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Review

From vegetable pomace processing to shortbread biscuits: a review

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A b s t r a c t. Vegetable pomace is a valuable by-product of juice production and has gained increasing attention in recent years as a potential ingredient for food fortification. This review analyses current trends in the processing of vegetable pomace into flour and its application in the fortification of shortbread-type biscuits. Particular attention is paid to drying and milling methods, as well as to the effects of different vegetable pomace types on the physicochemical properties of the final products. The review is based primarily on studies published over the past decade and draws on data retrieved from the Web of Science, Scopus, and Google Scholar databases. The analysed literature reveals a lack of comprehensive studies addressing the valorisation of vegetable pomace into powdered ingredients with controlled and optimised particle size distribution suitable for biscuit manufacture. In addition, the impact of pomace incorporation on product quality, functional characteristics, and sensory acceptability is discussed.

K e y w o r d s: cookies, drying, grinding, quality, fibre, antioxidant properties

1. INTRODUCTION

Shortbread biscuits (SB) are a popular snack product typically characterised by high energy and saturated fat content, while being low in dietary fibre and bioactive compounds. They are considered energy-dense foods, as they are commonly produced using large amounts of sugar, fat, and refined wheat flour. Excessive energy intake is frequently associated with adverse health outcomes. Diets rich in refined flour and added sugars, but poor in fibre and bioactive compounds, may lead to several negative health consequences, including nutrient imbalance, elevated glycaemic response, weight gain, digestive disorders, and disturbances in blood lipid profiles (Cauchi *et al.*, 2021; O'Keefe, 2019; Throsby, 2020). Contemporary consumers increasingly show a preference for innovative food products enriched with nutritional components that may help mitigate the risk of lifestyle-related diseases. Consequently, there is a growing demand for the development of novel functional foods fortified with health-promoting ingredients that meet changing consumer expectations. In recent years, SB enriched with plant-derived by-products have attracted increasing attention (Therdthai, 2022; Quiles *et al.*, 2018; Quitral *et al.*, 2023). As dietary patterns shift towards more plant-based options, understanding the implications of these changes is essential for the development of healthier SB. The enrichment of biscuits with plant-derived ingredients rich in bioactive compounds may contribute to health-promoting dietary patterns, as diets rich in dietary fibre and plant bioactives have been associated with a reduced risk of chronic diseases, improved weight management, and enhanced overall well-being (Krajewska and Dziki, 2023). As consumers become more aware of the relationship between diet and health outcomes, demand for SB aligned with plant-based principles has increased. Plant-based additions, such as seeds, bran, vegetables,

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fruits, and their by-products, provide essential nutrients, including dietary fibre, vitamins, minerals, and unsaturated fatty acids, thereby enhancing the nutritional profile of SB (Andrejko *et al.*, 2024; Bravo-Núñez and Gómez, 2023).

Particular attention has been directed towards studies investigating the potential applications of fruit and vegetable pomace. The number of publications addressing the properties and potential uses of these by-products has increased steadily in recent years (Fig. 1), reflecting growing interest from both academia and industry in their utilisation as raw materials with high biological and functional value. In addition, health-promoting plant-based additions may enhance flavour and aroma, thereby enabling a reduction in sugar content without compromising consumer acceptability (Mihaylova *et al.*, 2021). Moreover, plant-based ingredients incorporated into SB can serve as alternative sources of protein, as well as micro- and macronutrients that are less abundant in conventional formulations (Igbabul *et al.*, 2018). Importantly, the partial replacement of refined wheat flour with fibre-rich pomace has been shown to reduce the caloric value of biscuits (Ingle *et al.*, 2017). However, such modifications may also adversely affect product quality and sensory attributes, which in turn can influence consumer acceptance, depending on the type of pomace, its concentration, and the food matrix (Tama and Karaś, 2025).

During vegetable processing, large quantities of by-products, such as peels, cores, seeds, and pomace, are generated. In particular, vegetable juice processing produces substantial amounts of residues. These by-products represent a rich source of numerous valuable compounds from both nutritional and health perspectives (Ikram *et al.*, 2024; Kultys and Kurek, 2022; Sedlar *et al.*, 2021). Their recovery and utilisation contribute to waste reduction, improved resource efficiency, and the development of zero-waste strategies within the food industry, thereby supporting environmental sustainability and the transition towards more circular food production systems. An increasing number of studies have focused on the valorisation of vegetable pomace with respect to its potential application as an additive in cereal-based products, including SB. Such additions not only confer nutritional and health benefits but

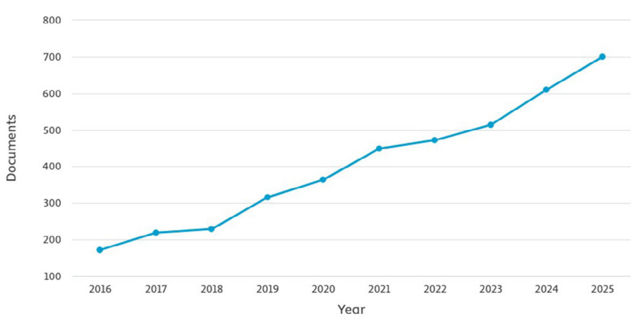

Fig. 1. Number of publications with the term "pomace" in the title published between 2016 and 2025, based on data retrieved from the Scopus database (accessed 3 January 2026).

also affect the physical and sensory characteristics of the final products, frequently leading to changes in structure, colour, and texture (Gölge *et al.*, 2022). In traditional SB formulations, water is generally not added, as its presence promotes excessive gluten development, increasing dough elasticity and compromising the characteristic crumbly texture. Consequently, pomace intended for incorporation into SB should be dehydrated and milled to particle sizes comparable to those of wheat flour.

Furthermore, drying and milling of fruit and vegetable pomace facilitate its incorporation into baked products, increase dietary fibre content, and enhance the health-promoting properties of the final products. At the same time, these processes reduce water activity, thereby extending shelf life and improving microbiological stability (Krajewska *et al.,* 2024a; 2025).

The aim of this review was to identify current trends in the drying and grinding of vegetable pomace and to evaluate the enrichment of SB with this by-product, with particular emphasis on the resulting physicochemical and health-promoting properties of fortified biscuits. The analysis focused primarily on studies published over the past decade and was based on data retrieved from the Web of Science, Scopus, and Google Scholar databases.

2. PROCESSING OF POMACE INTO FLOUR

2.1. Drying

By-products of vegetable processing, particularly pomace, are generally characterised by high moisture content, resulting in elevated water activity levels (Del Valle *et al.*, 2006). Consequently, their shelf life is severely limited due to increased susceptibility to microbial spoilage and biochemical degradation. Moreover, in conventional SB production, water is typically excluded, as its addition promotes excessive gluten development in wheat flour, leading to increased dough elasticity at the expense of the desired crumbly texture. Therefore, vegetable processing by-products must be dried prior to use; this step not only extends their shelf life but also improves grinding efficiency (Hassoon *et al.*, 2021). The most commonly applied methods of pomace drying, together with their advantages and limitations, are presented in Fig. 2.

Hot-air drying is the oldest and most commonly employed technique for food dehydration (Chandramohan, 2020). This convective method relies on heat transfer to the material *via* a stream of heated air. Moisture is removed due to the vapour pressure difference between the product surface and the surrounding air, causing water to migrate from the interior to the surface, where it subsequently evaporates. As a result, the material gradually reaches the desired level of dryness. The method is widely used in industry owing to its simplicity, cost-effectiveness, and scalability. The equipment required for hot-air drying is relatively straightforward to design and operate and can

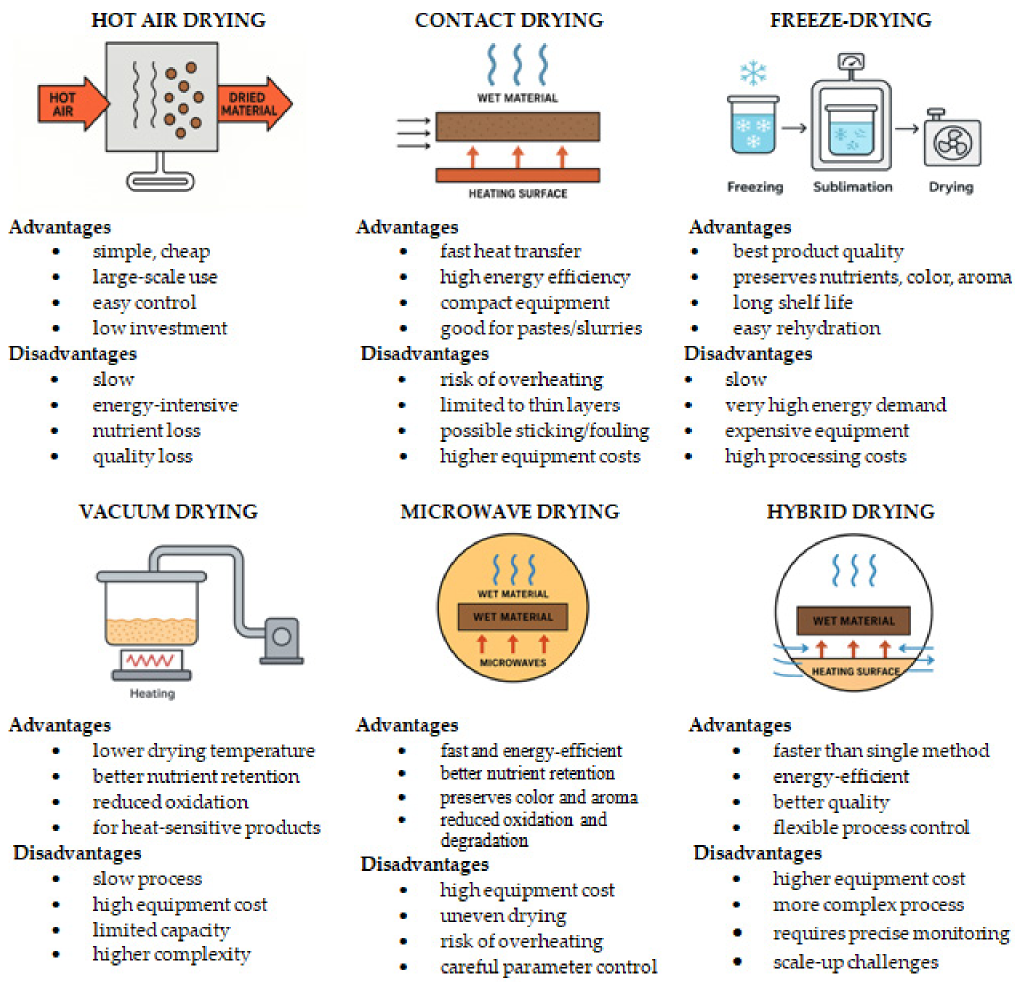

Fig. 2. Overview of drying methods applied to pomace, highlighting their main advantages and limitations.

accommodate both batch and continuous production systems. Moreover, the process allows for precise control of key parameters, such as air temperature, flow rate, and humidity, enabling adaptation to the specific properties of different materials (Zhang *et al.*, 2022). When properly managed, hot-air drying provides uniform moisture reduction and is widely applied in the food, agricultural, and feed industries, where large quantities of by-products must be processed efficiently. In the case of pomace, the majority of studies also focus on this drying method (Heras-Ramírez *et al.*, 2012; Kumar *et al.*; 2012; Luca *et al.*, 2022). However, the technique presents certain challenges. Drying times can be relatively long, reducing overall efficiency, and exposure to high temperatures may lead to the thermal degradation of sensitive compounds, such as proteins, vitamins, and other bioactive components (Batu and Kadakal, 2021; Bi *et al.*, 2022; Demiray *et al.*, 2013). To address these limitations, industrial practice increasingly employs hybrid or combined drying approaches, integrating hot-air drying with methods such as vacuum (Maamar *et al.*, 2023), microwave (Bhat *et al.*, 2023), or radio-frequency-assisted drying (Elik, 2021). These strategies aim to accelerate the drying process, reduce energy consumption, and preserve material quality, while maintaining the practicality and economic advantages of convective drying (Poblete *et al.*, 2024).

Most studies focus on the drying of carrot pomace (Abano *et al.,* 2019; Borowska *et al.*, 2017; Kaur *et al.*, 2024; Polat *et al.*, 2022; Rezvani and Goli, 2022), whereas comparative analyses of different drying methods for this type of by-product are scarce. The most favourable results are obtained through the application of freeze-drying to carrot pomace, as this approach allows for maximal preservation of valuable nutrients and bioactive compounds. In comparison with convective drying, freeze-drying leads to lower degradation of sensitive constituents such as polyphenols and carotenoids, although partial losses of β-carotene may occur (Borowska *et al.*, 2017). Furthermore, freeze-dried pomace exhibits higher antioxidant capacity, enhancing its functional potential in food products, such as SB enriched with dietary fibre and antioxidants. This method, by combining low temperature with moisture removal under vacuum, minimises damage to the cellular structure, which also translates into improved rheological and sensory characteristics of the final product. In contrast, very few studies address the analysis of this process in relation to pomace derived from other vegetables. The literature reports only isolated publications on the drying of such materials, including beetroot (Jedlińska *et al.*, 2025) and broccoli pomace (Krajewska *et al.*, 2024a). In the first study, the authors freeze-dried beetroot pomace under constant process conditions (pressure 0.63 Pa, shelf temperature 20°C, condenser temperature −55°C, duration 48 h) (Jedlińska *et al.*, 2025). In the second study, focusing on the drying of broccoli pomace, the effects of contact drying and freeze-drying on its physicochemical properties were analysed using different process temperatures. The freeze-dried powders exhibited significantly higher lightness and a more intense green colour compared to those obtained *via* contact drying. Contact drying, including microwave-assisted methods, resulted in increased levels of phenolic compounds and greater radical-scavenging activity relative to freeze-drying. Phytochemical profiling revealed the highest concentrations of quinic and fumaric acids, accompanied by trace amounts of aconitic acid, protocatechuic acid, piceid, coumarin, and astragalin. Considering both antioxidant activity and total polyphenol content, contact drying at 80°C was determined to be the most effective method for processing broccoli pomace (Krajewska *et al.*, 2024a).

Contact drying of pomace may serve as an alternative to hot-air drying; however, relatively few studies address this topic (Krajewska *et al.*, 2024a; Krajewska and Dziki, 2025). In convective drying, warm air primarily removes moisture from the surface of the material, while the interior remains relatively moist, significantly prolonging the drying time. Moreover, rapid airflow over the surface of the pomace can lead to the formation of a so-called crust, which impedes further moisture evaporation from deeper layers. In contrast, contact drying, performed for instance on heated plates or drums, enables direct heat transfer to the entire mass of the pomace, resulting in faster and more uniform moisture removal. In the food industry, contact drying is applied to products in the form of suspensions, pastes, or pulps that are difficult to dry using conventional convective methods. The technology involves spreading a thin layer of the raw material over a heated surface (e.g., the drum of a drum dryer), from which water rapidly evaporates, and the dried product is subsequently scraped off in the form of flakes or powder. This method is employed for drying dairy products (milk, whey, casein), starch and starch-based products, fruit and vegetable purees (e.g., apple, banana, tomato), cocoa and milk-cocoa mixtures, as well as fruit and vegetable pomace, from which dried purees can be obtained. Such dried pomace purees constitute a valuable source of dietary fibre and natural antioxidants and can be used as an ingredient in bread, biscuits, bars, instant products, as well as in animal feed and functional foods.

Due to the rapid evaporation of water, this method is energy-efficient, allows for the drying of dense and viscous products, and enables the production of stable, easily storable powders or flakes. In practice, hybrid contact-drying approaches are employed. Such methods may be particularly effective for dense, fine-grained, or highly moist materials. Accordingly, contact drying can be considerably more efficient, predictable, and cost-effective compared to convective drying (Sahni and Chaudhuri, 2012). However, the literature does not contain studies directly comparing these two drying methods for pomace. Furthermore, hybrid drying techniques can be applied to pomace, often yielding superior results compared to a single drying method. To date, however, these approaches have been applied only to fruit pomace (Cano-Lamadrid *et al.*, 2018; Bhat *et al.*, 2023; Mellalou *et al.*, 2022). Few studies also address the pre-treatment of pomace prior to drying. Alam *et al.* (2013) subjected carrot pomace to various blanching methods before hot-air drying. The most favourable combination was pre-treatment with citric acid followed by convective drying at 65°C, as this best preserved the quality attributes of the pomace (Alam *et al.*, 2013). Nevertheless, many authors incorporate vegetable pomace into products following only a single treatment protocol, which may prevent the full utilisation of its potential.

2.2. Grinding

The grinding of pomace represents a crucial stage in its further processing. Controlled grinding enables the production of powders tailored to specific applications. The size of the ground particles determines both their intrinsic properties (Yan *et al.*, 2023; Zhao *et al.*, 2015) and the properties of the final products (Jose *et al.*, 2022; Rocha-Parra *et al.*, 2019). Dried fruit or vegetable pomace constitutes a relatively low-energy-consuming material to grind, as it has already undergone preliminary size reduction during juice extraction. The additional decrease in moisture content resulting from drying increases pomace brittleness, thereby further facilitating the grinding process. Consequently, a wide range of grinding devices, such as hammer mills, roller mills, and ultrafine mills, can be applied (Fig. 3), depending on the desired particle size distribution and the intended application of the resulting powder. Both impact mills and roller mills are commonly used for grinding plant-based by-products, such as dried pomace; however, they differ in their operating mechanisms and resulting outcomes. Impact mills operate through high-speed impact, breaking the material into smaller particles and producing a relatively broad particle size distribution. In contrast, roller mills reduce particle size by compressing and shearing the material between rotating rollers, resulting in a more uniform particle size distribution and reduced dust generation (Zhang *et al.*, 2025). Overall, hammer mills are advantageous for rapid size reduction and for processing tougher or partially fibrous materials, whereas roller mills

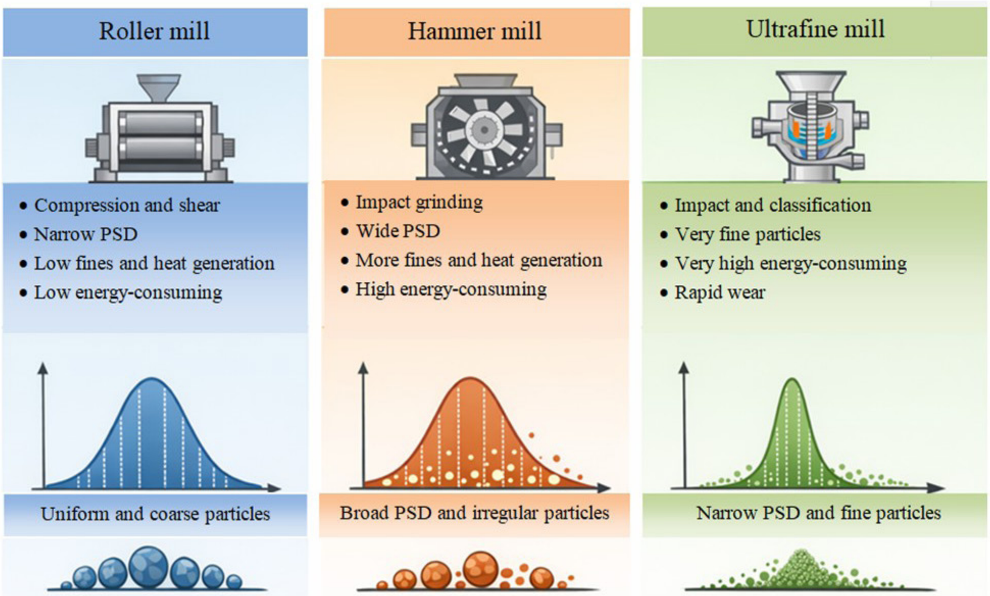

Fig. 3. Overview of grinding methods applied to pomace.

are preferred when uniform particle size and the preservation of functional compounds are priorities. This makes roller mills particularly suitable for producing flour from dried vegetable pomace intended for bakery applications. They are especially effective for well-dried, brittle pomace, providing controlled granulometry with minimal thermal degradation. However, roller mills may be less effective when processing very coarse or highly fibrous particles, in which case pre-crushing may be required (Dziki, 2011). Ultrafine mills enable the production of very fine and uniform powders from fruit and vegetable pomace; however, their use is associated with high energy consumption and rapid wear of components, despite their potential to enhance the availability of bioactive compounds (Zhao *et al.*, 2015). Although particle size reduction is known to improve functional properties, excessive grinding may lead to increased energy consumption as well as the degradation of bioactive compounds due to heat generation and intensified oxidation (Kim *et al.*, 2017).

Relatively little attention has been devoted in the literature to the grinding of pomace. Krajewska *et al.* (2024a) investigated the grinding behaviour of broccoli pomace dried under different conditions. The results demonstrated that freeze-dried pomace exhibited a higher degree of size reduction compared with pomace dried by contact methods, while also requiring lower energy input for the grinding process. Similar trends were observed during the grinding of pear pomace (Krajewska *et al.*, 2024b).

Over the past few years, superfine grinding technology has gained increasing attention in the food industry due to its ability to reduce particle size to the micrometre scale, thereby improving the physicochemical properties of raw materials, including water- and oil-holding capacities, and promoting the release of bioactive compounds (Wu *et al.*, 2021). Accumulating evidence indicates that this approach can enhance the quality of fruit and vegetable powders by improving their colour, flavour, and functional properties, positioning superfine grinding as a promising strategy for the production of high-quality, health-oriented food products (Chen *et al.*, 2018; Duguma *et al.*, 2023; Gao *et al.*, 2020). To date, however, limited research has addressed the application of ultrafine grinding to vegetable pomace, with most available studies focusing on fruit pomace. Zhao *et al.* (2015) investigated the ultrafine grinding of grape pomace and demonstrated that this process improved the extractability of bioactive compounds and increased antioxidant activity. Similar results were reported by other authors applying micronization to grape pomace (Zhao *et al.*, 2015). Furthermore, the application of ultrafine grinding has been shown to increase the proportion of soluble dietary fibre in powders obtained from grape (Bender *et al.*, 2020) and apple pomace (Lu *et al.*, 2020). In summary, further research on the grinding of pomace is warranted to optimize particle size distribution for subsequent applications. Controlled grinding is essential to balance functional quality, process efficiency, and the nutritional value of pomace.

3. UTILIZATION OF VEGETABLE POMACE IN SB PRODUCTION

3.1. Carrot pomace

Carrot (*Daucus carota* L.) is one of the most widely consumed root vegetables worldwide. It is commonly processed into juice, with a yield of approximately 30-50% (Surbhi *et al.*, 2018). As a result, a substantial amount of waste is generated annually, with global carrot pomace production estimated at around 175 000 t. Previous efforts to optimize the utilization of this by-product have primarily focused on the extraction of valuable compounds, particularly carotenoids and dietary fibre (Ikram *et al.*, 2024). Carrot pomace contains approximately 80% of the carotene originally present in the fresh carrot (Ajmal, 2023). It is a rich source of carbohydrates, which constitute about 72% of the dry matter of pomace powder, including 20.9% crude fibre and approximately 55.8% total dietary fibre. In addition, carrot pomace contains about 5.3-5.9% ash, 0.7-1.3% fat, 0.7-9.1% protein, and provides an energy value of 301-338 kcal per 100 g (Kumar Yadav and Rajpurohit, 2018; Luca *et al.*, 2022). Importantly, carrot pomace is abundant in calcium pectate, a pectic polysaccharide known for its cholesterol-lowering properties (Sharma and Kumar, 2017). Research indicates that bioactive compounds derived from carrot pomace may exert beneficial effects on gastrointestinal and colonic health. Specifically, carrot pomace has been shown to promote the growth of certain probiotic bacteria (Sharifi *et al.*, 2023) and to enhance the production of short-chain fatty acids (Mall and Patel, 2024). Moreover, carrot pomace is particularly rich in chlorogenic acids (Vaz *et al.*, 2022), which account for approximately 39% of the total phenolic compounds present in carrot pomace (Polat *et al.*, 2022). Chlorogenic acid exhibits strong antioxidant activity and may reduce susceptibility to various infectious diseases (Naveed *et al.*, 2018). Furthermore, dried carrot pomace is a valuable source of micronutrients, including K (18 600 mg kg^{-1}), Mg (10 800 mg kg^{-1}), Fe (30 500 mg kg^{-1}), and Zn (29 400 mg kg^{-1}) (Ikram *et al.*, 2024).

A few scholarly investigations have been undertaken to explore the feasibility of partially replacing wheat flour with carrot pomace powder. Bellur Nagarajaiah and Prakash (2015) demonstrated that the addition of carrot pomace powder to SB significantly influenced their nutritional composition, sensory acceptability, and shelf stability (Table 1). Importantly, they observed that both total carotenoids and β-carotene content decreased by approximately twofold during the 60-day storage period. However, the researchers did not determine the particle size of the carrot pomace powder used. Based on sensory evaluation results, they found that an 8% substitution of wheat flour did not adversely affect the overall acceptability of the SB. Similar findings were reported by Ajmal *et al.* (2023), who partially replaced wheat flour with carrot pomace powder. Additionally, they observed that the enriched SB exhibited enhanced antioxidant activity, as measured by DPPH (2,2-diphenyl-1-picrylhydrazyl) radical scavenging capacity. From a sensory perspective, biscuits containing a 6% substitution of wheat flour with carrot pomace by-products were found to be the most acceptable.

Other authors enriched SB by adding flour obtained from black carrot pomace (Gölge *et al.*, 2022). Black carrots are a significant source of polyphenolic compounds, particularly anthocyanins and phenolic acids. Scientific interest in black carrots has increased due to their distinctive anthocyanin profile, as these compounds are well known for their potential health-promoting properties and their role in the prevention of chronic diseases (Kamiloglu *et al.*, 2018). However, the cited study evaluated only the sensory acceptance of the enriched SB (Gölge *et al.*, 2022). Other researchers reported that the optimal level of wheat flour replacement with black carrot pomace powder is 10% (Cho and Chung, 2019). It is also worth emphasizing that the properties of enriched SB depend not only on the type of plant by-product used as an additive, but also on the method of its preparation (Barak *et al.*, 2014). In particular, drying conditions and the particle size of the resulting pomace powder significantly affect its characteristics and, consequently, the properties of SB (Krajewska and Dziki, 2023). These factors play a crucial role in the sensory acceptance of the final product (Yang *et al.*, 2022).

3.2. Beetroot pomace

Beetroot (*Beta vulgaris* L.) is a root vegetable rich in vitamin B9 (folate), K, Mg, Fe, and vitamin C. It is also a valuable source of phenolic acids, including p-coumaric, ferulic, protocatechuic, caffeic, vanillic, p-hydroxybenzoic, and syringic acids, as well as notable amounts of catechin and epicatechin (Theba *et al.*, 2021). Beetroot residues generated during juice processing, commonly referred to as beetroot pomace (BP), constitute a rich source of various bioactive compounds with well-documented antioxidant properties. Following juice extraction, approximately 15-30% of the resulting pomace is typically discarded or only occasionally utilised as animal feed, despite its considerable potential (Šoštarić *et al.*, 2023). Moreover, owing to its natural and non-toxic pigments and favourable colourant properties, BP is widely incorporated as an additive in the food industry. Dried and powdered BP contains (on a dry matter basis) approximately 1.3% fat, 11.9% fibre, 5.6% ash, 20.8% protein, and 45.1% carbohydrates (Costa *et al.*, 2017). Vulić *et al.* (2013) reported that BP contains total phenolics at a level of 45 6800 mg gallic acid equivalents/kg dry mass (DM) and total flavonoids at 25 8900 mg rutin equivalents/kg DM. Beetroot powder derived from pomace exhibits numerous functional properties and, consequently, is widely applied in a variety of food products (Theba *et al.*, 2021). It represents a good source of dietary fibre, comprising 45.1% insoluble fibre and 20.14% soluble fibre (Costa *et al.*, 2017). Therefore, BP can be incorporated into cereal-based and baked products such as bread, cakes, pasta, and SB, providing substantial amounts of bioactive compounds and dietary fibre while serving as a low-calorie food additive (Theba *et al.*, 2021). However, although numerous studies have focused on the enrichment of cookies with beetroot powder (Asadi and Khan, 2021; Mitrevski *et al.*, 2023, 2025), there is a limited number of publications addressing the use of beetroot pomace

Table 1. Effects of different vegetable pomace additions on the properties of shortbread biscuits

Kind of pomace	WFRL (%)	MPD/PS (μm)	Effect	Sensory evaluation	RL (%)	Reference
Orange carrot	0, 4, 8, 12	AD at 50°C and grinding/ND	Increased level of FB, AS, and TCA, little influence on sensory acceptance up to 8%	ST panel (n = 30)	8	(Bellur Nagarajaiah and Prakash, 2015)
Orange carrot	0, 3, 6, 9, 12	AD at 50°C and grinding/ < 2000	Increased level of FB, AS, AA, decreased HR and sensory acceptance	10 (9-point HS)	6	(Ajmal, 2023)
Black carrot	14, 25, 35	AD at 50°C and grinding/ 425-850	Significant influence on sensory properties	7 panellists, HS	14	(Gölge *et al*., 2022)
Beetroot	0, 5, 10, 15, 20, 25	AD at 50°C and grinding/< 250	Increased levels of TDF, AS, PT, and hardness.	10 panellists, 9-point HS	10	(Sahni and Shere, 2016)
Beetroot	0, 5, 10, 15, 20	Air-drying at 50°C and grinding/ND	Increase in PT, TDF, Ca, P, and Fe, improve HE, RBC count, and AA; alleviation of mild kidney and liver dysfunction	ND number of panellists, 9-point HS	15	(Abdo *et al*., 2021)
Tomato	0, 5, 10, 15, 20	Air-drying at 60°C and grinding/ND	Increase in PT and AS, darker colour with more yellow and red tones	8 panellists, 5-point scale	5	(Bhat and Ahsan, 2016)
Tomato	0, 5, 10, 15, 20, 25	ND/<150	Increase in TDF, TPC, reduced GI, no significant influence on sensory acceptance up to 15%	6 panellists, 5-point HS	20	(Bhat *et al*., 2017)
Tomato	0, 2, 4, 8	ND	Increase in TDF, and HR little influence on sensory acceptance up to 15%	14 panellists, 9-point HS		(Ahmad *et al*., 2017)
Tomato	0, 2.5, 7.5, 10	ND/<125	Increase in TDF, TPC, and AS, no significant influence on sensory acceptance up to 7.0%	7 TR panellists, 5-point HS	2.5-7.0	(Salem, 2020)
Olive	0, 10, 15, 20	ND/<425	Increase in TDF, decreased GI, no significant influence on sensory acceptance up to 15%	50 panellists, 5-point HS	15	(Lin *et al*., 2017)
Olive	0, 10, 20	Freeze-dried/ND	Increase in TDF, lipids and minerals. Decreased sensory quality	15 trained panellists, QDS	10	(Trindade *et al*., 2023)

AA – antioxidant activity, AS – ash content, FB – fibre, GI – glycaemic index, HE – haemoglobin content, HR- hardness, HS – hedonic scale, MPD – method of pomace drying, ND – not determined, PS – particle size, PT – protein content, QDS – quantitative descriptive analysis, RBC – red blood cells, RL – recommended level, SB – shortbread biscuits, ST – semi-trained panellists, TDF – total dietary fibre, TCA – total carotenoids, TPC – total phenolic content, TR – trained, WFRL – wheat flour replacement level.

specifically as an ingredient in SB (Table 1). Abdo *et al.* (2021) developed functional SB enriched with BP powder and reported that increasing pomace levels resulted in higher contents of protein, fibre, calcium, phosphorus, and iron. Furthermore, the consumption of SB formulated with 15% BP led to increased haemoglobin concentration, red blood cell counts, and antioxidant enzyme activity in anaemic rats after 28 days of feeding. In addition, mild kidney and liver impairments observed in the anaemic control groups were alleviated in animals receiving beetroot pomace-enriched SB. Overall, the incorporation of BP into SB demonstrated considerable potential for anaemia management and the reduction of oxidative stress. Sahni and Shere (2016) demonstrated that fibre-enriched SB can be produced by partially substituting refined wheat flour with BP powder, with this substitution significantly affecting the physical, chemical, textural, and sensory properties of the products. Their findings indicated that increasing levels of BP resulted in greater biscuit thickness, whereas diameter, spread ratio, and spread factor generally decreased. Higher pomace content also led to increased moisture, crude fibre, protein, and ash contents, while carbohydrate levels declined and fat content remained largely unchanged. Biscuit hardness generally increased with higher levels of pomace addition. Moreover, BP powder darkened the colour of SB and adversely affected texture scores. Sensory evaluation revealed that SB containing 10% beetroot pomace achieved the highest overall acceptability, primarily due to their superior taste and flavour. Other authors have reported that the addition of beetroot pomace extract, either in pure or microencapsulated form, can further enhance the nutritional quality of SB. In particular, microencapsulated pomace extract significantly increased antioxidant capacity, total phenolic content, and betalain levels in einkorn-based water SB enriched with pseudocereals (Hidalgo *et al.*, 2018).

3.3. Tomato pomace

While tomatoes are botanically classified as fruits, they are traditionally regarded as vegetables in culinary practice and food technology, in line with common usage reflected in dietary guidelines rather than botanical definitions (Cunningham, 2002). Consumer perceptions further support this classification, as tomatoes are frequently grouped with vegetables in dietary surveys and classification systems (Thompson *et al.*, 2011). For this reason, tomato-based ingredients are frequently included in studies on vegetable enrichment of bakery products (Santamaria *et al.*, 2024). Tomatoes, rich in lycopene, phenolic compounds, and dietary fibre, are among the most widely consumed vegetables worldwide (Lu *et al.*, 2019), with an annual production of 193 million tons in 2023 (FAO, 2025). Dietary intake of lycopene, one of the most potent carotenoids in the human diet, has been associated with a reduced risk of chronic diseases, including cancer and cardiovascular disorders (Kumar *et al.*, 2020). Approximately 42.5 million tons of tomatoes are processed industrially each year, with around 4% of the fresh fruit mass entering processing plants constituting waste (Lu *et al.*, 2022; Pan *et al.*, 2019). Tomato pomace, generated primarily during juice production, is a rich source of these bioactive compounds and is increasingly processed into powder, which is utilised, among other applications, as an ingredient in SB. Tomato pomace powder contains approximately 17.5% protein, 3.9% ash, 38% dietary fibre, 25.4% total sugars, and 6.3% fat (Belović *et al.*, 2018), thereby influencing the chemical composition of enriched products. Studies by Bhat and Ahsan (2016) and Ahmad *et al.* (2017), reported increases in protein and ash content in SB with higher levels of pomace addition (2-25%), which was further confirmed by Salem (2020), who also observed increases in macro- and microelements, including K, Ca, Mg, Na, Mn, Fe, and Zn. Dietary fibre content also increased significantly (Table 1). Salem (2020) observed that the incorporation of 2-10% pomace into SB resulted in a 1.5-2.8-fold increase in total dietary fibre content, with the soluble fibre fraction increasing by 1.1-1.5-fold and the insoluble fibre fraction by 1.6-3.6-fold, depending on the level of supplementation. Ahmad *et al.* (2017) reported a 4.2-13.9-fold increase in crude fibre at 2-8% addition. It should be noted that crude fibre analysis is based on the residue remaining fibre after sequential acid and alkali extraction and reflects only a limited portion of plant cell wall components, mainly cellulose and variable amounts of lignin (Fahey *et al.*, 2018). Consequently, crude fibre analysis underestimates total dietary fibre (TDF), as non-cellulosic polysaccharides are largely removed during the analytical procedure. As a result, differences in relative fibre increases among studies may reflect not only formulation effects but also methodological differences and baseline fibre levels in control samples. In the study by Ahmad *et al.* (2017), the very low crude fibre content of the control sample (1.3 g kg^{-1}) resulted in higher relative increases, whereas the control sample in study of Salem (2020) contained 11.4 g kg^{-1} insoluble fibre, leading to smaller relative changes despite higher absolute fibre contents. Consequently, increases in fibre content expressed as crude fibre and total dietary fibre are not directly comparable, and the determination of TDF more accurately reflects both the actual fibre content and its functional potential in products enriched with tomato pomace powder. Regardless of the addition level, SB enriched with tomato pomace powder exhibited decreased lightness and increased red colouration, attributed to lycopene and other natural pigments in tomato pomace (Bhat and Ahsan, 2016; Bhat *et al.*, 2017). Colour modification or saturation in food significantly influences consumer expectations and subsequent perception of taste and aroma under both laboratory and real-life conditions (Spence and Piqueras-Fiszman, 2016). Pomace addition also improved storage stability: the rates of increase in free fatty acids, peroxide value, and saponification value were lower in samples with higher pomace content, reflecting the antioxidant activity of lycopene and phenolic compounds. This effect is attributed to lycopene's high capacity to quench singlet oxygen and neutralize reactive oxygen and nitrogen species *via* radical reactions and electron transfer (Kulawik *et al.*, 2023), which may slow lipid oxidation. Additionally, total polyphenolic content tended to increase with 5-25% tomato pomace addition (Bhat *et al.*, 2017). The increase in polyphenols in SB enriched with tomato pomace powder may correlate with antioxidant activity, as phenolic acids and flavonoids are the primary compounds responsible for neutralizing reactive oxygen species (Muflihah *et al.*, 2021). The impact of tomato pomace on sensory properties of SB was inconsistent, and the results were not fully representative. Bhat and Ahsan (2016) reported that the lowest level (5%) of flour replacement improved overall acceptability, texture, colour, and appearance, whereas higher levels decreased sensory scores. Ahmad *et al.* (2017) observed a decrease in scores even at the lowest addition level, with 4% flour replacement being more acceptable than 2%. In both studies, the number of panellists was limited (8-14 participants), and the scales used varied (5- and 9-point), which may have contributed to discrepancies. Literature suggests that 50-100 consumers are recommended for representative sensory results, with simulation analyses indicating a minimum of approximately 20 participants depending on product complexity (Mammasse and Schlich, 2014). Results from small panels have limited statistical value, and interpretation is challenging; thus, further studies with larger consumer panels are necessary to fully elucidate the effects of powdered tomato pomace addition on SB.

3.4. Olive pomace

Although olives are botanically classified as fruits (drupes) because they develop from the ovary of a flower and contain a seed, in culinary practice and food technology they are often regarded and used as vegetables. In particular, table olives are widely described as one of the oldest fermented vegetables in Mediterranean cuisine, justifying their inclusion among vegetable-based ingredients in this review (Perpetuini *et al.*, 2020). Olive pomace (OP), the solid residue generated during virgin olive oil production, represents a rich source of bioactive compounds and has been widely utilised in research aimed at developing high value-added food products, thereby contributing to the sustainability of the olive oil industry. It consists of a mixture of olive pulp and pits, and the processing of one ton of olives yields approximately 0.5-0.6 t of OP, with a moisture content ranging from 50 to 65%, depending on the type of decanter employed (Difonzo *et al.*, 2021). Nunes *et al.* (2018) reported the chemical composition of fresh OP, with a moisture content of approximately 60%, while carbohydrates accounted for 34%, protein for 2.6%, ash for 0.7%, and total fat for 2%. Moreover, the pulp fraction has been shown to constitute a significant source of dietary fibre (53-59% on a DM basis) as well as a diverse array of phenolic compounds exhibiting notable antioxidant activity (De Bruno *et al.*, 2018). Specifically, olive pulp contains phenolic acids such as vanillin, hydroxybenzoic acid, caffeic acid-3-glucoside, caffeic acid, coumaric acid, and ferulic acid, along with flavonoids including rutin, luteolin-7-O-glucoside, luteolin, quercetin, and apigenin (Ribeiro *et al.*, 2020). These bioactive constituents contribute to the functional properties of olive pulp, underscoring its potential application as a value-added ingredient in the development of health-promoting and functional food products. Lin *et al.* (2017) developed SB enriched with OP powder and evaluated their physical, sensory, and nutritional properties. The results demonstrated that incorporation of 15% OP into the biscuit formulation yielded products with acceptable texture and appearance. Furthermore, nutritional analysis revealed that the enriched SB were characterized by a high dietary fibre content and a significantly lower predicted glycaemic index compared to traditional wheat SB. Other authors investigated the use of freeze-dried OP for SB enrichment (Trindade *et al.*, 2023). The incorporation of OP increased the dietary fibre, lipid, and mineral contents of the SB. From a sensory perspective, however, OP addition negatively affected attributes such as lightness, texture, and brittleness and did not enhance the descriptive sensory profile. Overall, SB containing 10% OP demonstrated potential for further investigation with regard to both physicochemical and sensory properties (Table 1).

4. CONCLUSIONS

Vegetable pomace constitutes a valuable by-product and a concentrated source of dietary fibre and a wide range of bioactive compounds. Owing to its high water activity, it is particularly susceptible to microbial growth and enzymatic reactions, which substantially limit its shelf life. Therefore, the application of appropriate preservation methods is required to extend its suitability for technological and food applications. Among the most commonly employed preservation techniques is drying. However, the number of studies focusing on the drying of vegetable pomace remains relatively limited, as do investigations addressing grinding processes aimed at producing raw materials with particle size characteristics tailored to specific technological applications. The incorporation of vegetable pomace into SB improves their nutritional value by increasing dietary fibre and phenolic compound contents, thereby enhancing the antioxidant activity of the final products. At the same time, it induces changes in quality attributes, particularly flavour, aroma, and texture. Based on the available literature, the optimal substitution level of wheat flour with vegetable pomace generally ranges from 5 to 15%, depending on the type of pomace used. Higher inclusion levels in biscuit formulations tend to reduce consumer acceptability. Future research should focus on the valorisation of vegetable pomace as an ingredient in a wider range of food products. Such approaches not only enhance the functional potential of food formulations but also contribute to food waste reduction and align with the principles of sustainable development.

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