity for optimized formulation strategies [14] Overall, the findings presented in Table 1 confirm that kale, broccoli, and radish sprouts represent valuable functional ingredients with significant nutritional, physiological, and technological potential [2, 5, 17, 26]. Their application in bakery products offers promising opportunities for developing innovative foods aligned with current trends in preventive nutrition and sustainable food systems [20, 21, 27].

Table 1: The nutritional composition of Brassicaceae sprouts (kale, broccoli, and radish), based on databases and literature sources, per 100 g.

Component	Unit	Kale Sprouts / 100 g	Broccoli Sprouts / 100 g	Radish Sprouts / 100 g
Water (H_2O)	%	88.5[5, 17]	89.2 [2, 17]	90.1 [15, 17]
Energy	kcal	49 [5, 30]	34[2]	16 [15, 17]
Carbohydrates	g	6.5 [5, 31]	6.6 [2, 31]	3.4 [15, 17]
Total Dietary Fiber (TDF)	g	4.0 [,11][5]	2.6 [2, 30]	1.6 [15, 30]
Total Fat Lipid (TFL)	g	1.3 [5, 30]	0.4 [2, 30]	0.1 [15, 17]
Protein	g	3.2 [5, 30]	3.0 [2]	0.7 [15, 17]
Ash	g	1.7 [5, 16]	0.9 [2, 28]	0.6 [15, 16]
K	mg	348 [5, 16]	316 [2, 28]	233 [15, 16]
Ca	mg	254 [5, 16]	47 [2, 28]	25 [15, 16]
Mg	mg	33 [5, 16]	21 [2, 28]	10 [15, 16]
P	mg	55 [5, 16]	66 [2, 28]	20 [15, 16]
Fe	mg	1.6 [5, 16]	0.7 [2, 28]	0.3 [15, 16]

Na	mg	38 [5, 16]	33 [2, 28]	39 [15, 16]
Zn	mg	0.4 [5, 16]	0.4 [2, 28]	0.3 [15, 16]
Cu	mg	0.05 [5, 16]	0.04 [2, 28]	0.02 [15, 16]
Mn	mg	0.8 [5, 16]	0.2 [16, 28]	0.1[15, 16]
Vitamin C	mg	93.4 [5]	89.2 [28]	14.8 [15]
Total Glucosinolates	mg	120 [17]	210 [2, 17]	240 [17]
Sulforaphane	mg	45 [17]	90 [17]	38 [17]
Phytates	–	Reduced [12, 13]	Reduced [12, 13]	Reduced [12, 13]
Antioxidant Activity	–	High [31]	Very High [31]	High [31]

Values are expressed per 100 g fresh weight. Data were compiled from food composition databases and peer reviewed literature. Minor variations may occur depending on cultivar, germination conditions, and analytical methods.

3.Technological and nutritional applications of sprouts in bakery products

Cake-type and gluten-free bakery products represent one of the most frequently investigated categories for Brassicaceae sprout incorporation. Studies have shown that gluten-free cakes enriched with broccoli sprout powder exhibited increased protein, dietary fiber, and antioxidant capacity, alongside improved crumb structure and moisture retention [18,24]. Optimized formulations showed acceptable sensory attributes and enhanced technological stability.

Bread and yeast-leavened products constitute another important application area. Research on wheat bread fortified with sprouted and vegetable-based ingredients, including Brassicaceae species, reported increased total phenolic content and antioxidant activity, accompanied by modifications in dough rheology and gas retention capacity [21, 23]. Low substitution levels (generally below 10%) preserved loaf volume and crumb elasticity, while higher concentrations resulted in reduced volume and increased firmness.

Flatbreads and fermented bakery products have also been explored as platforms for Brassicaceae sprout incorporation. Mancini et al. [23] demonstrated that kale-enriched flatbreads produced using sourdough fermentation exhibited improved phenolic bioaccessibility and reduced bitterness associated with glucosinolate degradation products.

From a nutritional perspective, the inclusion of Brassicaceae sprouts in bakery products consistently results in enhanced levels of polyphenols, vitamin C, and glucosinolate-derived compounds, particularly sulforaphane [5, 6, 8, 17]. These bioactive components are associated with antioxidant, anti-inflammatory, and chemoprotective effects [15, 16, 18, 19].

Germination also contributes to the partial degradation of phytates, improving mineral bioavailability and digestive tolerance [12, 13, 32]. In addition, several studies reported increased concentrations of free amino acids and improved protein digestibility in products containing sprouted ingredients [3, 4].

Technologically, Brassicaceae sprout incorporation influences dough hydration, viscoelastic behavior, and crumb structure. Increased water absorption, resulting from elevated fiber content and modified starch fractions, contributes to improved moisture retention and delayed staling in cakes and breads [25]. However, excessive hydration may lead to stickiness and reduced machinability.

Enzymatic activity represents another critical factor. Moderate amylase and protease activity may enhance dough extensibility and crumb softness, whereas excessive activity can destabilize starch–protein networks and impair gas retention [3, 33]. Therefore, strict control of sprouting duration and drying conditions is essential.

Color and flavor modifications are particularly relevant for Brassicaceae-based formulations. The presence of chlorophyll, phenolics, and sulfur-containing compounds often results in greener or darker products and characteristic vegetal or slightly bitter notes [34]. Fermentation and formulation optimization have been proposed as effective strategies to mitigate these effects [28].

Recent studies emphasize integrated processing strategies combining sprouting with low-temperature drying and fermentation to stabilize bioactive compounds and regulate enzymatic activity [25, 27].

Advanced rheological and microstructural analyses have contributed to understanding interactions between sprouted materials and cereal matrices [35]. Collectively, studies published over the past 10 years demonstrate that Brassicaceae sprouts represent valuable functional ingredients for bakery applications, including bread, pita, gluten-free cakes, biscuits, cookies, and crackers. Their incorporation allows for significant nutritional improvement by increasing antioxidant capacity, improving mineral bioavailability, and enriching with health-beneficial phytochemicals.

Nevertheless, successful industrial implementation requires careful optimization of inclusion levels, processing conditions, and complementary technologies. Future research should focus on standardized production protocols, evaluation of bioactive compound stability during baking and storage, and long-term consumer acceptance.

4. Conclusion

The findings synthesized in this review demonstrate that sprouts from Brassicaceae species, particularly broccoli, kale, and radish, constitute valuable functional ingredients for bakery applications. Germination induces significant biochemical and structural modifications, leading to enhanced levels of bioactive compounds, improved antioxidant capacity, and increased mineral bioavailability, while simultaneously reducing antinutritional factors. Therefore, optimized formulation strategies and controlled processing are essential to fully exploit the functional potential of Brassicaceae sprouts in bakery systems. Further research should focus on standardization of production protocols and evaluation of bioactive compound stability during baking and storage to facilitate their sustainable industrial application.

Conflicts of interest / Competing interests: No conflict of interest

Ethics approval: No ethic situation.

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