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Enhancement of functionality and quality of bakery products using oleaster (*Elaeagnus angustifolia* L.) fruit as a source of bioactive compounds: A review

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Abstract
As consumers become more health-aware, researchers are innovating with new products and reformulating traditional items. As staple and affordable foods, bakery products serve as ideal carriers for bioactive compounds that can promote health and prevent diseases. Thus, manufacturers are fortifying bread and bakery products by incorporating various beneficial components. Oleaster is a highly nutritious fruit renowned for its potent antimicrobial and antioxidant properties. Its rich bioactive profile and essential nutrients make it an excellent candidate for enhancing bakery products. The fruit contains a diverse array of beneficial bioactive compounds, including flavonoids, terpenoids, phenolic acids, glycosidic compounds, gallic acid, and ascorbic acid (vitamin C). Additionally, it provides essential fatty acids, organic acids, and vital minerals such as potassium, magnesium, sodium, iron, calcium, zinc, and copper, which support various physiological functions. Due to its floury texture, unique taste, and functional properties including high dietary fiber content, minerals, phenolic compounds, and antioxidant activity, oleaster can serve a functional purpose in the creation of baked goods. The incorporation of oleaster into bakery products can confer numerous health benefits, such as increased antioxidant capacity, anti-inflammatory effects, lowering glycemic index, improved nutritional value, and improve shelf life which is fully discussed comprehensively in this review.
Keywords: Antioxidant properties, bakery products, fiber, functional food, Oleaster fruit

1. Introduction

Cereal-based products are indeed essential components of diets worldwide, offering convenience, taste, and nutritional value. They serve as a primary source of energy, providing carbohydrates and proteins, along with essential B vitamins and minerals that support overall health. However, the nutritional quality of these products can be affected by processing methods. When formulated with refined flours, many beneficial phytochemicals, such as phenolic compounds known for their antioxidant properties, are often reduced or lost during grain processing. This highlights the importance of incorporating whole grains or minimally processed cereals into diets to preserve these valuable bioactive compounds and maximize health benefits [1]. One effective approach is to partially or completely substitute wheat flour (WF) with alternative flours or ingredients to enhance the nutritional value. This is especially relevant for products where WF is a primary component, such as refined (low-extraction) WF. Refined WF is characterized by its low content of dietary fiber, protein, minerals, and bioactive compounds. Moreover, the proteins in WF are incomplete—they lack certain essential amino acids like lysine—reducing their overall digestibility and nutritional quality. Wheat bread remains a staple food with an average per capita consumption of approximately 250 grams daily. It provides a significant energy source because of its high carbohydrate content (70–80% on a dry matter basis) and contributes protein (10–14%) and minerals (0.5–0.8%) [2, 3]. Despite its nutritional benefits, white wheat bread's dietary fiber content is relatively low, around 2–3%, which limits its contribution to dietary fiber intake. Incorporating alternative ingredients or modifying the formulation by replacing part of the WF can address these nutritional limitations—such as increasing dietary fiber, improving protein quality, and enhancing mineral content—thereby making bread a more nutritious component of the diet [4]. Dietary fibers are polysaccharides that human digestive enzymes cannot hydrolyze, leading them to undergo bacterial fermentation in the gastrointestinal tract, which positively influences the intestinal microflora [5]. White bread typically is also known for high calories and glycemic index; therefore, excessive consumption may contribute to health issues such as obesity and diabetes. To address this, various approaches have been explored in bread-making, including the addition of dietary fibers and diverse protein sources derived from cereals, tubers, corn gluten, corn germ, and rice bran to produce functional breads [6, 7]. Functional foods serve not only to alleviate consumer hunger and meet nutritional needs by providing essential nutrients but also to prevent nutrient deficiencies [6]. In response to the growing demand for healthier food options, the use of functional additives has increased to enhance the functionality and nutritional properties of foods [8]. Many plants contain antioxidant and nutritional compounds that are suitable options for the production of functional foods. For example, previous studies indicated the antioxidant properties of date pulp extract [9, 10], fennel extract [11], green walnut peel extract [12], potato peel extract [13], and essential oils [14, 15] in food products. Over recent years there has been a growing trend to fortify bread by incorporating fruits and vegetables, legumes, and pseudo-cereals such as chia, amaranth, quinoa, and buckwheat. Legumes are particularly attractive because of their high protein and fiber content, as well as vitamins and minerals. Among the fruits used, citrus and berries are notable for their high contents of ascorbic acid, flavonoids, and anthocyanins. Adding these ingredients can enhance the nutritional value and antioxidant capacity of bread, but may also affect dough rheology, gas retention, crumb structure, flavor, and shelf-life. Considerations include anti-nutritional factors in legumes, potential gluten-network disruption with some ingredients, and consumer acceptance. Optimizing inclusion levels and processing conditions is key to balancing nutrition, texture, and sensory properties [16]. Mandache et al. [17] investigated the influence of adding apple, sour cherry, and peach pomace at levels of 5%, 10%, and 15% on the bioactive compound content and antioxidant activity of bakery products. Their results showed that breads containing the highest substitution level (15%) of peach pomace had the greatest amounts of polyphenols (855.10 mg GAE/100 g), flavonoids (181.01 mg CE/100 g), and tannins (385.26 mg GAE/100 g). These breads also exhibited the strongest antiradical activity (42.84%). In another study Ho et al. [18] compared commercial bread, bread containing 10% banana pseudo-stem flour, along with xanthan gum and sodium carboxymethylcellulose. They found that breads with banana pseudo-stem flour possessed greater total phenolic compounds (TPC) and antioxidant activity than the control bread. However, substituting banana pseudo-stem flour for part of the WF reduced the bread's physical quality. The addition of sodium carboxymethyl cellulose with xanthan gum improved loaf height and volume, partially offsetting the negative textural effects of the substitution. Apple skin, a by-product of apple juice, pie, and jam production, shows potential as a natural antioxidant source for bakery products such as cakes, muffins, and breads, as demonstrated by Rupasinghe et al. [19]; thus it could enhance the antioxidant properties of these products. Green tea extract (GTE) contains polyphenols, which are natural antioxidants. Recently, GTE has been used as an active ingredient across a wide range of applications in the food, nutraceutical, and cosmeceutical industries. Wang et al. [20] studied the effect of GTE as a functional ingredient on bread quality and found that GTE significantly influenced the bread's taste. In addition, it affected textural attributes such as hardness, sweetness, stickiness, and astringency. Given its excellent antioxidant content, fortifying bread with GTE could yield a functional food product with added health benefits.

Among various natural compounds for enriching bread, oleaster has high potential due to its high fiber and polyphenol contents and structural similarity of oleaster flour (OF) to WF. Based on a review of the literature, to the best of our knowledge, there is no review article on the use of oleaster fruit as a good enrichment in bakery products or other food products. This study aims to explore the utilization of oleaster fruit in various bakery products, addressing the current lack of comprehensive review in this area. Specifically, it evaluates how incorporating oleaster fruit influences the rheological, physicochemical, nutritional, and sensorial properties of different bakery products. The findings could contribute to the development of healthier, functional bakery products enriched with oleaster fruit compounds, promoting innovation in food processing and product development.

2. Data sources and search strategy

A comprehensive review was undertaken by systematically identifying all relevant studies published in Science Direct, SciELO (Scientific Electronic Library Online), Wiley, and Springer prior to November 2025. The search strategy incorporated a combination of subject-specific and methodological keywords, including "oleaster fruit," "oleaster flour," "oleaster powder," as well as related terms such as "Senjed," "peeled oleaster flour," and "unpeeled oleaster flour." A total of sixty-eight pertinent references were ultimately included in the preparation of this review.

3. Oleaster fruit

Oleaster (*Elaeagnus angustifolia* L.) known as wild olive belongs to the *Elaeagnus* L. genus and *Elaeagnaceae* family has a broad geographical distribution, native to regions including Iran (where it is commonly called Senjed), Europe, and Central Asia. It is especially cultivated in Middle and East Anatolia, where its fruits are widely valued. Traditionally, oleaster fruits are consumed either fresh or dried and are also used in forms such as tea or powder. They are recognized for their health benefits, including alleviating conditions like nausea, vomiting, flatulence, gastric disorders, asthma, jaundice, and promoting muscle relaxation. The fruit is loaded with bioactive compounds that exhibit antibacterial, anti-inflammatory, and antinociceptive properties, making it an effective natural remedy against infections and also relieve from pain [21]. Research has highlighted the high antioxidant capacity of oleaster, and phenolic compounds extracted from the fruit have attracted attention for their chemopreventive properties, particularly against cancer, by potentially inhibiting tumor growth [22]. Condensed tannins possess cholesterol-lowering properties, exhibit cytotoxic activity against human cancer cells, offer cardio protective effects and promote angiogenesis during skin wound healing, all without triggering toxicological irritation [23]. Recent studies have focused on the mesocarp layer of oleaster fruit, which is rich in essential vitamins, minerals, and dietary fiber, indicating its promising use as a functional ingredient in various food products [21]. Oleaster is an inexpensive, readily available fruit in Iran. Because of its excellent nutritional properties, incorporating this valuable fruit into bakery products could yield nutritionally richer goods with potential health benefits for consumers. As consumers increasingly pay attention to healthy foods, producing oleaster-based functional bakery products at a low cost could capture a large share of profits for bakery manufacturers.

3.1. Nutritional properties of oleaster fruit

The oleaster fruit is highly nutritious, containing a diverse array of bioactive compounds and essential nutrients. It is rich in flavonoids, terpenoids, phenolic acids (including 4-hydroxy benzoic acid and caffeic acid), glycosidic compounds, gallic acid, and vitamins such as ascorbic acid (vitamin C). Additionally, it provides various organic acids like butyric acid and malic acid, which contribute to its antioxidant properties. Mineral content in oleaster includes vital elements such as potassium, magnesium, sodium, iron, calcium, zinc, and copper, supporting various physiological functions. Nutritionally, oleaster is an excellent source of essential fatty acids, notably linoleic acid, as well as palmitoleic acid, palmitic acid, phospholipids, lipids, and glycoproteins. It also contains beta-sitosterol, a plant sterol known for its cholesterol-lowering effects. Overall, the combination of these bioactive compounds and nutrients makes oleaster fruit a valuable addition to a healthful diet, potentially offering antioxidant, anti-inflammatory, and other health-promoting benefits [23]. Figure 1 indicates the nutritional attributes of oleaster fruit with skeleton structure of the main bio active compounds.

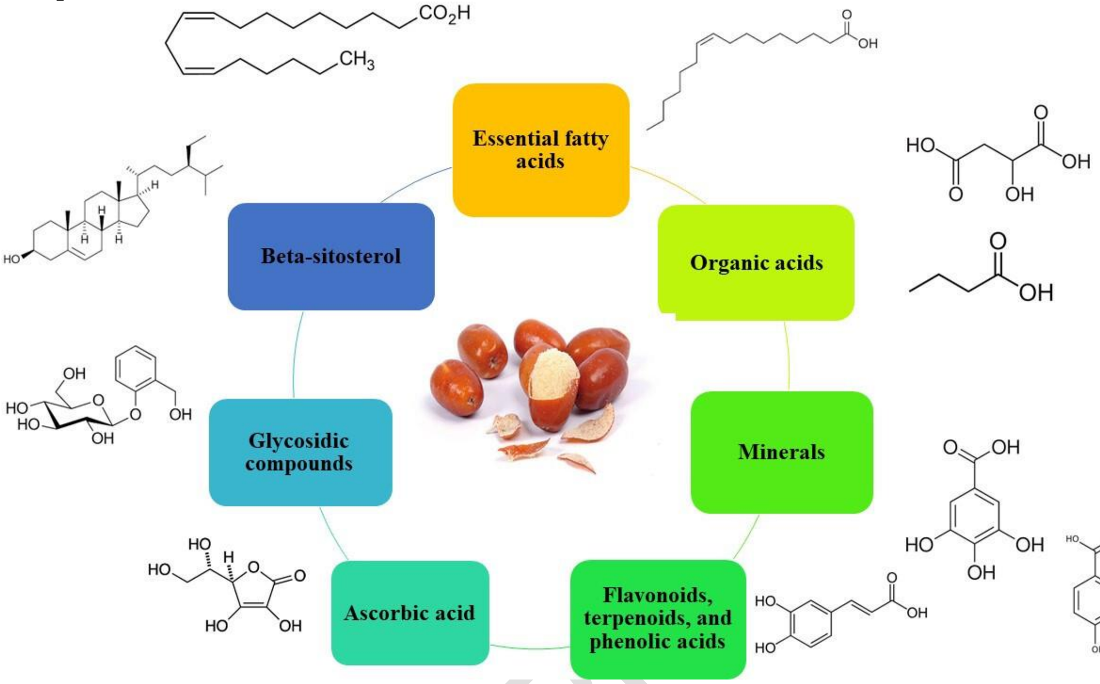

FIGURE 1: Nutritional attributes of oleaster fruit with skeleton structure of the main bio active compounds

3.2. Preparation of Oleaster flour (OF)

The oleaster fruit consists of three primary components: the peel (exocarp), the edible flesh (mesocarp), and the seed (endocarp) [21]. The overall composition of the whole fruit includes approximately 50% oleaster powder, 15% peel, and 35% seed [24]. Oleaster flour is obtained by grinding dried oleaster fruits after the peel and seeds have been removed [7, 25]. The conventional preparation procedure includes several steps, as illustrated in Figure 2: (i) **Cleaning**—the fruits are thoroughly washed with distilled water and gently scrubbed to eliminate external contaminants; (ii) **Separation**—the pulp and seed are manually separated from the peel; (iii) **Drying**—the separated components are dried in a hot-air oven at 45–50 °C for 24 hours; (iv) **Grinding**—the dried material is milled using a grinder to produce OF; and (v) **Sieving**—the ground product is passed through a sieve with 60 mesh number to obtain fine OF particles [26]. Various studies have used different methods to prepare OF. For instance, Sahan et al. [7] produced OF using two distinct approaches: (i) **Peeled oleaster flour (POF)**—the peel and seeds were manually removed with a plastic knife, after which the pulp was ground in a coffee grinder and sieved through a 60 μm mesh; and (ii) **Unpeeled oleaster flour (UPOF)**—only the seeds were removed manually, and the whole fruit, including the peel, was ground and sieved using the same mesh size. These methodological differences affect the final composition of OF and consequently influence its functional properties and potential applications.

FIGURE 2: Preparation of OF

3.3. The proximate composition of OF

Table 1 shows some physical and bioactive properties of the OF. Oleaster flour exhibits high moisture levels (8-21%), primarily due to its elevated fiber content, which can influence shelf life and processing characteristics [27]. It has a significantly higher ash content (around 1.93%) compared to WF (0.6%), indicating a greater mineral presence [28]. Specifically, calcium (Ca) content in OF (526.8 mg/kg) surpasses that of WF (1.88 mg/kg) markedly, suggesting OF as a richer source of minerals [29]. The fat content in OF is in the range of (0.47-8.2%), which in most cases is considerably higher than in WF (2%) [28]. Oleaster flour contains less protein (approximately 5.34%–6.3%) than WF (around 9.32%–10.91%), aligning with previous research indicating lower protein levels in OF [29, 34]. Moreover, OF shows higher crude fiber (up to 10.47%) compared to WF (0.69%) suggesting it as a good source of nutritional compounds. Also, OF contain a high level of total phenolic compounds (438.6 mg Gallic acid/100 g) compared to WF, contributing to potential health benefits such as antioxidant activity [34].

TABLE 1: Chemical composition, proximate analysis, total phenolic content and antioxidant capacity of Oleaster flour

Type of oleaster flour	Moisture content (g/100 g)	Ash (g/100 g)	Fat (g/100 g)	Protein (g/100 g)	Crude fiber (g/100 g)	Total dietary fiber (g/100 g)	Total sugar (g/100 g)	TPC	AA by DPPH	References
Mesocarp layer	8.99%	2.66%	0.55%	5.99%	3.32%	26.36%	-	10.55-22.30 mg GAL/g DM	5.01-14.05 µmol TE/g DM	[21, 30]
Peeled olestaer fruit flour	21.96%	1.85%	-	3.88%	-	-	-	3957 mg GAE/g	-	[7, 24]
Whole oleaster powder	7.1%	1.9%	2%	7.2%	20.7%	-	48.5 %	-	-	[27]
Whole oleaster powder	11.27%	1.93%	8.2%	5.73%	-	-	-	-	-	[28]
Fruit and crust flour	7.46%	1.53%	0.47%	5.35%	-	-	-	16.44 mg GAE/g DM	69.35 %	[29]
Fruit, crust and core flours	6.35	1.23%	4.71%	4.75%		4.99%		0.983 mg/g	54.55%	[31]
Fruit, crust and core flours	5.2%	0.19%	0.52%	6.29%	-	24.12%		-	-	[32]
Oleaster flour	6.225%	1.779%	2.17%	6.64%	-	5.7%	48.87 %	-	-	[23]
Crust OF Crumb OF	-	-	-	-	-	-	-	13.43-22.30 mg GAE/g DM 10.58-16.44 mg GAE/g DM	6.28-14.05 µmol TE/g DM 5.01-11.56 µmol TE/g DM	[33]

Total phenolic content (TFC); Antioxidant activity (AA); Gallic acid equivalent (GAE); Catechin equivalent (CE); Trolox equivalent (TE)

4. Utilization of oleaster flour used in food products

Since there have been very few recent studies exploring the use of oleaster flour in food formulations, this section focuses exclusively on research related to products other than bakery items. Due to its floury texture, unique taste, and functional properties—including high dietary fiber content, minerals, phenolic compounds, and antioxidant activity—OF could serve as a valuable ingredient in a wide range of food products. Potential uses include bakery items, yogurt, ice cream, infant foods, chocolates, and confectionery, contributing both nutritional benefits and functional properties to these products [8]. The most application of OF is in bakery products, however, there are some few studies which used OF in different food products. For example, Gul et al. [35] studied on the effect of OF with high pressure homogenization (HPH) on some physicochemical, functional and rheological properties of kefir. Enrichment of kefir with OF significantly ($p < 0.05$) increased the TPC (85.31 mg GAE/g) and antioxidant activity (17.22%) of kefir, indicating enhanced health-promoting properties. The addition of 1% OF improved kefir's firmness and water-holding capacity. When combined with HPH, these samples exhibited the highest viscosity (0.049 Pa.s at 50/s shear rate) and a higher consistency index (1.115 Pa.s), suggesting improved texture and stability. The combined treatments positively influenced probiotic bacteria, with Lactobacillus and Lactococcus counts reaching maximum levels of 9.63 and 9.31 log cfu/mL, respectively, indicating enhanced microbial viability and potential probiotic benefits. Sarvarian et al. [36] studied on the effects of oleaster extract (5, 10, 15, 20, and 25%) on the physicochemical, antioxidant and sensorial properties of orange juice fortified with oleaster extract. Fortification of orange juice with oleaster extract increased TPC and antioxidant capacity at all concentrations tested. Despite the health benefits, higher levels of oleaster extract (especially at 15-25%) led to reductions in sensory scores concerning color and taste, highlighting a trade-off between functional enhancement and consumer acceptance. In another study, Tatari et al. [37] found that substituting WF with OF in breakfast formulations led to a decrease in expansion value. This decline was linked to the higher sugar and fiber content in OF, which reduce the overall starch content. The lower starch levels can impair starch gelatinization during processing, resulting in a denser and more compact product structure. Öztürk et al. [38] studied the effect of adding 1% and 2% of OF on the quality characteristics of set yoghurt and showed that with 2% unpeeled oleaster flour, product syneresis was reduced, and that the scavenging activities and functional and textural properties were improved. Roshandel et al. [39] used OF as a fat replacer in mayonnaise at different concentrations (4%, 6%, and 8%). They indicated that increasing the concentration of OF enhances its antioxidant properties in the formulation. Specifically, after 60 days of storage, the peroxide value was significantly ($p < 0.05$) lower in samples with higher OF content. For instance, the sample with 30% OF exhibited a peroxide value of only 2.01%, compared to 10% in the control sample without any antioxidant and 2.68% in the sample containing TBHQ. Furthermore, the stability index, reached 100% in the 30% and 40% OF samples, indicating excellent stability. The Rheological properties indicated that the 30% OF sample demonstrated the highest viscosity and the lowest frequency dependency, suggesting favorable textural properties suitable for mayonnaise. Overall, the findings suggest that OF can serve as an effective natural fat replacer and antioxidant in low-fat mayonnaise formulations, improving shelf life and maintaining desirable rheological characteristics. Shabani et al. [40] investigated the impact of adding varying amounts of oleaster powder (OP) (0, 5, 10, 15, 20, 25, 30, 35, 40, and 45 wt%) on the physicochemical, sensory, and microbial properties of cheese during a 15-day storage time at refrigeration temperature. The findings indicate that increasing the amount of OP generally enhanced the antimicrobial properties of the cheese and contributed to its enrichment. Notably, the control sample without OP (0%) received the highest scores in sensory evaluations, with evaluators describing it as having an optimal texture, softness, and color. This suggests that while OP can improve certain functional properties, its addition may influence sensory attributes, and optimal levels should be considered to balance health benefits with consumer preferences. Studies show that among food products, OF has been used more in bakery products than in other foods. Oleaster flour 's increasing use in bakery products suggests it has favorable properties, such as unique flavor, nutritional benefits, and functional qualities. Table 2 shows some applications of OF into bakery products.

TABLE 2: Utilization of OF into bakery products

Bakery product	Type	Content	Nutritional properties	Technological and functional properties	Reference
Cookie	Peeled and unpeeled OF	5, 10, 15, 20, 25% w/w	Increased total phenolic contents, antioxidant capacities and bioaccessibilities of cookies	-	[8]
Sponge cake	OF	15%, 30% and 45%	Increased the calcium, potassium, crude fibre, fat and total phenolic compound contents of the sponge cakes as compared to the control.	Increased the density but decreased the hardness and cohesiveness of the cake	[34]
White bread	OF	0%, 5%, 10% and 15% w/w	-	Water absorption decreased gradually from 57.25% to 51.85%	[7]
Toast bread	Oleaster and black cumin flours	0, 1.5, 2, and 2.5%	The highest phenolic compounds and DPPH free radical scavenging capacity for the highest contents of additives, increase the protein and calcium contents	Increase the compactness of bread	[29]
Dough-nut	OF	3, 6, 9, 12 and 15%	Decrease oil absorption during frying	The protein content, pH, volume and porosity increased, while the fat, sugar, ash and fiber decreased as the replacement percentages increased	[23]
Tarhana	OF	-	-	Incorporating oleaster components led to significant alterations in protein, ash, fat, dietary fiber, in vitro starch digestibility, total phenolic substance, antioxidant capacity, and the texture and organoleptic properties of tarhana compared to the	[41]

				control	
Gluten free sponge cake	OF	1-2 g	-	OF increased moisture content, hardness, gumminess, and porosity but decreased the cohesiveness and index b* of the cake crumb	[28]
Cracker	OF	5, 10 and 15% (w/w)	increased the TP contents and antioxidant content of the crackers	-	[42]
Cookie		10, 20, and 30%	Increased dietary fiber content, free, bound, and total phenolic contents, as well as antioxidant capacity, increased a notable increase in Ca, Mg, K, Fe, and Zn levels.	Decreased hardness	[21]
Cracker	Oleaster powder	0, 10, 20, 30, 50%	Glycemic index reduction, total dietary fiber, polypheolic content and antioxidant properties increased	The hardness and fracturability of the samples decreased with increasing OP concentration	[26]
Sangak bread	OF	0, 5, 10, 15 and 20%	Increased fiber	Increased hardness, decrease bread volume	[32]

5. The physicochemical properties of functional bakery products enriched with Oleaster flour

Because of its high content of minerals, dietary fiber, phenolic compound, floury structure, special taste, and also improving the rheological properties of the batter, OF can serve functional purpose in the creation of baked goods. The effects of OF addition on different physicochemical, rheological, nutritional, and sensorial properties of bakery products are illustrated in figure 3 and discussed below.

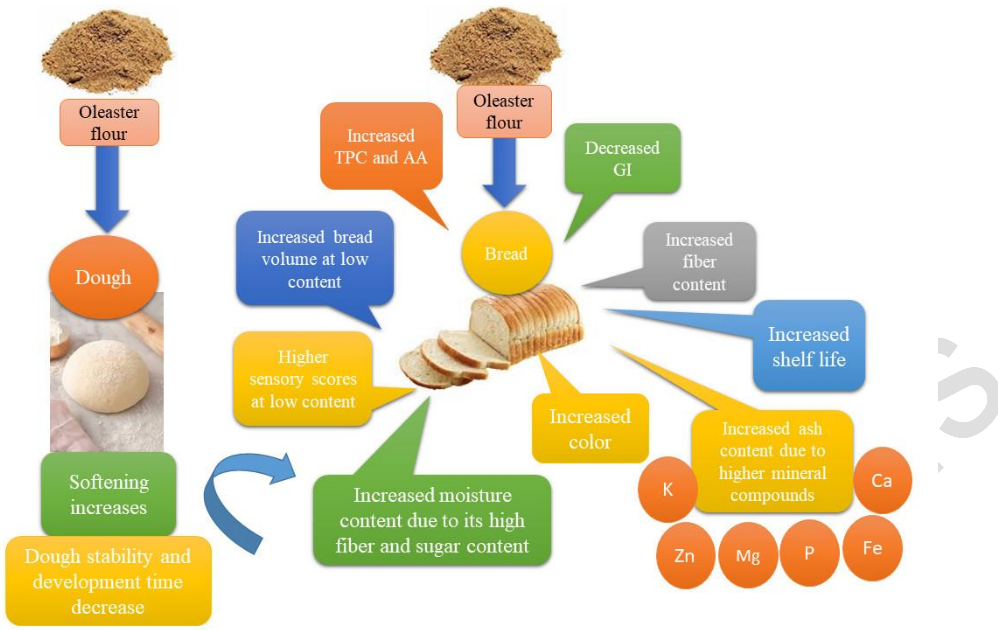

FIGURE 3: The effects of OF addition on different physicochemical, rheological, nutritional, and sensorial properties of dough and bread

5.1. Rheological behavior of doughs containing Oleaster flour

The formulation of bakery products with OF can affect the rheological properties of dough. Yavuz et al. [24] showed that how the incorporation of OF into bread formulations affected dough rheology and the potential quality of the resulting bread. Increasing the OF content led to a significant decrease in the water absorption capacity of the flour mixtures. Wheat flour exhibited the highest water absorption (approximately 57.25%), whereas higher levels of OF reduced this parameter to 51.85%. This reduction was likely attributed to interactions between the soluble fibers in OF and gluten through hydrogen bonding and hydrophobic interactions, which consequently diminished the overall hydrophilicity of the flour [43]. Additionally, the decrease in wheat starch proportion (which is highly hydrophilic) with more OF substitution could further decrease water absorption. The addition of OF decreased dough development time and stability, indicating a reduction in dough strength and gluten network formation. The optimal gluten network formation was observed at around 90 minutes of proving, but extended proving times led to structural relaxation. Oleaster flour substitution increased the degree of softening of the dough, with values ranging from 62.00 to 122.50 BU. Higher OF levels resulted in softer dough that is less stable during mixing, implying negative effects on dough handling and processing. Incorporation of OF increased energy, resistance to extension, and maximum resistance of the wheat dough, suggesting improved dough strength and processing qualities with OF. These changes could influence bread quality, necessitating further research to optimize OF levels for desirable bread properties. Similar results were also obtained by Mis et al. [44] who reported that increased dough softening by increasing the content of oat wholemeal from 0% to 25%. Elevated softening indicates rheological weakening, making dough less suitable for processing. The extensograms in Yavuz et al's study [24] showed incorporation of OF increased energy, resistance to extension, and maximum resistance, implying improved dough strength and processing qualities. While higher OF content enhances dietary fiber and potentially nutritional value, it adversely affects dough handling qualities—specifically, decreasing water absorption and stability and increasing softening. These rheological changes could influence bread volume, texture, and overall quality, highlighting the need for optimizing OF levels to balance nutritional benefits and processing performance.

5.2. Chemical composition and proximate analysis (moisture, protein, ash, fat)

The moisture content of different baked products is significantly influenced by the addition of OF, as demonstrated by multiple studies. Madadi et al. [28] reported that incorporating OF increases the moisture content of gluten-free sponge cakes, primarily due to its high fiber and sugar content, which exhibit hygroscopic properties. Adding fiber sources generally enhances the water absorption capacity of the flour mixture. Notably, fibers derived from fruits, which are rich in pectin, demonstrate a higher water-holding capacity than cereal and legume fibers. Furthermore, sugars such as glucose and fructose are highly hydrophilic and soluble, contributing to increased moisture retention in baked goods containing OF [28]. Supporting this, Zanganeh et al. [40] observed that gluten-free cakes supplemented with OF had higher moisture content compared to controls, attributed to the high fiber and sugar content of OF with hygroscopic activity. Similarly, Lavini et al. [27] found that gluten-free bread enriched with OF exhibited increased moisture content, which correlated with its high fiber (20.7%) and sugar (48.5%) levels compared to other ingredients. Yavuz et al. [7] further confirmed that adding OF at varying concentrations (0%, 5%, 10%, and 15% w/w) significantly increased the moisture content of white bread ($p < 0.05$). These findings highlight that OF enhances moisture retention in baked products through its high fiber and sugar content, which improve water absorption and hygroscopicity. Previous studies have reported an increase in ash content in various food products, including bread [29], lavash bread [45], white bread [7], and ice cream [46], following the incorporation of OF into their formulations. This increase is attributed to the higher mineral compounds such as calcium, magnesium, phosphorus, and iron present in OF [27]. Incorporating 20% OF into cookies resulted in a notable increase in Ca, Mg, K, Fe, and Zn levels [15]. However, OF contains lower level of protein compared to WF, the overall protein content in the formulated bakery products is consequently reduced. In study of Lavini et al. [27] the protein and fat contents reduced in gluten-free bread samples added OF, due to their lower content compared to chickpea flour, corn starch, and rice flour. The increased in fiber content in gluten-free bread samples was related to the increased fiber content in OF. Ghadarloo et al. [29] indicated increased calcium content in toast bread enriched with OF and black cumin (BC) (467.65–600.41 ppm) compared to the control (363.9 ppm). In another study, Zanganeh et al. [40] indicated increased ash and fiber contents in gluten free sponge cake, which was associated to the high mineral and fiber compounds in the OF. They also showed reduced fat, and protein contents in the cakes due to the lower fat and protein contents in OF compared with WF. Similar declines in protein content have been observed in breads enriched with apple pomace [47], banana pseudo-stem [18], date pomace [48], and pomegranate bagasse [49]. Sarraf et al. [23] incorporated OF into doughnuts at varying levels (3% to 15%), observed increase in fat, ash, and fiber contents with higher substitution levels, however the protein content was reduced because of the low protein content in OF when compared to the WF.

5.3. Polyphenol content, antioxidant properties, and glycemic response

The collective findings from various studies highlight the potential health and functional benefits of incorporating OF into food products. Sahan et al. [8] observed a significant increase in TPC in cookies supplemented with OF, especially in unpeeled forms—rising from 141.07 mg GAE/100 g dw in the control to 656.09 mg GAE/100 g in samples with 25% OF. This suggests that OF can serve as a rich source of phenolic compounds, contributing to dietary antioxidant intake. Furthermore, they indicated that the antioxidant effects of cookies supplemented with OF were higher than that of control, especially for unpeeled OF. Lavini et al. [27] reported increased antioxidant effects in gluten-free breads enriched with OF, attributing these effects to the poly phenolic compounds such as flavonoids, tannins, and anthocyanins, which are known for their high antioxidant capacities. Ghadarloo et al. [29] demonstrated that adding OF along with BC (1:1 w/w) at higher levels (2% and 2.5%) significantly increased TPC and DPPH free radical scavenging activity in toast bread. The enhancement was linked to flavonoids and phenolic acids present in both OF and BC, including catechin, quercetin, caffeic acid, ferulic acid, and others. Oleaster contains a diverse array of phenolic compounds—catechin, epicatechin, gallocatechin, quercetin, kaempferol, luteolin, isorhamnetin, phenolic acids (e.g., 4-hydroxybenzoic, caffeic, ferulic, vanillic acids), chlorogenic acid, and gallic acid—that contribute to its antioxidant properties. Düşkün et al. [26] showed the TPC of the cracker samples ranged from 7.39 to 15.06 mg GAE/100 g for those sample incorporating 0 to 50% OF. Also, the obtained results indicated that the DPPH radical scavenging activity increased proportionally with the concentration of OF. This suggests a strong correlation between TPC and antioxidant capacity, highlighting the role of poly phenolic compounds in enhancing radical scavenging activity. Similarly, significant improvements in the antioxidant properties of foods enriched with OF—such as ice cream [7, 25], cookies [8], orange juice [36] and kefir [35] has been shown. Farzaei et al. [50] reported that flavonoid glycosides from oleaster fruits—isorhamnetin-3-O-β-D-galactopyranoside-4'-O-β-D-glucopyranoside, quercetin 3-O-β-D-galactopyranoside-4'-O-β-D-glucopyranoside, and quercetin 3,4'-O-β-D-diglucoside—exhibit concentration-dependent antioxidant activity, effectively scavenging DPPH and $ABTS^+$ radicals.

The Glycemic index **(**GI) is a useful measure for the clinical management and prevention of chronic diseases such as diabetes, cardiovascular disease (CVD), obesity, and certain cancers. Low-GI foods tend to cause a milder rise in postprandial blood glucose, with only small increases in insulin and gut hormones, which can enhance satiety and reduce voluntary energy intake. In contrast, high-GI foods provoke larger insulin responses, leading to postprandial hyperinsulinemia that is linked to greater hunger and higher food consumption. Therefore, adopting a low-GI diet may help prevent and manage diabetes, obesity, and CVD [51]. Due to the powerful water absorbing capacity and food viscosity enhancing property, dietary fiber has been found to slow down the rate of digestion of starchy foods, resulting in a reduced blood sugar response after consumption. It has also been demonstrated that polyphenols inhibit the digestion of starch, which assists in maintaining blood sugar homeostasis after a meal [52]. Düşkün et al. [26] indicated that incorporating 50% OF into crackers reduced their GI by approximately 19.04% compared to control crackers. This reduction suggests that OF-enriched crackers elicit a lower glycemic response, leading to a more gradual increase in postprandial blood glucose levels. Such formulations may be more suitable for individuals aiming to manage their blood sugar levels effectively. The decrease in GI values with OF addition can be attributed to the inhibitory effects of phenolic compounds on carbohydrate-digesting enzymes, as described by Erol et al. [53]. Since OF is rich in phenolic compounds, its inclusion likely contributed to the observed reduction in GI. According to Erol et al. [53], foods are classified based on their GI as low (<55), medium (55–69), or high (>70) levels. Despite the reductions, all cracker samples, including those enriched with OF, still fall within the high GI category, with values ranging from 80.6 ± 0.94 to 99.55 ± 0.92. In conclusion, crackers enriched with 30% and 50% OF demonstrate lower GI and Glycemic Impact (HI) values compared to control samples. Although all samples remain in the high GI range, the significant reductions with increasing OF levels highlight OF's potential to improve the glycemic profile of crackers. These findings align with previous research, such as Heidari et al. [54], who reported that OF supplementation in sugar-free biscuits reduces GI, reinforcing the beneficial role of OF in modulating glycemic responses. The study findings indicate that substituting WF by OF into biscuits significantly impacts their glycemic properties and satiety. Commercial biscuits had a high GI of 71.7. Replacing 25% and 50% of WF lowered the GI to 50, and 42.9 indicating a substantial decrease in blood sugar response. Also, the Glycemic Load (GL) of biscuit was 12.03, which decreased to 7.60 and 5.38, respectively, for 25% and 50% samples, reflecting a lower overall impact on blood glucose levels. Moreover, biscuits with 50% WF substitution showed a higher satiety index (114.65) compared to commercial biscuits (91.81), which was statistically significant ($p < 0.05$). This suggests that higher WF substitution content may enhance feelings of fullness.

5.4. Physical quality characteristics (bread volume, color, texture)

Bread volume is a critical indicator of its quality, reflecting the extensibility and strength of the gluten-starch matrix [55]. Increased bread volume can enhance the visual appeal and texture, contributing to a more satisfying eating experience [56]. Yavuz et al [7] have shown a negative effect of OF formulation in bread samples enriched with 10 and 15% OF. However, the volume of bread was increased after addition of 5% of OF to the bread compared to control. The tested bread samples exhibited volumes ranging from 315 mL to 390 mL. The highest loaf volume was achieved with bread containing 5% (w/w) of OF, followed by the control sample. Previous research has indicated that loaf volume can vary depending on the type of fiber added. Specifically, the incorporation of insoluble fibers tends to reduce loaf volume, as these fibers can interfere with the dough's gas retention capacity by interacting with gluten. Conversely, the addition of low-level soluble fibers has been shown to enhance loaf volume, likely due to their ability to improve the dough's gas retention and overall structure [57]. The findings of the current study indicate that increasing the OF content leads to a significant reduction ($p < 0.05$) in the volume of the bread. This decrease is likely attributable to the disruption of the wheat gluten network, which is essential for gas retention and dough elasticity [58]. Similarly, Suwannarong et al. [59] reported that adding excessive fiber can negatively impact bread loaf volume, corroborating the present results. The impairment of the gluten network by higher fiber concentrations could hinder dough expansion during proofing and baking, resulting in denser bread with lower volume. The cross-sectional images of the fresh loaves are presented in Figure 4. Accordingly, it can observe that the loaves with 5% OF addition maintained acceptable volume and crumb structure comparable to the control sample. The primary difference noted was a slight darkening of the crumb color, which may be attributed to the pigmentation of OF. Importantly, this level of supplementation did not adversely affect the pore structure or overall crumb integrity. However, when the OF was increased to 10% and 15%, the resulting loaves exhibited a denser and more compact crumb structure with fewer pores. The pore size distribution shifted towards smaller, more uniformly distributed cells, indicating a finer crumb texture. This suggests that higher levels of OF may interfere with gas retention or dough expansion during baking, leading to less aerated loaves. Smaller, homogeneously distributed cells are generally preferred as they contribute to a softer and more uniform crumb. The images indicate that at higher OF levels, the cells tend to be smaller and more evenly spread, which could enhance certain textural qualities. Conversely, larger cells create a coarser, more open crumb, which may be less desirable depending on the intended bread texture (Figure 4) [7].

Similarly, Hasan et al. [52], and Almoumen [48] reported decreases in bread volume in samples containing mango peel, and date fruit pomace, respectively. They attributed this to the peel's fiber, which absorbs more water and may hinder gluten formation, a key factor for dough leavening. The fiber could also disrupt the gluten network, weakening the dough's structure and its capacity to expand. Additionally, it may limit the availability of fermentable sugars to yeast, resulting in less gas production and a reduced rise.

FIGURE 4: Cross-sectional images of bread samples enriched with OF (0-15%) [7] Copyright 1999-2025 John Wiley & Sons

The volume and porosity of bread significantly influence its texture and perceived hardness. Specifically, when bread has a smaller volume, it tends to be more compact with fewer air cells or voids. This results in a denser structure, making the bread feel firmer and harder to bite. In addition, higher porosity, meaning more and larger air cells within the crumb, typically leads to a softer, lighter texture. Conversely, lower porosity (fewer or smaller air cells) results in a denser, firmer crumb. Thus, bread with reduced volume and lower porosity generally exhibits increased hardness, giving it a more compact and firm texture [29]. Previous study indicates that adding OF to the cake formulation reduces hardness and stickiness of the product [28]. However, Lavini et al. [27] observed that adding OF at concentrations above 7.5% increases bread firmness. This increase in firmness correlates with a reduction in the specific volume of the bread, attributable to decreased air bubble formation during mixing, which impairs dough aeration. Yavuz et al. [7] reported that incorporating 5% (w/w) OF enhances bread volume, but higher OF levels tend to negatively affect volume, indicating an optimal inclusion level for volume retention. Ghadarloo et al. [29] used SEM imaging to show that toast bread with added OF and BC exhibits a more compact microstructure with fewer empty spaces (cavities) compared to control bread. The microstructure reveals aggregated gelatinized starch particles filling the cavities, leading to a denser, tougher texture (Figure 5). This suggests that OF and BC particles fill the voids and reinforce the microstructure, but may also reduce gas retention capacity, slightly increasing toughness. Moreover, the inability of their protein to effectively retain the gas produced during fermentation resulted in a slightly tougher texture compared to the control. Madadi et al. [28] demonstrated that increasing the amount of whole OF elevates the hardness of gluten-free sponge cakes. Zanganeh et al. [31] found that higher percentages of OF increase perceived hardness. The increased hardness in gluten-free products is partly due to the absence of gluten, leading to weaker gas retention during baking. Additionally, moisture migration from crumb to crust and starch crystallization (notably amylopectin) during storage contribute to staling and hardness development. Several studies indicate that the inclusion of dietary fiber, such as that of Oleaster flour, tends to increase the hardness of cereal-based products, likely due to water-binding effects and interference with the gluten network (or its absence in gluten-free products). Babashahi Kouhanestani et al. [34] investigated how varying levels of OF at 15%, 30%, and 45%, along with active gluten at 0% and 30%, influence the physical, chemical, and sensory qualities of sponge cakes. Their findings indicated that the inclusion of OF increased the cake's density. This increase was attributed to the dilution of gluten and the adverse effects of fiber-gluten interactions, which impaired gas retention within the batter. The high fiber content in OF weakens the gluten network, leading to increased gas emission and a reduction in the specific volume of the cake. However, the addition of active gluten helped mitigate these negative effects; cakes containing gluten were found to be less dense and less hard compared to those without gluten, suggesting that gluten can enhance gas retention and improve the overall texture of the product despite the high fiber content of OF. Düşkün et al. [26] indicated decrease in hardness of crackers formulated with OF with increasing OF concentration, which can be attributed to several factors. Primarily, the reduction in gluten content associated with higher OF levels weakens the structural integrity of the cracker, resulting in a more crumbly and less firm product. Additionally, higher OF concentrations may enhance water retention during baking, which can soften the texture of the final product. The poly phenolic compounds present in OF are also known to inhibit amylase activity [60], slowing down starch breakdown and contributing to a softer, less rigid texture. Furthermore, the inclusion of dietary fibers from OF can dilute the gluten network and disrupt the matrix that contributes to hardness, further softening the crackers [61]. However, it is important to note that a decrease in hardness is generally not favored by consumers who prefer crisp, firm crackers with a light texture. Therefore, balancing OF addition to harness its nutritional benefits while maintaining desirable textural qualities is crucial in cracker formulation.

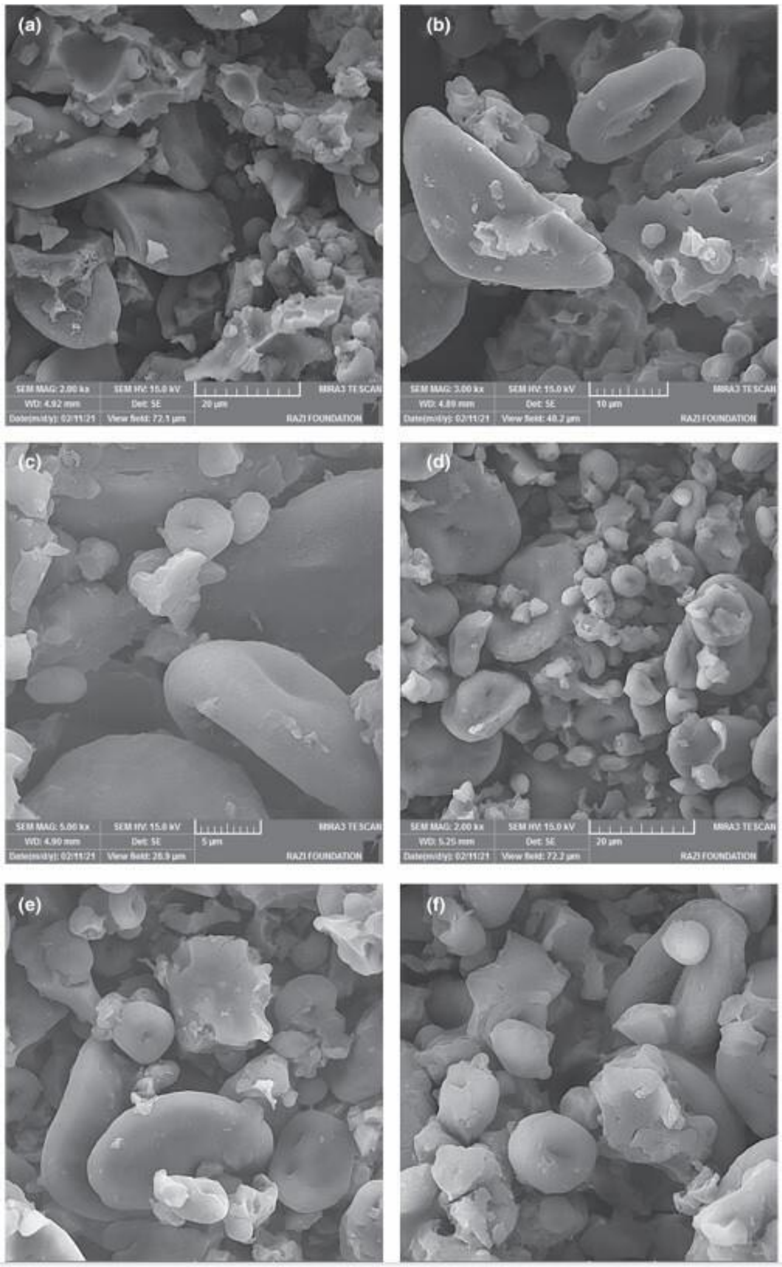

FIGURE 5: SEM images of bread samples enriched with OF and BC flour; a-c (control); d-f (1% OF + 1% BC flour) [29] Copyright 1999-2025 John Wiley & Sons

Color plays a crucial role in consumers' bread purchasing decisions. The changes in crust color are primarily associated with Maillard and caramelization reactions during baking. However, these color alterations are also affected by the ingredients used in the bread formulation. Specifically, baking temperature and the residual sugar content in the dough significantly influence the final crust color, contributing to the visual appeal and perceived quality of the bread [7]. Lavini et al. [27] observed that adding OF to non-gluten free breads increased the color score, attributed to OF's higher color relative to WF. Ghadarloo et al. [29] found that adding OF and BC to toast bread decreased brightness, yellowness, and chroma, while redness increased compared to the control, likely due to the inherent red hue of OF. Zangeneh et al [31] reported that incorporating OF significantly reduced the yellowness of cake samples, but increased redness proportionally with OF content, again linked to OF's natural red coloration. The addition of OF led to a decrease in the L* (lightness) value of bread from 52.3 in the control to approximately 42.88–43.24, due to OF's darker color compared to WF. The OF increased the a* (redness) values and decreased b* (yellowness), consistent with findings by Sahan et al. [8] and Al-Ansi et al. [62] in cookies and biscuits enriched with OF, respectively. The chroma (color intensity) was significantly lower in samples with OF, indicating a less vivid color, primarily because of decreased yellowness. Çakmakçı et al. [46] also noted reduced chroma in ice cream when OF was added. Overall, the incorporation of OF influences the color properties—generally reducing lightness and yellowness while increasing redness—due to the intrinsic pigments and darker hues. Düşkün et al. [26] showed L* value reduction in crackers formulated with OF. The observed decrease in L* values with increasing levels of OF in baked goods can be explained by several interconnected factors. Primarily, Maillard reactions play a significant role, as these non-enzymatic browning processes occur when reducing sugars react with amino acids during baking, leading to darker coloration of the product. Additionally, the formation of brown pigments directly within OF itself contributes to the overall darkening effect. They also showed that increasing the OF concentration led to significantly ($p < 0.05$) higher a* values, reflecting a notable shift in color towards red. In terms of b* values, a comparable trend was observed, suggesting that modifications in OF concentration and proportion also influenced the yellowness or blueness of the product, aligning with the changes seen in the a* parameter. This overall pattern demonstrates that higher OF levels contribute to a more reddish and potentially warmer coloration in the enriched crackers. Furthermore, substituting WF with fiber-rich flours containing sugars enhances non-enzymatic browning, as these sugars participate in Maillard reactions, thus intensifying the product's darkening [26]. This phenomenon is supported by the findings of Yavuz et al. [7], who reported that higher OF levels resulted in darker bread. Similar trends have been observed in other foods such as ice cream [25, 46] and doughnuts [23], where increased OF content correlates with a darker appearance, likely due to the same browning mechanisms. Sahin [21] showed the substitution of OF in the cookies resulted in a darker color compared to the control. In the study of Khodaeyan Karim and Ataye Salehi [32] the addition of OF to Sangak bread led to noticeable changes in its colorimetric parameters: a decrease in L* (lightness) and b* (yellow-blue axis) values, along with an increase in the a* (red-green axis) value. These changes are primarily attributed to the inherent brown coloration of OF, which imparts a darker hue to the bread. Additionally, oleaster is rich in monosaccharide sugars such as glucose and fructose. These sugars play a crucial role in enhancing Maillard reactions during baking, leading to increased browning and a deeper, more reddish-brown coloration of the crust and crumb. In another study, Sarraf et al [23] showed how increasing the level of OF in doughnuts affects the color characteristics of crust (a), and crumbs (b), based on L*, a*, and b* color parameters (Figure 6). They indicated that as OF percentage increases (from control to 9%, 12%, and 15%), the crust and crumbs become darker, evidenced by a decrease in the L* value. This is respected, due to the fact that OF is darker than WF. The decrease in brightness correlates with reduced porosity and a more coherent texture, which affects the light reflection. The a* value shows an increasing trend with higher OF levels, indicating a shift toward red hues. A significant difference is only observed between the 3% sample and the control. The b* value decreases as OF content increases, indicating a shift toward blue hues. Significant differences are noted between the control and higher substitution levels (9%, 12%, 15%), especially between the 15% sample and others (except 12%).

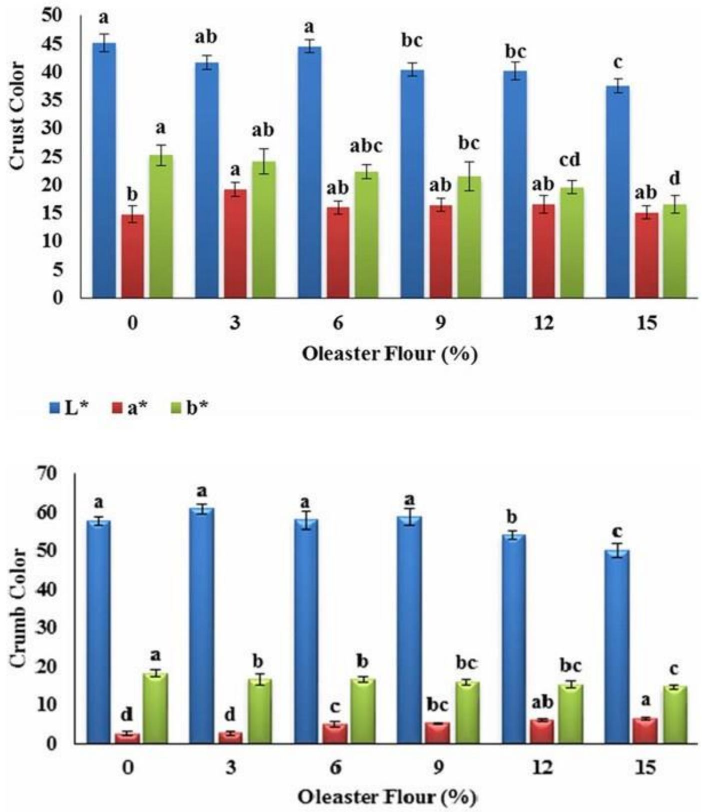

FIGURE 6: Color properties of donut enriched with OF (0-15%) [23] Copyright 1999-2025 John Wiley & Sons

5.5. Sensory evaluation and consumer acceptability

The studies collectively highlight the impact of incorporating OF on the sensory properties of baked products. In the study of Lavini et al. [27] sensory evaluation was conducted with 25 evaluators utilizing a linear scoring method. They found that increasing OF concentration in gluten-free breads generally decreased sensorial qualities, although higher OF levels improved texture by enhancing porosity and flavor. In the study of Zanganeh et al. [31] the sensory characteristics of the gluten-free breads were assessed by 10 evaluators, who rated attributes such as color, texture, aroma, taste, chewiness, and overall acceptability using a 5-point hedonic scale. The study's findings indicate that incorporating 20% OF into gluten free cake samples resulted in the highest scores for color, taste, and chewability, suggesting an optimal level for sensory acceptance. Conversely, samples with 5% oleaster husk flour received the lowest ratings in texture, chewability, and overall acceptability, highlighting potential limitations at lower inclusion levels or specific flour types. Furthermore, the comparison of mean scores revealed that increasing the proportion of OF generally led to a decrease in chewability, implying that higher substitution levels may negatively impact this attribute. While color and aroma remained relatively unaffected across different formulations, taste differences were statistically significant ($p < 0.05$). Notably, samples containing oleaster kernel flour received the lowest taste scores, which suggests that this particular type of oleaster flour may adversely influence flavor profiles. Conversely, Ghadarloo et al. [29] conducted a sensory evaluation involving 30 panelists, comprising 15 women and 15 men. They utilized a nine-point hedonic scale to assess various attributes of the toast bread samples, including taste, odor, aftertaste, color, texture, and overall acceptance. They observed no significant difference in overall acceptability of bread samples when using a mixture of OF and BC compared to a control, suggesting that certain combinations may not adversely affect consumer acceptance. Düşkün et al. [26] identified a significant correlation between OF content and overall acceptability ($p < 0.05$) of crackers enriched with OF, indicating that as OF levels increased, overall preference tended to decrease. Among the samples, the sample with no OF content (control) scored the highest in acceptability. The decline in acceptability, especially observed in the sample added 50% OF, was mainly due to alterations in taste, aroma, and texture. Panelists reported a noticeable reduction in crispness with higher OF concentrations, which negatively impacted their overall perception of the product. Sahin [21] assessed the sensory attributes of different cookie samples using semi-trained panelists. Cookies coded with different letters and the sensory evaluation was performed with a scalar scoring approach in terms of color, flavor, odor, and overall acceptability using a 7-point test. According to the obtained results the cookies incorporating OF at 10% and 20% levels demonstrated superior flavor and overall acceptability, making them the most preferred formulations among the tested options. However, increasing the inclusion rate to 30% appeared to adversely affect the sensory qualities, leading to undesirable changes in color, flavor, odor, and overall acceptability. This suggests that while moderate incorporation of these ingredients enhances cookie quality, higher levels may compromise sensory appeal. In another study was conducted by Khodaeyan Karim and Ataye Salehi [32] ten trained judges assessed various quality attributes of the Sangak bread, including overall acceptability, crust color, chewiness, texture firmness, flavor, porosity, and other sensory parameters. Each attribute was rated using a 5-point scale, where typically, a score of 1 indicates poor or undesirable qualities, and a score of 5 signifies excellent or highly acceptable qualities. The results indicated higher sensory scores for those Sangak breads containing up to 10% of OF than the control sample, while adding higher amounts of 25 and 20% decreased the sensory evaluation scores.

5.6. Shelf life and storage stability

Sahan et al. [63] discussed how incorporating OF into WF can enhance the shelf life of baked products by slowing down starch retrogradation, which is associated with product staling. This effect is partly attributed to OF being rich in poly phenolic compounds and antioxidants. These compounds can interact with gluten proteins through protein–polyphenol interactions, embedding poly phenolic compounds within the gluten network over hydrophobic interactions. Such interactions can induce structural and functional modifications in gluten, including protein aggregation and changes in disulfide bridge conformation. Phenolic acids—acting as free radical scavengers—may accelerate dough breakdown. Conversely, Han and Koh [64] observed that adding phenolic acids to dough can reduce kneading time and improve dough tolerance, elasticity, and bread volume. Babashahi Kouhanestani et al. [34] found that adding OF and active gluten significantly affected sponge cake hardness; initially, the addition reduced hardness due to fiber's role in detaching the gluten-starch matrix. Over storage, hardness increased in all samples, but after 14 days, the OF-enriched sample remained softer than the control. This is attributed to fiber's ability to retain water, delaying moisture migration and staling. Staling results from starch retrogradation and moisture migration. Similar findings by Lebesi & Tzia [65] and Curti et al. [66] support the idea that dietary fibers can delay staling by maintaining moisture and softening crumb texture during storage.

6. Future considerations

Bakery products can deteriorate through physical, chemical, and microbiological processes. In bakery goods, spoilage problems can be broken down into: physical spoilage (loss of moisture and staling), chemical spoilage (rancidity), and microbiological spoilage (growth of yeast, molds, and bacteria). To prevent microbial growth and oxidative reactions, the bakery industry routinely utilizes various chemical agents [2, 67]. Nevertheless, growing consumer interest in preservative-free products could lead to the development of alternative options. Some natural antioxidants have already been used in food products [13]. These natural antioxidants can extend shelf life, but they are not as effective as synthetic antioxidants [67]. As noted earlier, researches have shown that oleaster fruit is rich in TPC and exhibits strong antioxidant activity. Therefore, incorporating oleaster into bakery products could enhance their nutritional value by increasing antioxidant activity, as well as fiber and mineral content, due to its antioxidant properties, and potentially extend the products' shelf life. This aspect has not yet been addressed in the studies conducted and could represent a promising area for future research on bakery products.

7. Conclusions

The growing consumer demand for healthier food options has driven interest in incorporating ingredients rich in health-promoting agents such as antioxidants, vitamins, minerals, probiotics, and dietary fibers. Oleaster flour has gained attention due to its distinct nutritional profile, characterized by higher moisture, ash, fiber, and phenolic contents, as well as a notable mineral richness, especially calcium. In contrast, WF typically offers higher protein content. These differences highlight OF's potential to enhance the nutritional quality of various bakery products. Incorporating OF into diverse bakery matrices can significantly enrich products with phenolic compounds and antioxidants, contributing to improved nutritional value and functional properties. Specifically, the addition of OF can enhance texture, stability, and antioxidant capacity, making products more beneficial for health-conscious consumers. From a microstructural perspective, OF tends to create a more compact structure within bakery matrices by filling cavities, which may influence gas retention and product aeration. For gluten-free cakes, increasing OF content has been observed to raise hardness levels, primarily due to moisture migration and starch crystallization processes. While moderate levels of OF can improve certain textural attributes, excessive incorporation may lead to microstructural densification and moisture dynamics that negatively affect overall product quality. However, the addition of active gluten helped mitigate these negative effects; cakes containing gluten were found to be less dense and less hard compared to those without gluten, suggesting that gluten can enhance gas retention and improve the overall texture of the product despite the high fiber content of OF. In conclusion, OF shows promise as a functional ingredient for developing healthier, antioxidant-rich food products. However, careful optimization is necessary to balance its nutritional benefits with desirable textural and sensorial qualities by using moderate levels of OF, ensuring consumer acceptance and product performance.

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