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THE INFLUENCE OF HORTICULTURAL BY-PRODUCTS IN BAKERY PRODUCTS - A REVIEW

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Abstract

Horticultural by-products (HBP) are valuable functional ingredients and natural preservatives that enhance the nutritional value and shelf life of foods. The review includes articles examining HBP addition in bakery products. Following PRISMA Guidelines, 1,970 articles were identified, with 47 selected for analysis. These studies explored HBP's impact on phenolic content, physicochemical composition, colour, rheological, and sensory properties in bakery products. The published data suggests that increasing the concentration of HBP positively correlated with high phenolic content and antioxidant capacity in bakery products. The main limitation of the published data was that no articles were found to contain a complete characterisation of the products: physicochemical parameters, rheological parameters and sensory analysis. Moreover, no standardisation of rheological methods was identified. Further investigations into HBP properties and usefulness will help optimize formulations, meet consumer preferences and increase the use of HBP to produce more healthy and sustainable food.

***Key words**: texture; sensory analysis; phenols; minerals; rheology.*

INTRODUCTION

Reducing food losses and waste is crucial in mitigating pressure on natural resources and fostering sustainable food systems (FAO, 2019). One approach involves valorising by-products to harness phenolic compounds for developing functional foods, with bakery products serving as effective carriers for fortification (Dziki et al, 2014; Echave et al., 2023; Krajewska & Dziki, 2023; Santos et al., 2022).

Methods for extracting valuable phenolic compounds from these by-products have been investigated, and their incorporation into baked goods has been shown to increase phenolic content and antioxidant capacity (Olaoye & Ade-Omowaye, 2011; Piasecka & Górska, 2021; Ramya et al., 2023; Ranasinghe et al., 2022). However, further research is needed to optimize formulations, align with consumer preferences, and ensure regulatory compliance, in order to enable the development of innovative and sustainable bakery products that address both nutritional and environmental goals.

This review focuses on potential functional ingredients from horticultural by-products incorporated to bakery products.

Physicochemical characterization of the functional ingredients, and their effect on dough and final products properties will be summarized, but due to the wide variety of these by-products existing in literature, they were organized according to their origin in four categories: peels and skins; pomace; seeds and petals, leaves, stems and other floral by-products.

MATERIALS AND METHODS

Search Strategy

This review was conducted based on an extensive literature search across three major databases, following PRISMA 2020 guidelines to ensure rigor and minimize bias. The search focused on studies that investigated the influence of horticultural by-products on the quality, physicochemical, sensorial and rheological properties of bakery products, published in peer-reviewed English journals.

The initial search yielded 1,970 publications. After excluding 636 duplicates, 1,334 potentially relevant titles were identified. Screening of titles and abstracts resulted in 132 articles, and subsequent full-text screening led to the final inclusion of 47 articles.

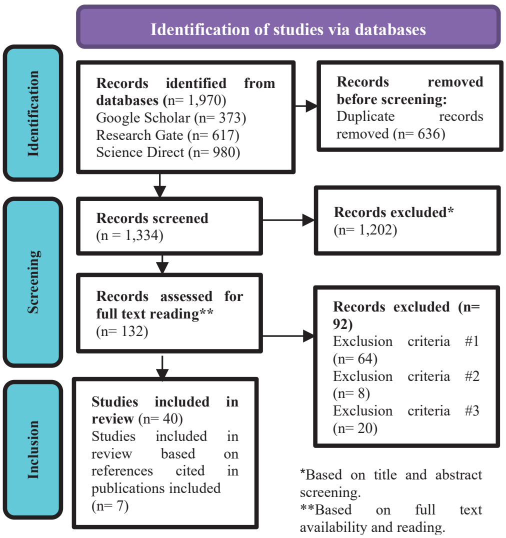

Figure 1. PRISMA flow diagram
(From: Page M.J. et al., 2021)

RESULTS AND DISCUSSIONS

Composition of Potential Functional Ingredients Obtained from Horticultural By-Products

Horticultural by-products, such as pomace, peels, seeds, and leftover fruits and vegetables, typically make up 20% to 45% of total produce. These by-products are rich in dietary fiber, polyphenols, antioxidants, essential fatty acids, and carotenoids. Incorporating them into baked goods can enhance the nutritional profile, sensory characteristics, and shelf life. This has been shown to significantly improve the nutritional and functional properties of products like cakes, muffins, cookies, crackers, and bread. It can also modify the texture, flavour, and overall nutritional composition, making the final products more appealing to consumers (Gómez & Martinez, 2018; Kauser et al., 2024; Kuyu, 2015; Sahni & Shere, 2019; Melini et al., 2020).

The composition of different horticultural by-products used in bakery products is summarized in Table 1.

The total phenolic content (TPC) varies widely, with peels and skins ranging from 2.14 to 6.47 g kg^{-1}, pomace from 10.16 to 45.75 g kg^{-1}, and petals, stems, leaves, and other floral by-products from 0.56 to 537.40 g kg^{-1} (Upadhyay et al., 2023; Sudha et al., 2007; Fardaghi et al., 2020; Tukassar et al., 2023). Analyses of pomace indicate protein is generally below 10 g kg^{-1}, except for mushrooms which are higher (Djeghim et al., 2021; Sudha et al., 2007; Upadhyay et al., 2023; Lu et al., 2018). Fat and ash levels are below 7 g kg^{-1} and 5 g kg^{-1}, while total dietary fiber (TDF) ranges from 10.15 to 49 g kg^{-1}. Other HBPs have fiber contents between 7.24 and 52.90 g kg^{-1}, with protein and fat levels generally ranging from 8.58 to 30.60 g kg^{-1} and 1.03 to 31.83 g kg^{-1}, respectively (Djeghim et al., 2021; Upadhyay et al., 2023; Segura-Badilla et al., 2022 Ojeda et al., 2023; Matseychik et al., 2021; Abdel-Hameed et al., 2023; Cerda-Bernad et al., 2023; Drabińska et al., 2018; Vinod et al., 2023). Mineral analysis shows potassium is particularly high in saffron stigmas and chickpeas, while iron levels in saffron stigmas are lower than cauliflower by-products and chickpeas (Cerda-Bernad et al., 2023; Tukassar et al., 2023; Vinod et al., 2023).

Table 1. Composition of potential functional ingredients recovered from horticultural by-products incorporated in bakery products

HBP	TPC	Moisture	Protein	Fat	Ash	TDF	Energy value (Kcal/100g)	Carbohydrate	Macrominerals			Microminerals					References
									Ca	Mg	Na	K	Fe	Mn	Zn	Cu	
PEELS AND SKINS																	
Pepper peels	-	6.04	4.38	2.46	2.92	15.90	-	35.20	-	-	-	-	-	-	-	-	Djeghimet al. (2021)
Prickly pear peels	-	10.29	8.48	1.69	19.60	52.90	-	52.53	-	-	-	-	-	-	-	-	
Prickly pear seed peels	-	7.87	7.00	1.03	16.42	50.80	-	16.88	-	-	-	-	-	-	-	-	
Potato peel	2.14	11.44	2.17	2.42	2.92	8.15 ± 0.22	-	-	-	-	-	-	-	-	-	-	Upadhyayet al. (2023)
Bottle gourd peel	6.47	9.40	2.74	2.43	3.92	7.24 ± 0.13	-	-	-	-	-	-	-	-	-	-	
Banana peel	-	3.56	6.41	10.22	11.86	14.38	-	57.13	-	-	-	-	-	-	-	-	Segura-Badilla et al. (2022)
POMACE																	
Orange pomace	-	9.90	5.40	4.37	3.76	12.41	-	64.16	-	-	-	-	-	-	-	-	Djeghim et al. (2021)
Apple pomace	-	11.41	3.66	3.16	1.51		-	64.36	-	-	-	-	-	-	-	-	
Tomato pomace	-	5.23	7.87	3.31	3.61	49.00	-	27.08	-	-	-	-	-	-	-	-	
Apple pomace	10.16	10.80	2.06	2.70	0.50	51.10	-	-	-	-	-	-	-	-	-	-	Sudha et al. (2007)
Apple pomace	10.45	5.50	1.53	4.15	1.89	10.15	-	-	-	-	-	-	-	-	-	-	Upadhyay et al. (2023)
Indian gooseberry pomace	45.75	9.31	1.77	6.14	0.86	13.15	-	-	-	-	-	-	-	-	-	-	
Vinal (Neltuma ruscifolia) residue	-	8.90	10.20	2.40	4.50	21.20	-	53.00	-	-	-	-	-	-	-	-	Ojeda et al. (2023)
Shiitake mushroom	-	10.49	24.68	-	-	-	-	-	-	-	-	-	-	-	-	-	Lu et al. (2018)
Black ear mushroom	-	13.81	10.92	-	-	-	-	-	-	-	-	-	-	-	-	-	
Silver ear mushroom	-	11.83	10.88	-	-	-	-	-	-	-	-	-	-	-	-	-	
SEEDS																	
Amaranth seed	-		13.80	7.10	2.20	-	-	62.30	-	-	-	-	-	-	-	-	Matseychik et al. (2021)
Papaya seed	-	7.15	27.95	31.83	7.86	18.53	6.68	424.99	-	-	-	-	-	-	-	-	Abdel-Hameed et al. (2023)
Vinal (Neltuma ruscifolia) seeds	-	5.90	30.60	4.60	3.20	20.90	-	35.00	-	-	-	-	-	-	-	-	Ojeda et al. (2023)
Vinal (Neltuma ruscifolia) endocarp	-	8.90	11.80	2.10	3.90	38.60	-	35.00	-	-	-	-	-	-	-	-	
PETALS, LEAVES, STEMS AND OTHER FLORAL BY-PRODUCTS																	
Spanish saffron petals	-	6.42 - 5.52	8.58 - 8.68	5.81 - 4.56	8.39 - 4.89	26.59 - 22.56	369 - 381	70.80 - 76.35	415.20 - 112.60	120.30 - 103.30	9.00 - 9.20	1530 - 1450	46.26 - 6.38	2.51 - 0.95	3.89 - 2.10	0.57 - 0.55	Cerda-Bernad et al. (2023)
Spanish saffron stigmas	-	8.90	13.15	7.01	5.59	17.86	377.00	65.26	118.30	100.20	19.00	1114.00	5.45	1.15	2.65	0.35	
Iranian saffron stigmas	-	9.01	13.61	6.08	5.57	21.17	372.00	65.73	86.25	102.50	33.75	1136.00	12.28	1.30	2.13	0.25	
Greek saffron stigmas	-	10.74	12.29	6.22	4.81	17.64	369.00	65.94	123.30	88.70	33.25	971.30	8.13	1.25	1.98	1.63	
Saffron stigma	2.72	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Fardaghi et al. (2020)
Saffron stamen	1.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Saffron style	0.76	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Saffron petal	1.96	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Saffron corm	0.56	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
Broccoli leaves	-		28.99		10.65	-	-	-	-	-	-	-	-	-	-	-	Drabińska et al. (2018)
Cauliflower stems, stalks and leaves	537.40	5.50	22.80	2.95	5.81	15.32	-	47.62	-	363.00	-	-	200.30		14.60	8.30	Tukassar et al. (2023)
Vinal (Neltuma ruscifolia) pods	-	8.70	12.80	2.40	4.10	31.10	-	41.00	-	-	-	-	-	-	-	-	Ojeda et al. (2023)
Chickpea	-	-	22.40	60.69	2.82	17.40	-	57.80	45.00	166.00	-	846.00	4.86	-	-	-	Vinod et al. (2023)

The Influence of Fruit, Vegetable and Legumes Peels and Skins on Bakery Products

The formulations of breads and bakery goods incorporating potential functional ingredients from peels and rinds are presented in Tables 2 and 3.

Variation of the total phenolic content, chemical composition and mineral content

According to a study by Manzoor et al. (2024), bagels containing banana peel and lavender extract exhibited high TPC compared to control samples.

The incorporation of horticultural by-products increased protein levels in breads by 8% to 182% when compared to their respective control samples. However, a study conducted by Upadhyay et al. (2023) found that protein content decreased by 70% to 76% in HBP-containing bread compared to the control. Fat content in wheat-based bakery products increased by 11% to 81% with HBP addition, except for banana peel bread where fat levels decreased by 41%. TDF values rose by 12% to 192% in HBP-containing bakery items compared to their controls, while carbohydrate content decreased by 4% to 9% for banana peel bread and biscuits, but increased by 7% in bread with potato and bottle gourd peels compared to their respective control samples (Manzoor et al., 2024; Segura-Badilla et al., 2022; Upadhyay et al., 2023). The reviewed studies did not examine the influence of adding HBP peels and skins on the mineral content of bakery products.

Table 2. Nutritional composition of bakery products with horticultural peels and skins incorporated in bakery products

HBP	Bakery product	% added	TPC	Moisture	Protein	Fat	Ash	TDF	Energy value (Kcal/100 g)	Carbohydrate	Macrominerals			Microminerals					Reference
											Ca	Mg	Na	K	Fe	Mn	Zn	Cu	
Banana peel and lavender	Bagels	10 5, 10, 15 mL	15-21.53 (1.58)	28.68 - 29.64	11.65 - 12.43	5.25 - 7.21	-	5.25 - 6.353 (2.17)	-	-	-	-	-	-	-	-	-	-	Manzoor et al. (2024)
Banana peel	Bread	10	-	12.6 (36.8)	34.5 (12.2)	10.7 (18.11)	-	2.7 (2.4)	-	38.9 (40.7)	-	-	-	-	-	-	-	-	Segura-Badilla et al. (2022)
	Biscuits	10, 20	-	6.2 - 5.3 (7.4)	2.3 - 13.1 (12.1)	30.2 -31.5 (28.3)	-	1.8 - 2.6 (1.5)	-	48.1 - 46.1 (50.7)	-	-	-	-	-	-	-	-	
Apple pomace, Indian gooseberry pomace, potato peels and bottle gourd peels	Bread	4, 5, 8, 10, 12, 15, 16, 20, 25	11.89 - 14.48 (2.23)	12.246 - 9.38 (12.2)	2.57 - 3.16 (10.79)	1.5 - 3.15 (1.74)	2.58 -4.67 (0.50)	6.26 - 8.28 (3.16)	255.2 - 365.46 (303.04)	54.32 - 70.36 (65.41)	-	-	-	-	-	-	-	-	Upadhyay et al. (2023)

Variation of colour analysis, rheological, physical, textural and sensorial proper

The addition of horticultural by-products to bakery products often results in a decrease in lightness (L*) values, likely due to Maillard and caramelization reactions, as well as the original colour of the HBP. Variations in redness (a*) and yellowness (b*) can also be attributed to the HBP colour (Djeghim et al., 2021; Upadhyay et al., 2023; Manzoor et al., 2024).

Rheological properties of bakery products can be measured or tested with different instruments (farinograph, alveograph, mixolab, visco anlyser), which provide data that can be correlated with final product's quality. Incorporating HBP into wheat-based doughs can modify their rheological properties, such as increased water absorption (WA) and dough development time (DDT) (Hussain et al., 2023). Changes in DDT and dough stability (DS) can be related to TDF composition of HBP.

HBP incorporation in wheat-based bakery products frequently leads to increased weight loss, specific volume, and moisture, along with decreased pH (Djeghim et al., 2021).

The texture of banana peel bagels shows higher hardness/firmness and cohesiveness, but lower gumminess and springiness (Manzoor et al., 2024).

Sensory scores for odour, flavour, taste, and texture generally decrease with higher HBP addition, though some wheat bread formulations show no impact or even improved scores for certain attributes.

Overall, the highest HBP addition without significant differences is often 5-10%, with a range of 2.5-25% reported in the literature.

Table 3. Influence of potential functional ingredients obtained from horticultural peels and skins on dough and final bakery product properties

HBP	Bakery product	% added	Dough rheological properties	Bakery products properties			Sensorial analysis	Reference
				Physical properties	Textural properties	Colour		
Pepper peels	Gluten-free bread	2.5, 5, 7.5	↓[1]K, [4]χ2 ↑[2]n, [3]r	↑[9]WL, [10]Vsp, moisture ↓pH	-	↓crust and crumb L*, crumb b* ↑crust and crumb a*, crumb b*	-	Djeghim et al. (2021)
Prickly pear peels	Gluten-free bread	2.5, 5, 7.5	↑[1]K, [4]χ2, [3]r ↓[2]n	↑[9]WL, [10]Vsp ↓pH, moisture	-	↓crust and crumb L*, crust b* ↑crust and crumb a*, crumb b*	-	
Prickly pear seed peels	Gluten-free bread	2.5, 5, 7.5	↑[1]K, [4]χ2 ↓[2]n, [3]r	↑[9]WL, [10]Vsp, pH and moisture	-	↓crust and crumb L* and b* ↑crust and crumb a*	-	
Apple pomace, Indian gooseberry pomace, potato peels and bottle gourd peels	Bread	4, 5, 8, 10, 12, 15, 16, 20, 25	-	-	-	↓L* ↑a*, b*	-	Upadhyay et al. (2023)
Banana peel	Bagels	10	-	-	↑hardness and cohesiveness ↓gumminess and springiness	↓L*, b* ↑a*	↑odour, taste and overall acceptability ↓crust colour and mastication	Manzoor et al. (2024)
Pumpkin peel	Biscuits	5, 10, 15	↑[5]WA, [6]DDT ↓[7]DS, [8]MTI, mixing time, peak height and spread factor	↓width ↑thickness	-	-	-	Hussain et al. (2023)
Banana peel	Bread	10	-	-	-	-	↓appearance, colour, texture	Segura-Badilla et al. (2022)
	Biscuits	10, 20	-	-	-	-	↓appearance, flavour, colour, smell and texture	

[1]K: consistency coefficient; [2]n: flow behaviour index; [3]r: statistical correlation coefficient; [4]χ2: chi-square; [5]WA: water absorption; [6]DDT: dough development time; [7]DS: dough stability; [8]MTI: mixing tolerance index; [9]WL: weight loss; [10]Vsp: specific volume;

The Influence of Fruit, Vegetable and Legumes Pomace on Bakery Products

The compositions of bakery products enhanced with potential functional components derived from various horticultural pomaces are summarized in Tables 4 and 5.

Variation of the total phenolic content, chemical composition and mineral content

The incorporation of horticultural by-product pomaces in bakery products, such as cakes, bread, and cookies, has been found to have various effects on their nutritional composition. Compared to control samples, cakes containing tomato, apple, and bread with apple and Indian gooseberry pomaces exhibited 40%, 52%, and 550% higher phenolic content, respectively (Bhat et al., 2022; Sudha et al., 2007; Upadhyay et al., 2023).

The addition of HBP pomaces to cakes and biscuits resulted in a decrease in protein content of up to 70% %. (Bhat et al., 2022; Jose et al., 2022; Ojeda et al., 2023; Sudha et al., 2007; Upadhyay et al., 2023). Oppositely, the inclusion of mushroom powder increased protein levels by 1 to 22% in comparison to control samples (Lu et al., 2018). Cookies enriched with pineapple pomace had higher protein content, while cakes with tomato and apple pomace presented lower protein levels. The TDF content increased significantly, ranging from 1.3 to 30 times, in bakery products formulated with HBP pomaces. Furthermore, higher ash and carbohydrate levels were observed in cookies with pineapple pomace and cakes with apple pomace (Jose et al., 2022; Sudha et al., 2007; Upadhyay et al., 2023). The effect on fat content varied, with cakes and bread containing tomato, apple, and Indian gooseberry pomaces exhibiting higher fat values compared to controls, while biscuits with pineapple pomace had lower fat content. However, none of the bakery products with fat content higher than 7 g kg^{-1} qualified for the “low fat” (<3 g fat kg^{-1} food product) and “fat-free” (<0.5 g fat kg^{-1} food product) nutrition claims (Regulation (EC) No. 1924/2006), except for the bread with apple and Indian gooseberry pomace, which could be classified as "low fat."

The reviewed studies did not report the influence of HBP pomace addition on the mineral content of the bakery products.

Table 4. Nutritional composition of bakery products with horticultural pomaces incorporated in bakery products

HBP	Bakery product	% added	TPC	Moisture	Protein	Fat	Ash	TDF	Energy value (Kcal/100 g)	Carbohydrate	Macrominerals			Microminerals					Reference
											Ca	Mg	Na	K	Fe	Mn	Zn	Cu	
Papaya seeds	Cupcakes	5, 10, 15, 20		20.09 - 21.56 (22.58)	13.40 - 18.55 (11.73)	20.69 - 21.07 (20.42)	3.09 - 4.65 (2.55)	1.44 - 4.22 (0.61)	389.51 - 399.15 (399.18)	-	-	-	-	-	-	-	-	-	Abdel-Hameed et al. (2023)
Pineapple pomace	Cookies with 400–251μm powder	5, 10, 15	-	3.26 - 3.49 (3.13)	11.88 - 11.19 (12.96)	18.50 - 15.33 (19.77)	1.70 - 1.76 (1.70)	2.09 - 2.22 (1.72)	-	62.45 - 66.20 (60.86)	-	-	-	-	-	-	-	-	Jose et al. (2022)
	Cookies with 250–150μm powder	5, 10, 15	-	3.12 - 3.40 (3.13)	12.09 - 11.59 (12.96)	18.37 - 16.23 (19.77)	1.72 - 1.75 (1.70)	2.02 - 2.32 (1.72)	-	62.57 - 64.57 (60.86)	-	-	-	-	-	-	-	-	
	Cookies with ≤ 149μm powder	5, 10, 15	-	3.29 - 3.58 (3.13)	11.22 - 10.94 (12.96)	18.35 - 16.32 (19.77)	1.72 - 1.75 (1.70)	2.23 - 2.45 (1.72)	-	63.68 - 65.04 (60.86)	-	-	-	-	-	-	-	-	
Shiitake mushroom	Sorghum biscuits	5, 10, 15	-	6.75 - 6.76 (5.66)	7.76 - 8.84 (7.21)	-	-	-	-	-	-	-	-	-	-	-	-	-	Lu et al. (2018)
Black ear mushroom	Sorghum biscuits	5, 10, 15	-	5.72 - 6.43 (5.66)	7.28 - 7.38 (7.21)	-	-	-	-	-	-	-	-	-	-	-	-	-	
Silver ear mushroom	Sorghum biscuits	5, 10, 15	-	5.71 - 6.24 (5.66)	7.20 - 7.33 (7.21)	-	-	-	-	-	-	-	-	-	-	-	-	-	
Vinal (Neltuma ruscifolia) residue	Bread	5	-	8.90	10.20	2.40	4.50	21.20	-	53.00	-	-	-	-	-	-	-	-	Ojeda et al. (2023)
Apple pomace	Cake	25	3.15 (2.07)	21.8 (20.9)	8.46 (8.5)	20.5 (19.3)		14.20 (0.47)	-	-	-	-	-	-	-	-	-	-	Sudha et al. (2007)
Apple and Indian gooseberry pomace, potato and bottle gourd peels	Bread	4, 5, 8, 10, 12, 15, 16, 20, 25	11.89 - 14.48 (2.23)	12.246 - 9.38 (12.2)	2.57 -3.16 (10.79)	1.5 - 3.15 (1.74)	2.58 - 4.67 (0.50)	6.26 - 8.28 (3.16)	255.2 - 365.46 (303.04)	54.32 - 70.36 (65.41)		-	-	-	-	-	-	-	Upadhyay et al. (2023)

Variation of colour analysis, rheological, physical, textural and sensorial properties

A darker colour is commonly observed in bakery products formulated with HBP pomaces, while cookies with pineapple pomace and silver ear mushroom had a higher L* value. This can be attributed to Maillard and caramelization reactions, as well as the original colour of the HBP. Differences in a* and b* values were likely related to the original HBP colour (Bhat et al., 2022; Djeghim et al., 2021; Din et al., 2024; Upadhyay et al., 2023).

Dough rheology changes in enriched bakery products are shown in Table 5. Biscuits enriched with pumpkin pomace had increased WA and DDT, but decreased dough stability (DS). The opposite was true for light-grain rye semi-finished products enriched with apple and pumpkin pomace, where WA decreased (Hussain et al., 2023; Sadygova et al., 2021). Changes in dough WA can be linked to protein content, dietary fiber structure, molecular interactions, particle size, and fiber porosity. The impact of HBP pomaces on starch pasting properties, such as peak viscosity (PV), though viscosity (TV), final viscosity (FV), setback viscosity (SV) and breakdown viscosity (BV), as well as pasting time and temperature, also varied in cookies with pineapple pomace and sorghum biscuits with mushrooms. These properties increased in products enriched with pumpkin pomace and decreased with shiitake mushroom addition (Jose et al., 2022; Lu et al., 2018).

Physical characteristics, such as volume and specific volume (Vsp), increased for enriched gluten-free bread with apple and orange pomace, except for tomato pomace and cake with apple pomace (Djeghim et al., 2021; Sudha et al., 2007). Other physical properties, like weight, frequently increased, while thickness and diameter decreased (Jose et al., 2022; Lu et al., 2018; Hussain et al., 2023).

As shown in Table 5, a consistent increase was observed for hardness/firmness, fracturability, chewiness, and gumminess, with a decrease in cohesiveness (Jose et al., 2022; Upadhyay et al., 2023; Mildner-Szkudlar et al., 2016; Lu et al., 2018).

Regarding sensory analysis, scores for flavour, taste, texture, and overall acceptability usually decreased with increasing addition of HBP pomaces to bakery formulations. However, some formulations showed better scores for these characteristics (Bhat et al., 2022; Sudha et al., 2007; Ojeda et al., 2023; Upadhyay et al., 2023).

Based on the analysis of various parameters, especially sensory analysis, the highest incorporation of HBP pomaces in bakery products like cakes, biscuits, muffins, and bread without significant overall differences was often 5 and 10%, with the maximum addition at 30% and minimum at 2.5%.

Table 5. Influence of potential functional ingredients obtained from horticultural pomaces on dough and final bakery product properties

HBP	Bakery product	% added	Dough rheological properties	Bakery products properties			Sensorial analysis	Reference
				Physical properties	Textural properties	Colour		
Tomato pomace	Cakes	2, 4	-	-	-	↑crust L*, crust and crumb a*, crumb b* ↓crumb L*, crust b*	↑appearance and texture ↓flavour, Aftertaste and overall acceptability	Bhat et al. (2022)
Orange pomace	Gluten-free bread	2.5, 5, 7.5	↓[1]K, [2]χ2, [3]n ↑[4]r	↑[20]WL, [21]Vsp ↓pH, moisture	-	↓crust and crumb L* ↑crust and crumb a* and b*	-	Djeghim et al. (2021)
Apple pomace	Gluten-free bread	2.5, 5, 7.5	↑[2]χ2 ↓[1]K, [3]n, [4]r	↑[20]WL, [21]Vsp, moisture ↓pH	-	↓crust and crumb L* and b* ↑crust and crumb a*	-	
Tomato pomace	Gluten-free bread	2.5, 5, 7.5	↓[1]K, [2]χ2 ↑[3]n, [4]r	↓[20]WL, [21]Vsp ↑pH, moisture	-	↑crust and crumb L* and b*, crumb a* ↓crust a*	-	
Pineapple pomace	Cookies with 400–251µm powder	5, 10, 15	↓[5]PV, [6]TV, [7]BV, [8]FV, [9]SV, [10]WSI, [11]SP ↑[12]WA, [13]OA, [14]PT and pasting time	↓thickness and diameter ↑aw, spread ratio and weight	↓hardness and fracturability	↑L*, b* ↓a*	-	Jose et al. (2022)
	Cookies with 250–150µm powder	5, 10, 15	↓[5]PV, [6]TV, [7]BV, [8]FV, [9]SV, [10]WSI, [11]SP ↑[12]WA, [13]OA, [14]PT and pasting time	↓spread ratio and diameter ↑aw, thickness, weight	↓hardness ↑fracturability	↑L* ↓a*, b*	-	
	Cookies with ≤ 149µm powder	5, 10, 15	↓[5]PV, [6]TV, [7]BV, [8]FV, [9]SV, [10]WSI, [11]SP ↑[12]WA, [13]OA, [14]PT and pasting time	↓thickness, diameter and weight ↑aw and spread ratio	↓hardness ↑fracturability	↓L* ↑a*, b*	-	
Apple and Indian gooseberry pomace, potato peels and bottle gourd peels	Bread	4, 5, 8, 10, 12, 15, 16, 20, 25	↑[11]SP, [15]EC, [16]FC	↑weight ↓volume and [14]Vsp	↑hardness ↓cohesiveness	↓L* ↑a*, b*	↑colour, texture, flavour, appearance and overall acceptability	Upadhyay et al. (2023)
Apple pomace	Cake	10, 20, 30	-	↓volume and weight ↑ρ and texture	-	-	↓crust and crumb colour, crumb grain, crumb texture, eating quality and overall acceptability	Sudha et al. (2007)
Raspberry pomace	Muffins baked at 140 °C/30min	10, 20	-	-	↑hardness and cohesiveness ↓gumminess and chewiness	-	-	Mildner-Szkudlarz et al. (2016)
	Muffins baked at 180 °C/20min	10, 20	-	-	↑hardness, cohesiveness, gumminess and chewiness	-	-	
	Muffins baked at 240 °C/15min	10, 20	-	-	↑hardness, cohesiveness, gumminess and chewiness	-	-	
Cranberry pomace	Muffins baked at 140 °C/30min	10, 20	-	-	↑hardness, gumminess and chewiness ↓cohesiveness	-	-	
	Muffins baked at 180 °C/20min	10, 20	-	-	↑hardness, gumminess and chewiness ↓cohesiveness	-	-	
	Muffins baked at 240 °C/15min	10, 20	-	-	↑hardness, gumminess and chewiness ↓cohesiveness	-	-	
Apple pomace	Light-grain rye semi-finished product	15	↓[12]WA, kneading and gluten ↑viscosity, amylase and retrogradation	-	-	-	-	Sadygova et al. (2021)
Pumpkin pomace	Light-grain rye semi-finished product	15	↓[12]WA, kneading and gluten ↑viscosity, amylase and retrogradation	-	-	-	-	
Shiitake mushroom	Sorghum biscuits	5, 10, 15	↑[5]PV and [7]BV ↓[6]TV, [8]FV, [9]SV and [14]PT	↓diameter, thickness and [13]WL ↑weight	↑hardness	↓L*, b*, chroma, hue-angle ↑a*	-	Lu et al. (2018)
Black ear mushroom	Sorghum biscuits	5, 10, 15	↑[5]PV, [6]TV, [7]BV, [8]FV and [9]SV ↓[14]PT	↓diameter, thickness and [13]WL ↑weight	↑hardness	↓L*, a*, b*, chroma, hue-angle	-	
Silver ear mushroom	Sorghum biscuits	5, 10, 15	↑[5]PV, [6]TV, [7]BV, [8]FV and [9]SV ↓[14]PT	↓diameter and thickness ↑weight and [13]WL	↑hardness	↑L*, a*, b*, chroma, hue-angle	-	
Vinal (Neltuma ruscifolia) residue	Bread	5	-	-	-	-	↑colour, odour, texture and overall acceptability	Ojeda et al. (2023)
Pumpkin pomace	Biscuits	5, 10, 15	↑[12]WA, [17]DDT ↓[18]DS, [19]MTI, mixing time, peak height and spread factor	↓width ↑thickness	-	-	-	Hussain et al. (2023)

[1]K: consistency coefficient; [2]χ2: chi-square; [3]n: flow behaviour index; [4]r: statistical correlation coefficient; [5]PV: peak viscosity; [6]TV: trough viscosity; [7]FV: final viscosity; [8]BV: breakdown viscosity; [9]SV: setback viscosity; [10]WSI: water solubility index; [11]SP: swelling power; [12]WA: water absorption; [13]OA: oil absorption; [14]PT: pasting temperature; [15]EC: emulsion capacity; [16]FC: foaming capacity; [17]DDT: dough development time; [18]DS: dough stability; [19]MTI: mixing tolerance index; [20]WL: weight loss; [21]Vsp: specific volume.

The Influence of Fruit, Vegetable and Legumes Seeds on Bakery Products

The nutritional profile of bakery goods fortified with potentially functional ingredients derived from seeds is summarized in Tables 6 and 7.

Variation of the total phenolic content, chemical composition and mineral content

Higher phenolic content values, compared to the control samples, were found in cookies and pita bread containing pumpkin seeds had 11% and 6%, respectively. However, pan bread with yellow pumpkin seeds recorded a 10% decrease in phenolic content (Weldeyohanis Gebremariam et al., 2024; Aljahani, 2022).

Compared to the control samples, protein content increased between 7% and 98% in formulations with papaya seeds, pumpkin seeds, amaranth seeds, and vinal seeds. A small 0.3% protein reduction was reported for pita bread with yellow pumpkin seed addition. Overall, pumpkin seeds and vinal seeds had higher protein content, while amaranth seeds had lower protein content (Abdel-Hameed et al., 2023; Weldeyohanis Gebremariam et al., 2024; Aljahani, 2022; Apostol et al., 2020; Bojňanská et al., 2024; Matseychik et al., 2021; Ojeda et al., 2023).

The incorporation of HBP seeds increased the TDF content from 159% to 591% in all bakery products. Compared to the control samples, the addition of seeds raised the fat concentration from 1% to 12%, while pomegranate peel reduced the fat concentration with 3-153%. The fat content can be used to determine eligibility for the "low fat" and "fat-free" nutrition claims (Regulation (EC) No. 1924/2006). Therefore, the pita bread with yellow pumpkin seeds qualifies for the "fat-free" nutrition claim, while the breads with pumpkin seeds and vinal endocarp are "low fat" (Abdel-Hameed et al., 2023; Weldeyohanis Gebremariam et al., 2024; Aljahani, 2022; Apostol et al., 2020).

Cookies and bread enriched with pumpkin seeds reported increased mineral content compared to the control samples (Weldeyohanis Gebremariam et al., 2024; Apostol et al., 2020).

Table 6. Nutritional composition of bakery products with horticultural seeds incorporated in bakery products

HBP	Bakery product	% added	TPC	Moisture	Protein	Fat	Ash	TDF	Energy value (Kcal/100 g)	Carbohydrate	Macrominerals			Microminerals					Reference
											Ca	Mg	Na	K	Fe	Mn	Zn	Cu	
Papaya seeds	Cupcakes	5, 10, 15, 20		20.09 - 21.56 (22.58)	13.40 - 18.55 (11.73)	20.69 - 21.07 (20.42)	3.09 - 4.65 (2.55)	1.44 - 4.22 (0.61)	389.51 - 399.15 (399.18)	-	-	-	-	-	-	-	-	-	Abdel-Hameed et al. (2023)
Pumpkin seeds	Cookies	6, 10.5, 15	43.19 (38.72)	2.52 (3.05)	14.28 (11.49)	17.73 (13.99)	2.16 (1.77)	2.41 (0.93)	469.81 (452.00)	-	46.25 (32.23)	51.33 (40.12)	-	-	3.20 (2.12)	-	2.63 (1.42)	-	Weldeyohanis Gebremariam et al. (2024)
Yellow pumpkin seeds	Pan bread	5, 10, 15	5.21 - 5.37 (5.95)	8.04 - 8.27 (8.42)	11.15 - 11.41 (10.60)	2.44 - 3.12 (2.17)	2.89 - 3.48 (2.72)	-	-	75.14 - 74.21 (76.08)	-	-	-	-	-	-	-	-	Aljahani (2022)
	Pita bread		5.21 - 5.30 (5.01)	7.69 - 9.51 (8.25)	10.33 - 10.81 (10.84)	0.20 - 0.27 (0.18)	1.91 - 2.41 (1.68)	-	-	77.86 - 79.29 (79.05)	-	-	-	-	-	-	-	-	
Pumpkin seeds	Wheat flour and dough	5, 10, 15	-	-	15.35 - 18.65 (13.70)	1.66 - 2.79 (1.10)	0.90 - 1.59 (0.55)	3.18 - 5.74 (1.90)	-	82.09 - 76.97 (84.65)	58.41 - 87.83 (43.70)	69.77 - 113.9 (47.70)	28.22 - 29.81 (30.60)	239.4 - 344.2 (187)	4.42 - 11.05 (1.10)	1.27 - 2.68 (0.56)	5.65 - 6.03 (5.45)	0.85 - 0.98 (0.78)	Apostol et al. (2020)
Amaranth seeds	Bread	5, 10, 15	-	11.8 - 11.9 (11.9)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Bojňanská et al. (2024)
Amaranth seeds	Rolls	-	-	40.3 - 36.4 (36.0)	13.2 - 12.1 (6.1)	-	3.04 - 2.6 (1.5)	-	119.0 - 118.0 (140.0)	-	-	-	-	-	-	-	-	-	Matseychik et al. (2021)
Vinal (Neltuma ruscifolia) seeds	Bread	5	-	5.90	30.60	4.60	3.20	20.90	-	35.00	-	-	-	-	-	-	-	-	Ojeda et al. (2023)
Vinal (Neltuma ruscifolia) endocarp	Bread	5	-	8.90	11.80	2.10	3.90	38.60	-	35.00	-	-	-	-	-	-	-	-	

Variation of colour analysis, rheological, physical, textural and sensorial properties

A decrease in crust and crumb L* value is typically observed in bread and cupcake formulations containing pumpkin and papaya seeds, respectively. This can be attributed to Maillard and caramelization reactions, as well as the original colour of the horticultural by-products, leading to a darker appearance and differences in a* and b* values (Abdel-Hameed et al., 2023; Aljahani, 2022).

The effects of HBP seeds on dough rheology in enriched bakery products are summarized in Table 7. Water absorption increases with the addition of HBP seeds, except for dough with pumpkin seeds. The influence of HBP seeds on dough development time, dough stability, and mixing tolerance index varies depending on the type and concentration of seeds used, but generally increases (Bojňanská et al., 2024; Hussain et al., 2023; Apostol et al., 2020).

Physical characteristics such as volume, specific volume, thickness, and diameter are affected by the addition of HBP seeds. These changes can be related to the gluten and TDF content and structure (Matseychik et al., 2021; Abdel-Hameed et al., 2023; Aljahani, 2022; Hussain et al., 2023).

Scarce data is available on textural parameters, but an increase in cohesiveness and springiness, as well as a decrease in hardness, adhesiveness, and gumminess, have been reported with the addition of yellow pumpkin seeds to pan and pita bread (Aljahani, 2022).

Sensory analysis often shows that the addition of HBP seeds to bakery formulations decreases scores related to aroma, flavour, taste, colour, and texture. However, in the bread formulation with vinal endocarp addition, there is no significant difference or a slight increase in the scores for these sensory attributes (Abdel-Hameed et al., 2023; Aljahani, 2022; Ojeda et al., 2023).

Based on the information gathered from all the analyzed parameters, the highest incorporation of HBP seeds in bakery products without significant overall differences is frequently 5%. The maximum addition value possible is 20%, while the minimum is 5%.

Table 7. Influence of potential functional ingredients obtained from horticultural seeds on dough and final bakery product properties

HBP	Bakery product	% added	Dough rheological properties	Bakery products properties			Sensorial analysis	Reference
				Physical properties	Textural properties	Colour		
Amaranth seeds	Rolls	5, 10, 15	-	↑humidity, porosity, acidity	-	-	-	Matseychik et al. (2021)
Amaranth seeds	Bread	5, 10, 15	↑[1]WA, [2]DDT, [3]DS ↓consistency	-	-	-	-	Bojňanská et al. (2024)
Papaya seeds	Cupcakes	5, 10, 15, 20	-	↑height and weight before and after baking, volume and [4]Vsp	-	↓crust and crumb L*, b* and chroma, crumb a* ↑crust a*, crust and crumb ΔE and hue angle	↓aroma, flavour, Aftertaste and overall acceptability	Abdel-Hameed et al. (2023)
Yellow pumpkin seeds	Flour and dough	5, 10, 15	↓[5]PV, [6]BV, [7]FV, [8]SV and [9]PT	-	-	-	-	Aljahani (2022)
	Pan bread	5, 10, 15	-	↑weight and aw ↓volume and [4]Vsp	↓hardness, adhesiveness and gumminess ↑cohesiveness and springiness	↓crust and crumb L* ↑crust and crumb a* and b*	↓crust colour, symmetry, break and shred, crumb colour, grain and texture, flavour and overall acceptability	
	Pita bread		-	↑weight and aw ↓volume and [4]Vsp	↓hardness, adhesiveness and gumminess ↑cohesiveness and springiness	↓crust L* ↑crumb L*, crust and crumb a* and b*	↓crust colour, symmetry, break and shred, crumb colour, grain and texture, flavour and overall acceptability	
Pumpkin seeds	Biscuits	5, 10, 15	↑[1]WA, [2]DDT ↓[3]DS, [10]MTI, mixing time, peak height and spread factor	↓width ↑thickness	-	-	-	Hussain et al. (2023)
Pumpkin seeds	Wheat flour and dough	5, 10, 15	↓[1]WA ↑[3]DS and amplitude	-	-	-	-	Apostol et al. (2020)
Vinal (Neltuma ruscifolia) seeds	Bread	5	-	-	-	-	↓colour, odour, texture and overall acceptability	Ojeda et al. (2023)
Vinal (Neltuma ruscifolia) endocarp	Bread	5	-	-	-	-	↑colour, odour, texture and overall acceptability	

[1]WA: water absorption; [2]DDT: dough development time; [3]DS: dough stability; [4]Vsp: specific volume; [5]PV: peak viscosity; [6]BV: breakdown viscosity; [7]FV: final viscosity; [8]SV: setback viscosity; [9]PT: pasting temperature; [10]MTI: mixing tolerance index.

The Influence of Petals, Leaves, Stems and Other Floral By-Products on Bakery Products

The composition of bakery products enriched with ingredients from petals, stems, leaves and other floral by-products is summarized in Tables 8 and 9.

Variation of the total phenolic content, chemical composition and mineral content

Higher phenolic content is generally observed in baked goods like cakes, cookies, bread, and muffins that are enriched with by-products from saffron, broccoli, tea, and cauliflower. Compared to control samples, these values increased significantly, from 4% to 197% (Bhat et al., 2022; Bhat et al., 2018; Cerda-Bernad & Frutos, 2023; Drabińska et al., 2018; Koh et al., 2023; Tukassar et al., 2023).

Bhat et al. (2022) also reported a non-significant decrease ($p>0.05$) in TPC of saffron and tomato enriched cakes during a storage period of 0-15 days, possibly due to the by-products' high antioxidant activity. Baking significantly increased TPC of cookies supplemented with saffron stigmas due to the release of bound phenolics and the formation of Malanoidins produced in the Maillard reaction, though a gradual decline was seen over storage, becoming significant after 9 months (Bhat et al., 2018).

In contrast, Drabińska et al. (2018) found no significant impact of thermal processing on TPC or antioxidant activity in gluten-free cakes with broccoli leaves. Similarly, Tukassar et al. (2023) reported that baking caused less nutrient loss than prolonged mixing in cauliflower-enriched muffins and improved phenolic bioavailability by releasing cell wall-bound phenolic compounds.

Protein content also increased, from 1% to 31%, in formulations containing by-products from saffron, tea, banana blossoms, and cauliflower. However, a slight reduction of 0.3% was reported for bread with saffron tepals, and little to no increase was seen in patties with spinach leaves and cookies with tea leaves. Overall, higher protein was found in cakes with banana blossoms, muffins with cauliflower, and bread with vinal pods, while saffron stigmas and tea leaves had lower protein content (Bhat et al., 2022; Bhat et al., 2018; Koh et al., 2023; Ojeda et al., 2023; Sapozhnikov et al., 2019; Tasnim et al., 2020; Tukassar et al., 2023).

The TDF content increased greatly, from 25% to 412%, in baked goods enriched with tea leaves, banana blossoms, and cauliflower by-products (Koh et al., 2023; Tasnim et al., 2020; Tukassar et al., 2023). The incorporation of floral by-products slightly raised fat concentration, from 0.3% to 3%, for saffron, tea, spinach, and banana, while cauliflower increased it by 52%. Conversely, these by-products generally lowered carbohydrate content, from 6% to 20% (Bhat et al., 2022; Bhat et al., 2018; Koh et al., 2023; Ojeda et al., 2023; Sapozhnikov et al., 2019; Tasnim et al., 2020; Tukassar et al., 2023).

Bread with saffron tepals and muffins with cauliflower reported increased mineral content compared to controls. Cake with banana blossoms also had 11% and 122% increases in calcium and iron, respectively (Cerda-Bernad & Frutos, 2023; Tasnim et al., 2020; Tukassar et al., 2023).

Table 8. Nutritional composition of bakery products with horticultural petals, leaves, stems and other floral by-products incorporated in bakery products

HBP	Bakery product	% added	TPC	Moisture	Protein	Fat	Ash	TDF	Energy value (Kcal/100 g)	Carbohydrate	Macrominerals			Microminerals					Reference
											Ca	Mg	Na	1K	Fe	Mn	Zn	Cu	
Saffron stigmas	Cakes	0.05, 0.1	0.66 - 0.75 (0.62)	30.8 - 36.1 (33.4)	6.79 - 6.68 (6.57)	30.15 - 30.21 (30.11)	1.76 - 1.80 (1.77)	-	-	-	-	-	-	-	-	-	-	-	Bhat et al. (2022)
Saffron stigmas	Cookies	0.05, 0.1	0.86 - 0.94 (0.90)	2.29 - 2.37 (2.43)	6.14 - 6.11 (6.13)	27.13 - 27.41 (27.18)	1.91 - 1.92 (1.83)	-	-	-	-	-	-	-	-	-	-	-	Bhat et al. (2018)
Saffron tepals	Wheat bread	2.5, 5, 10	111 - 272 (91.31)	25.47 - 32.44 (31.12)	-	-	2.95 - 3.79 (2.75)	-	-	-	56.18 - 91.63 (39.22)	34.72 - 41.61 (31.21)	713 - 605 (641)	196 - 277 (162)	6.01 - 15.87 (2.01)	1.22 - 1.42 (1.03)	0.97 - 1.03 (0.77)	-	Cerda-Bernad & Frutos (2023)
	Spelt bread	2.5, 5, 10	124 - 261 (102)	29.51- 31.89 (32.71(	-	-	3.37 - 3.95 (3.05)	-	-	-	52.74 - 94.56 (33.47)	34.46 - 48.46 (33.95)	713 - 743 (810)	178 - 289 (153)	6.27 - 17.85 (3.27)	0.91 - 1.37 (0.74)	0.78 - 0.96 (0.71)	-	
Broccoli leaves	Gluten-free mini sponge cakes	2.5, 5, 7.5	0.77 - 0.99 (0.46)	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	Drabińska et al. (2018)
Green tea leaves	Gluten free shortbread cookie	8	80 (30)	2.18 (1.62)	6.88 (6.86)	20.60 (20.17)	2.04 (1.43)	14.47 (7.70)	428.21 (457.84)	53.83 (62.21)	-	-	-	-	-	-	-	-	Koh et al. (2023)
Oolong tea leaves	Gluten free shortbread cookie	8	60 (30)	2.35 (1.62)	6.89 (6.86)	20.80 (20.17)	1.91 (1.43)	14.89 (7.70)	427.36 (457.84)	53.16 (62.21)	-	-	-	-	-	-	-	-	
Black tea leaves	Gluten free shortbread cookie	8	65 (30)	2.19 (1.62)	6.84 (6.86)	20.39 (20.17)	1.96 (1.43)	14.75 (7.70)	426.37 (457.84)	53.87 (62.21)	-	-	-	-	-	-	-	-	
Vinal (Neltuma ruscifolia) pods	Bread	5	-	8.70	12.80	2.40	4.10	31.10		41.00	-	-	-	-	-	-	-	-	Ojeda et al. (2023)
Spinach leaves	Wheat flour roll	4	-	-	6.0 (6.0)	6.2 (6.5)	1.7 (0.97)	-	138 (144)	20.9 (22.3)	-	-	-	-	-	-	-	-	Sapozhnikov et al. (2019)
	Curd patty	4	-	-	12.8 (12.1)	10.0 (9.8)	0.91 (0.75)	-	271 (262)	38.1 (36.8)	-	-	-	-	-	-	-	-	
	Lingonberry patty	4	-	-	6.0 (5.9)	9.2 (9.1)	0.97 (0.63)	-	289 (285)	49.0 (48.7)	-	-	-	-	-	-	-	-	
Banana blossoms	Cake	4, 6, 8	-	16.78 - 20.31 (14.32)	9.10 - 11.20 (8.53)	22.70 - 23.95 (22.10)	1.46 - 1.89 (1.23)	3.10 - 3.45 (2.75)	440.54 - 430.99 (448.30)	49.96 - 42.66 (53.82)	160.2 - 168.5 (151.5)	-	-	-	21.50 - 33.30 (15.0)	-	-	-	Tasnim et al. (2020)
Cauliflower stems, stalks and leaves	Muffins	10, 20, 30	282.40 - 561.20 (193.10)	26.13 - 23.91 (27.26)	8.93 - 9.70 (7.53)	6.55 - 6.82 (6.44)	2.01 - 2.38 (1.83)	1.17 - 3.74 (0.73)	126 - 106 (134)	55.23 - 53.46 (56.24)	189.69 - 244.56 (171.47)	53.94 - 61.19 (51.35)	119.51 - 167.76 (108.19)	-	2.66 - 6.56 (1.66)	-	1.29 - 1.58 (1.19)	0.68 - 1.99 (0.26)	Tukassar et al. (2023)

Variation of colour analysis, rheological, physical, textural and sensorial properties

Crust and crumb L* generally decreased with the addition of floral by-products. This is due to Maillard and caramelization reactions, as well as the original colour of the horticultural by-products. The original colour of the by-product also explains the differences in a* and b* values (Bhat et al., 2022; Bhat et al., 2018; Cerda-Bernad & Frutos, 2023; Koh et al., 2023; Tasnim et al., 2020; Tukassar et al., 2023).

Data on dough rheology changes in bakery products enriched with floral by-products is limited. The pasting properties PV, BV, FV and SV increased with the addition of cauliflower stems, stalks, and leaves to muffins compared to control samples, while trough viscosity, peak time, and pasting temperature decreased (Tukassar et al., 2023).

Physical characteristics like Vsp, spread factor, density, thickness, and diameter are affected by the addition of floral by-products. Changes in these parameters can be attributed to gluten, TDF content and the structure of the respective HBP (Bhat et al., 2018; Rizi et al., 2024; Chaalal et al., 2023; Koh et al., 2023; Tasnim et al., 2020; Tukassar et al., 2023).

Textural data shows an increase in hardness, firmness, gumminess, and chewiness, while cohesiveness and springiness generally decrease with the addition of floral by-products (Bhat et al., 2018; Cerda-Bernad & Frutos, 2023; Rizi et al., 2024; Koh et al., 2023; Tasnim et al., 2020; Tukassar et al., 2023).

Sensory analysis indicates that the addition of floral by-products such as leaves, petals, stems, and stalks to bakery formulations usually decreases scores for aroma, flavour, taste, and texture. However, in many formulations, the scores for colour, odour, appearance, and even aroma, taste, and texture show a significant increase compared to control samples (Bhat et al., 2022; Bhat et al., 2018; Cerda-Bernad & Frutos, 2023; Rizi et al., 2024; Chaalal et al., 2023; Koh et al., 2023; Tasnim et al., 2020; Tukassar et al., 2023; Ojeda et al., 2023; Sapozhnikov et al., 2019). These scores suggest that bakery formulations with floral by-products are generally better accepted by consumers than those with peels, skins, pomaces, or seeds.

Based on the analysis of various parameters, especially sensory analysis, the highest incorporation of floral by-products in bakery formulations without significant overall differences is frequently 4-5%. The maximum addition value possible is 30%, while the minimum is 0.05%.

Table 9. Influence of potential functional ingredients obtained from horticultural petals, leaves, stems and other floral by-products on dough and final bakery product properties

HBP	Bakery products	% added	Dough rheological properties	Bakery products properties			Sensorial analysis	References
				Physical properties	Textural properties	Colour		
Saffron stigmas	Cakes	0.05, 0.1	-	-	-	↓crust and crumb L* ↑crust and crumb a* and b*	↑appearance and texture ↓flavour, Aftertaste and overall acceptability	Bhat et al. (2022)
Saffron stigmas	Cookies	0.05, 0.1	-	↓weight, diameter and spread ratio ↑thickness	↓hardness	↑L*, b* ↓a*	↓texture ↑appearance, mouth feel, flavour and overall acceptability	Bhat et al. (2018)
Saffron tepals	Wheat bread	2.5, 5, 10	-	-	↑hardness, gumminess and chewiness ↓cohesiveness and springiness	↓crust and crumb L* and a*, crust b* ↑crumb b*	↑evenness colour of crust, sweetness, flower-ID, floral-herbaceous taste, sourness astringency, bitterness, aftertaste, hardness, cohesiveness, adhesiveness, stickiness ↓crispiness, saltiness	Cerda-Bernad & Frutos (2023)
	Spelt bread	2.5, 5, 10	-	-	↑hardness, gumminess and chewiness ↓cohesiveness and springiness	↓crust and crumb L*, crust a* and b* ↑crumb a* and b*	-	
Saffron petals	Mung bean sourdough bread	10	-	↑porosity ↓pH	↓hardness, gumminess ↑resilience and cohesiveness	-	↑aroma and taste ↓chew-ability, colour, mouth feel and overall acceptability	Rizi et al. (2024)
Saffron stigmas	Biscuits	0.1	-	↓humidity, pH ↑acidity			↑colour, odour, taste, texture, aspect and overall acceptability	Chaalal et al. (2023)
Green tea leaves	Gluten free shortbread cookie	8	-	↓ρ, pH ↑spread factor, loss rate and aw	↑hardness	↓L*, a*, b*	↑appearance, taste, smell, texture and overall acceptability	Koh et al. (2023)
Oolong tea leaves	Gluten free shortbread cookie	8	-	↓ρ, pH ↑spread factor, loss rate and aw	↑hardness	↓L*, a*, b*	↓appearance, taste, smell, texture and overall acceptability	
Black tea leaves	Gluten free shortbread cookie	8	-	↓ρ, pH ↑spread factor, loss rate and aw	↑hardness	↓L*, a*, b*	↓appearance, taste, smell, texture and overall acceptability	
Banana blossoms	Cake	4, 6, 8	↑[1]WA, [2]OA, [3]FC ↓[4]SP	↓ρ ↑solubility	↑hardness, gumminess and resilience ↓cohesiveness, springiness and chewiness	↓L*, b* ↑a*	↓colour, flavour, texture and overall acceptability	Tasnim et al. (2020)
Cauliflower stems, stalks and leaves	Muffins	10, 20, 30	↑[6]PV, [7]BV, [8]FV, [9]SV ↓[10]TV, peak time and [11]PT	↓[5]Vsp	↑hardness and chewiness ↓cohesiveness and springiness	↓L*, b* ↑a*, ΔE*	↓appearance, taste, aroma, texture, softness, palatability, colour and overall acceptability	Tukassar et al. (2023)
Vinal (Neltuma ruscifolia) pods	Bread	5	-	-	-	-	↑colour, odour, texture and overall acceptability	Ojeda et al. (2023)
Spinach leaves	Wheat flour roll	4	-	-	-	-	↓scent and taste ↑consistency	Sapozhnikov et al. (2019)
	Curd patty	4	-	-	-	-	↓scent ↑taste and colour	
	Lingonberry patty	4	-	-	-	-	↑appearance, colour and consistency ↓taste	

[1]WA: water absorption; [2]OA: oil absorption; [3]FC: foaming capacity; [4]SP: swelling power; [5]Vsp: specific volume; [6]PV: peak viscosity; [7]BV: breakdown viscosity; [8]FV: final viscosity; [9]SV: setback viscosity; [10]TV: trough viscosity; [11]PT: pasting temperature

CONCLUSIONS

The exploration of horticultural by-products as valuable sources of functional ingredients in bakery products has been extensively researched. Fruit and vegetable by-products, which constitute a significant portion of food waste, are studied for their potential to enhance baked goods quality. By-products are commonly processed into powders or flours, which are easily integrated into bakery formulations.

Research shows increasing inclusion of these powders correlates positively with higher phenolic content and antioxidant capacity in bakery products. These bioactive compounds have potential health benefits.

Understanding sensory attributes and ensuring safety are crucial for consumer acceptance and market success. Comprehensive investigations into their phenolic profile, chemical and mineral content, as well as sensory, textural and rheological properties will provide insights to optimize formulations, meet consumer preferences, ensure product safety, and leverage the potential of horticultural by-products for human health and sustainable food systems.

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