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Application of fruit pomace in cereal-based products

Fiber from fruit pomace: A review of applications in cereal-based products

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Abstract

Fruit pomace is a by-product of the fruit processing industry composed of cell wall compounds, stems and seeds of the fruit; after washing, drying and milling, a material high in fiber and bioactive compounds is obtained. In bakery products, dried fruit pomace can be added to replace flour, sugar or fat and thus reduce energy load while enhancing fiber and antioxidant contents. The high fiber content of fruit pomace, however, results in techno-functional interactions that affect physicochemical and sensory properties. In this paper, different sources of fruit pomace are discussed along with their application in bread, brittle and soft bakery products, and extrudates.

Keywords

bread; healthy bakery products; aerated structure; consumer acceptability

1. Introduction

Fiber from sources other than wheat can be added to cereal-based baked or extruded product formulations to confer particular nutritional or sensory properties. The fiber may come from many sources including barley, oats, rice, soy, sugar beet and pea (1; 2). Their chemical and physical properties have some similarities with those of wheat fiber, and they all tend to have high water-absorption capacities so that additional water is required in the formulations in which they are applied. Another important source of fiber can be fruit pomace, as an alternative to its traditional use as for example animal feed or in composting (3). When using fruit pomace fiber in cereal baked product formulations, it is important to consider that it contains a high amount of soluble dietary fiber (SDF) whereas, in cereal fiber, the fraction of insoluble dietary fiber (IDF) is higher (4). Moreover, fruit dietary fiber (DF) concentrates generally exhibit a better nutritional quality than those from cereals because of the presence of significant amounts of associated bioactive compounds (flavonoids, carotenoids, etc.) and their balanced composition (higher fiber content, IDF:SDF ratio, water and oil binding capacity, lower energy, and phytic acid content) (5).

2. Dietary fiber in fruit pomace

Different definitions of dietary fiber have been proposed in recent years. In 2009, an agreed definition was published (6): DF means carbohydrate polymers with ten or more monomeric units, which are not hydrolyzed in the small intestine of humans, and which belong to the following categories:

- Edible carbohydrate polymers naturally occurring in the food as consumed;
- Carbohydrate polymers obtained from food raw material by physical, enzymatic or chemical means that have been shown to exhibit beneficial health effects as demonstrated by generally accepted scientific evidence to authorities; and
- Synthetic carbohydrate polymers that have also been shown to exhibit beneficial health effects.

Based on chemical, physical and functional properties, dietary fiber can be classified into soluble and insoluble DF. SDF includes pectins, gums, inulin-type fructans and some hemicelluloses, which dissolve in water by forming viscous gels. They are resistant to digestion in the small intestine but easily fermented by the microbiota of the large intestine. The fermentation of IDF, including lignin, cellulose and some hemicelluloses, is however severely limited in the human gastrointestinal tract (7). SDF is considered to have benefits on serum lipids, while IDF is linked to laxation benefits. In addition, many fiber sources such as oat bran and psyllium are mostly soluble but still elevate stool weight (8).

Despite a recommended fiber intake for adults of 25 g/d (EFSA, 2010), most commonly consumed foods are low in DF; higher fiber contents are found in foods such as whole grain cereals, legumes and dried fruits (8). In this context, the addition of processed fruit pomace to food formulations should also be considered because it may provide additional health benefits (9), and because it enhances sustainability of the food supply chain, as pomace is a by-product that usually goes into waste (3).

Apple pomace fiber is considered as a potential food ingredient because of its well-balanced proportion of IDF and SDF and the presence of bioactive compounds such as polyphenols, flavonoids and carotenes. Concentrates from apple pomace as such and after processing have been also evaluated for their functional properties$^{(4)}$. Depending on apple variety, pomace fiber content varies from around 35.5 g/100 g dry matter (DM) in Golden Delicious to as high as 89.8 g/100 g DM in Liberty $^{(2; 4)}$. High amounts of phenolic compounds such as catechins and flavonol glycosides have been found in Golden Delicious, Red Delicious, and Granny Smith varieties $^{(4)}$.

By-products from orange juice extraction also have a high potential as DF sources; this material is rich in pectin. There is an increasing interest in pectin because of its potential to lower blood cholesterol levels and triglycerides; pectin also affects glucose metabolism by lowering the glucose response curve. The main use of pectin is as a food additive because of its specific gelling properties $^{(10)}$. Total DF content has been determined in different types of citrus fruits. Some orange varieties such as Valencia have substantial DF contents (64.3 g/100 g DM) $^{(2)}$, while others have lower contents as is the case for Navel, Salustiana and Valencia Late (35.4-36.9 g/100 g DM) $^{(10)}$. Fiber content in pomace from lemon varieties has been determined by Figuerola et al.$^{(2)}$: Fino 49 had the highest amount of total DF (68.3 g/100 g DM), with 90.8% of this being insoluble, while Eureka lemon had lower values of DF (60.1 g/100 g DM) with an IDF:SDF ratio of 5.5:1. Another citrus fruit pomace that has been proposed as a valuable DF source is grapefruit with 61.8 g/100 g DM $^{(11)}$; the IDF:SDF ratio can also vary, being e.g. 12.7:1 for Ruby, and 5.9:1 for the Marsh cultivar $^{(2)}$. Grapefruit fiber has also exhibited a high binding capacity to cholesterol compared to other citrus fibers $^{(11)}$. Different tangerine varieties have also been proposed as good alternatives to cereal fiber for supplementation in foods (12). Grape pomace fiber is a rich source of bioactive compounds such as phenolic compounds, polysaccharides, fatty acids and others (13). Factors such as variety, culture characteristics or wine-processing procedures (i.e., time of contact between pomace and grape must during fermentation) may influence grape pomace fiber composition. Usual ranges of DF in these products are 50-75 g/100 g DM (5). Grape skins are important for the food industry as fiber-rich ingredient; Bravo and Saura-Calixto(14) characterized grape skins from red and white varieties and found a DF content of 54.2 and 59.0 g/100 g DM in red and white skins, respectively. Although data about SDF and IDF content of grape pomace vary, there is no doubt that grape pomace fiber is low in solubility. Owing to the large quantity generated from worldwide wine and grape juice production, grape pomace has the potential to serve as an important IDF source for functional food development (15).

Peach DF concentrate obtained by drying the washed peach bagasse remaining after peach juice extraction was characterized by Grigelmo-Miguel and Martín-Belloso(10). Total DF constituted 30.7-36.1 g/100 g of the peach DF concentrate. IDF was the major fraction in the product, but the high presence of soluble fraction (11-12 g/100 g DM) in comparison to cereal DF is noteworthy.

Plum pomace fiber has considerable amounts of DF, up to 64.5 g/100 g DM (16). The fiber content depends on cultivar and on pomace processing as Milala et al.(16) found when drying plum pomace with different methods such as air drying or freeze-drying (values of total DF from 38-49 g/100 g); they also found important contents of polyphenols as hydroxycinamic acids, quercetin glycosides and anthocyans in the different plum cultivars. Tropical fruits have been considered as DF source as well. Guava bagasse contains 37.7 g /100 g DM total DF (17), while mango peel contains high amounts (up to 28.1 g/100 g) of SDF and a high amount of polyphenols (up to 70 g/kg) (18). Kiwi and pear pomaces were studied for composition and utilization as sugar and DF source by Martín- Cabrejas et al. (19). Berries are considered an emerging source of fruit pomace; they contain high amounts of polyphenols, which remain in the pomace after juice extraction and promote health advantages (9; 20).

3. Application of fruit pomace fiber in bread

The distinctive appeal of most cereal-based foods derives from their aerated structure, and none more than bread, the archetypal aerated food and grandfather of all aerated foods (21). The problem with incorporating DF into bread is that it is generally detrimental to the creation of the aerated structure, diminishing the appeal of the bread and restricting the benefits to be obtained through consumption of the fiber (22). Studies into the effects of fiber in baked goods have revolved around several themes, with most of the emphasis on cereal brans, particularly wheat bran; this work is instructive for considerations of effects of fruit pomace fibers.

Van der Kamp(23), reporting on the Dietary Fibre 2003 conference, advised that "*the development of products that are attractive to consumers and underpinning research to this end is a key element in efforts to increase the intake of dietary fibre*". In the case of bread, the key to producing fiber-rich products that are attractive to consumers is softness. Cauvain et al.(24) noted "*there are sections of the community who find the density and coarse texture of traditional wholemeal bread unacceptable and would prefer to increase their fibre intake by consuming bread with the large volume and soft crumb characteristics of white bread*."

Collins(25) noted that many consumers equate the firmness of dense brown and wholemeal breads with staleness, and advises that to produce such a bread so that it will sell "*the key lies in making it feel soft and that is most successfully achieved by increasing the specific volume close to white bread values*."

Much early work on the incorporation of fiber in bread concentrated on providing bakers with urgently needed practical guidelines for the production of acceptable wholemeal or high fiber breads (26; 25; 27-35). Alongside this, a prominent theme has been understanding the mechanisms by which bran and other fibers have their deleterious effects. The most obvious effect is dilution of the gluten protein when a proportion of white flour is replaced with bran. This mechanism was first stated by Shetlar and Lyman(36); however, they demonstrated that gluten dilution was not the only contributing effect, and subsequent studies have established that loaf volume decrease is greater than would be expected from dilution of the gluten alone (37-39; 30; 31; 40; 34; 35).

Secondly, bran particles are conceived to have a mechanical effect that physically disrupts gluten films, either during their formation in the mixer or when they are stretched into thin lamellae during the later stages of proving and early stages of baking (28; 39; 41; 40; 36; 42; 43). This postulation led Shetlar and Lyman(36) to propose fine grinding of the bran to minimize this mechanical effect, a strategy that proved successful, although possibly for reasons in addition to the mechanical effectiveness of the smaller particles, such as their increased rate of hydration. Studies of other DF sources have similarly found that particle size has a major effect on the fiber performance in breadmaking.

The possibility that bran decreases loaf volumes by reducing gas production has been firmly negated, with decreased gas retention clearly established as the reason for lowered loaf volumes (40; 34; 44). Gluten dilution and physical disruption by bran particles contribute to this reduced gas retention, along with an assembly of additional contributing factors. The interaction of bran with water is a major focus. Bran absorbs water, reducing its availability for film formation, and thus increases the optimum level of water required in the dough formulation (45; 46; 37; 47; 30; 40; 48; 43). However, it absorbs this water only slowly, and at a rate and extent that depends on its composition and particle size (49; 50; 37; 51-54). This slow hydration causes a lengthening of dough mixing times, while prehydration of the bran removes the increase in mixing times and increases the optimum water level still further (37; 44). This additional water is retained by the loaf during baking, giving a heavier loaf and a lower specific volume (55; 22; 37; 56). Dreese and Hoseney(37) and Rogers and Hoseney(34), based on measurements of dough height during baking in an electrical resistance oven, argue that this water is also available for starch gelatinization during baking, thereby lowering the starch gelatinization temperature and, as a result, the extent of gas retention during baking (oven spring). This mechanism, if predominant, would imply that ultimately the effect of bran on gas retention is principally during baking, rather than earlier in the breadmaking process.

Thus, the three major mechanisms by which bran damages the aerated structure of bread are gluten dilution, physical disruption of gluten films, and competition for water (causing inadequate water availability for gluten film formation or, if extra water is added to compensate, increased water availability for starch gelatinization and the consequent reduction in setting temperature and reduced oven spring). Sivam et al.(57), reviewing effects of added fiber in bread, similarly list for various noncereal fibers negative effects including reduced loaf volume, increased crumb firmness and darkened appearance, and conclude that "*the two mechanisms causing reduced loaf volume are the dilution of gluten, and the interactions among fibre components, water and gluten*" – essentially the same mechanisms as for cereal bran, although the higher soluble fiber content of some fruit pomace fibres compared with cereal brans will modify the nature and extent of these effects.

Another major theme has been evaluation and comparison of the breadmaking performance of alternative sources of dietary fiber, including (the following list is representative but not exhaustive): wheat bran fractions and extracts, oat bran and hulls, rye bran, corn bran, barley bran and flour, brewer's spent grains, triticale bran, soybean bran, coconut residue, hazelnut testa, field pea hulls, apple pomace, pear pomace, orange pomace, lemon pomace, grape pomace, date pomace, sugar beet fiber, chicory roots, potato peel and microcrystalline cellulose (58; 59; 45; 46; 37; 60; 52; 53; 61-64; 33; 40; 65; 66; 35; 44; 67). In the context of the current review, a notable omission is work on berry pomace. In general, these studies demonstrate that the fiber under study has similar deleterious effects to cereal brans, and conclude that they can be incorporated at some level while maintaining acceptable bread quality. One can reasonably speculate that berry pomace studies will follow similar routes, attempting to minimize deleterious effects through sourcing or pretreatment, and concluding that acceptable products can be obtained up to certain levels of incorporation.

Bran tends to be deleterious to highly aerated baked goods, of which bread is the prime example and therefore possibly not the ideal vehicle for delivering bran into the diet (33). As discussed elsewhere in this review, numerous workers have therefore studied the incorporation of bran and other fibers into other, less aerated, cereal-based goods including cakes, biscuits, muffins, breakfast cereals, snack foods and flat breads (68; 45; 33; 44; 69).

The majority of studies are concerned primarily with wheat bran and wholemeal bread, and useful guidance for the likely effects of other DF sources including berry and other fruit pomace can be derived from these studies. The literature on this subject has some discrepancies, and different brans vary in the details and extent of effects; however, generally, addition of wheat bran increases dough water absorption and loaf weight, decreases dough strength, increases dough stickiness, decreases mixing and fermentation tolerances, reduces loaf volume and specific volume, coarsens crumb texture, darkens crumb colour, reduces crumb softness and can impart a bitter flavor (70; 71; 55; 22; 25; 72; 37; 28; 38; 47; 39; 41; 56; 60; 30-32; 61; 73; 74; 40; 54; 34; 36; 35; 42; 48; 43) . The adverse effects are greater at higher levels of bran substitution.

Second only to wheat bran are studies on the incorporation of oat bran into bread. Krishnan et al.(52) note that "*The nutritive value of oats, their low cost, useful protein functionality, and desirable bland taste make oats a suitable supplement ingredient*", while further interest in the production and consumption of oat bran was stimulated by the FDA's proposal to allow foods containing sufficient quantities of β-glucan to be labelled with health claims relating to heart disease (75). Generally, at equal levels of addition, oat bran gives higher water absorption, stickier doughs and lower baked loaf volumes than wheat bran, but taste panellists tend to prefer the oat bran bread (46; 52; 44).

With the rise of concerns about celiac disease and studies on gluten-free breads, a recent theme has been the incorporation of noncereal fiber sources into these breads (63; 64). As noted above, the aerated structure of bread arises through the unique gluten proteins of wheat. It is these proteins that are problematic to sufferers of celiac disease, hence making production of gluten-free breads with acceptable aerated structures particularly challenging. The further damage to aeration contributed by DF makes the production of acceptable high-fiber, gluten-free breads even more challenging, hence the recent focus on this subject. O'Shea et al.(63) incorporated orange pomace into gluten-free bread formulations. They found, as with cereal brans, that the high water absorption capacity of fiber competes with starch for the available water, reducing starch granule swelling and decreasing batter viscosity and gelatinization rate. At a level of 5.5 g pomace per 100 g (rice flour + potato starch), the orange pomace bread was considered similar in sensory acceptability to the control, with a slightly less pleasant texture while chewing. Rocha Parra et al.(76) incorporated apple pomace into a gluten-free bread formulation, noting that high levels of fiber gave less cohesive and resilient crumbs and lowered specific volume. Increasing water level served to counteract the negative effects of the pomace addition to some extent.

As noted above, compared with wheat and oat bran, studies on the incorporation of other fiber sources into bread formulations are sparse, and studies of berry pomace addition into bread appear to be absent. However, several patents relate to the use of wild berry, grape and apple or pear pomace in bread (77-80), with claims around structure formation and higher yield due to the increased water binding capacity conferred by the fiber.

4. Application of fruit pomace in sweet bakery products

4.1. Cakes and muffins enriched with fruit pomace fibre

Sponge cake batters are complex systems in which air is incorporated into an oil in water emulsion (81). Although they have a cellular structure similar to that of bread dough, there is limited, if any, gluten formation (82). The cake batter usually consists of many ingredients including flour, sugar, egg, fat, leavening agents, salt, milk solids and water, and each of these has an important function in the batter. This has to be taken into account when adding DF, or when using DF to substitute flour, fat or sugar in this type of product. Table 1 shows the amount and type of fruit pomace that was used in different studies for these purposes. The main problems generated by incorporating fruit pomace fibre in a formulation come from detrimental effects of the fiber on the creation of the aerated structure, as is also the case for bread. The fruit pomace fiber has a high affinity for water, so the interaction of bran with water is one of major concerns related to this problem. In general, wheat flour substitution by DF decreases cake volume development, and because of the increased density, the texture of the final products becomes firmer, more gummy and less cohesive (83). In fact, texture is the sensory attribute most influenced by the presence of fiber in cakes and muffins, A meta-analysis of sensory data (84) showed that in the case of muffins, the texture acceptability was lowered when the muffin base acceptability was high.

4.1.1. Fiber fortification

Dried apple pomace was used by Wang and Thomas(85) to substitute 50% of wheat bran in muffins. Products had a similar total DF content but, when conducting sensory experiments, the overall preference showed that they were significantly more desirable than the control bran muffins because of their softer texture. Masoodi et al.(86) prepared cakes by adding 5, 10 or 15% of apple pomace to wheat flour and observed acceptable physical properties of the cakes. Apple skin powder was used by Rupasinghe et al.(87) to replace up to 32% of wheat flour in muffins, which resulted in a higher DF and total phenolic contents, and a higher total antioxidant capacity than in the control.

Different methods for incorporating apple pomace in bakery products have been tested, and an improved method for preparing fiber-rich cakes was patented by Madhugiri et al (88). Here, apple pomace powder (20-40%) was converted into a gel-like substance that was part of the cake formulation. Muffins with mango pulp fiber were reported as nutritionally improved due to the retention of phenolic acids and carotenoids (89). The addition of fiber-rich fruit pomace to soft bakery products can also be an alternative for people requiring a low glycemic response, as Romero-Lopez et al.(90) demonstrated in muffins with DF from orange bagasse. Walker et al.(67) prepared muffins with 5-10% grape pomace; DF and total phenolic contents and radical scavenging activity were increased compared to the control formulation. The enrichment of muffins with 20% grape pomace (91) enhanced their nutritive value without showing significant changes in the sensory profile. Aronia pomace powder was proposed to increase DF content in cakes and muffins, which also contained fresh Aronia berries or Aronia jam as fruit filling (79). A similar procedure was given for different cakes using dried and milled apple and pear pomace to increase DF content, and to reduce energy load (78).

4.1.2. Use of fruit pomace fiber for fat substitution

Fat substitution by fruit pomace results in major changes of cake structure and consequently of their physical properties, such as reduced volume and increased crumb firmness (92). Fat functionality is highly versatile in baked products (93; 94): it not only helps in the incorporation of air bubbles into cake batter during mixing, it also contributes to emulsification. Fat further helps to leaven the product (95; 96) and holds considerable amounts of liquid to increase and extend cake softness, and “shortens”, that is, it interrupts the protein particles to break gluten continuity to tenderize the crumb (97). Furthermore, the polar lipids stabilize the gas bubbles, thanks to their surface-active properties; they fill the gaps in proteinaceous films and consequently prevent the release of gas (98). In reduced fat content products, the stability of air bubbles in the batter is lowered; they tend to coalesce and disappear, giving harder cakes (99). Therefore, a prerequisite of fat replacers based on DF is that these are low in energy but sufficiently mimic techno-functional properties of fat (100).

Fruit pomace-derived fibers used to replace fat in soft bakery products include, for example, peach DF where high-fiber muffins showed fiber contents of up to 10% (101; 10). In the reduced fat and high-fiber muffins, moisture increased with DF content because of its high water-holding capacity. The addition of the peach DF darkened the muffins and increased their hardness. Muffins with peach DF up to 4-5% were considered as being similarly acceptable as the control by consumers. Melon skin and rinds were used by Al-Sayed and Ahmed(102) to substitute wheat flour or fat in a cake formulation. The use of these materials retarded staling and reduced lipid oxidation during storage. Medium substitution levels (5% flour and 10% fat) produced acceptable cakes that were not significantly different from the control.

4.1.3. Use of fruit pomace fiber for sugar replacement

Sugar substitution by fruit pomace is challenging because of the important role that sugar plays in batters of soft bakery products. Sugar contributes to sponge cake characteristics by providing energy, sweetness, aroma and crust color formation via caramelization (103), but also influences many technical and functional aspects. Sugar restricts gluten network development, and it raises starch gelatinization temperature (104) and egg protein denaturation temperature (105), causing a tenderizing effect on the final product texture. It also contributes to volume, as well as to humidification, which is linked to the sensory perception of a moist mouthfeel and tenderness. Sugar furthermore assists the formation of crystalline agglomerations of fat, thus improving air entrapment and air bubble stability during baking, giving rise to a more porous and spongy product.

When substituting sugar, it has to be taken into account that the main mechanism that destabilizes cake batter is gas diffusion from small to large bubbles. That is, a batter with more extreme variations in bubble size is less stable (81). A sufficiently high batter viscosity decreases air mobility, which prevents bubble coalescence and improves the stability of the mixture (105). When sugar is replaced by a sweetener, it is required that these functions are retained in the system, so fillers are needed to replace the bulk of sugar (106). Different plant fibers have been used as fillers; some have additional advantages such as being prebiotic, having antioxidant properties or increasing DF content. In this context, it is important to emphasize that the impact of sugar replacement and fiber addition on batter viscosity can be balanced by adjusting the water level in the formulations; in this regard, apple fiber has been used as bulk agent in sugar-replaced muffins (9; 107).

4.2. Fruit pomace fiber in brittle bakery products – cookies and biscuits

Apart from energy content and nutritional value, the incorporation of fruit pomace as, for example, partial wheat flour replacement influences the development and the properties of a cookie or biscuit dough, the behavior during baking, and the properties of the final products. Types of pomace that were used in recent studies, the methods of initial pomace processing, and the respective replacement quantities are summarized in Table 2.

4.2.1 Influence on dough properties

Farinograph experiments generally provide information on the moisture absorption capacity of the components of a formulation and on dough development time and dough stability, and they also provide a mixing tolerance index. Partial replacement of wheat flour or other formulation components by dried fruit by-products generally leads to increased moisture absorption. Ten percent wheat flour replacement by mango peel powder in a cookie formulation resulted, for example, in an increase of moisture absorption during dough kneading from 60% to 68% (108). A 10% flour replacement by grapefruit powder showed an even greater effect on moisture absorption by increasing it from 58.3% to 73.4% (109). Similar consequences were observed when different quantities of lemon or orange fiber (110), apple pomace powder (111), or orange pulp powder (112) were used. The most plausible explanation for this behavior comes from the composition of the fruit powders, namely from its high content of pectin, being capable of binding high amounts of water (108). Another reason that has been proposed is the formation of additional hydrogen bonds between the hydroxyl groups of the fruit pomace (113). On the other hand, Mildner-Skudlarz et al. (114) observed a reduced moisture absorption capacity of biscuit dough with white grape pomace and stated that several factors such as the chemical structure of the fiber, the association between fiber molecules, and fiber size and porosity influence the dough characteristics. The white grape pomace that was used in that study had high lignin content and therefore contributed differently to the dough matrix than high-pectin pomace powder.

The time necessary for dough development generally increases with fruit pomace addition because of gluten hydration prevention, either by interactions of DF with gluten proteins, or because of the competition for water that comes from the high moisture binding capacity of the fiber itself (110; 109; 111; 112). For example, mango peel powder replacing 10% wheat flour in biscuits resulted in a dough development time of 5.8 min, compared with 4.2 min for the corresponding control (108). Dough stability measured by the Farinograph decreased, and dough development time increased when wheat flour was replaced by fruit pomace in different quantities (110; 109; 114; 115). This was explained by the dilution of the gluten proteins when DF is added, so that the proteins are not able to form a strong network (108). The use of a surfactant may counteract this decrease, as was observed when 7.5% wheat flour of a biscuit formulation was replaced by dried pomegranate peel powder (115). However, other authors attributed the increase in dough stability caused by the addition of fruit pomace (111; 112) to enforced intermolecular interactions between DF, water and gluten.

In experiments with mixtures of wheat flour and pectin-enriched material (PEM) from apple pomace, it was observed that PEM interacts with the starch granules, and that starch pasting parameters increased with the addition of PEM. Differential scanning calorimetry experiments showed that PEM increased the endothermic starch gelatinization peak, indicating that more energy is required for the breakdown of the starch granules. Additionally, starch gelatinization temperature increased because of the high moisture absorption of PEM, so that less water remained available for starch gelatinization (116).

4.2.2. Influence on product characteristics

In most studies on the application in biscuits or related products, dried pomace was employed as wheat flour replacement at levels of 2.5-50%. The reduction of wheat flour in the dough and interactions of pomace components with wheat macromolecules result in a broad variation of product characteristics (e.g., volume, diameter, spread ratio, texture and color).

One important technological parameter is dough spreading during baking. Ajila et al.(108) observed a significant decrease of cookie diameter at wheat flour replacement levels above 10%, but no influence on the spread ratio. For citrus, grapefruit and apple pomace powder, the specific cookie volume and spread ratio decreased with increasing DF level (5, 10 and 15%), which was explained by the reduced gluten content (110; 109; 111). Extruded orange pulp powder had no significant influence on diameter up to 15% wheat flour replacement, whereas, compared to reference products, a 25% replacement reduced the diameter by 3.7%, increased thickness by 17.9%, and reduced the specific volume by 20.6%. This was attributed to the high pectin content of the orange pulp powder (117). The same behavior was observed for biscuits with pomegranate peel powder (115). Contrasting results were reported for white grape pomace, where a 20% replacement of wheat flour increased cookie diameter by 4.4%, decreased their thickness by 27.7%, and the spread ratio by 44.3%. White grape pomace in biscuit dough also increased moisture absorption, and the enhanced spread of the biscuits in the oven finally occurred before the products were becoming firm (114).

Biscuit texture is most commonly measured as breaking strength in three-point snap experiments, and studies concerning the incorporation of fruit pomace show varying results. For example, the replacement of 20% wheat flour by the same amount of mango peel powder increased breaking strength from 8.8 N to 19.7 N, which was explained by the higher moisture content of the dough with mango peel powder, causing an extensive gluten structure and therefore harder biscuits (108). A similar observation was also reported by Larrea et al.(117) for biscuits with orange pulp. Softer biscuits after addition of fruit pomace powder were reported for apple, where the fiber had a lower water content (5%) compared to wheat flour (14%) and thus influenced the protein and carbohydrate structure (118). A similar behavior was observed for white grape pomace (114).

Fruit pomace powder is often characterized by a yellow-brownish color (e.g., mango peel powder (108), apple pomace powder (118) or grape extract (119)). Consequently, replacement of wheat flour by fruit pomace usually affects the color of the respective biscuits.

Since the incorporated pomace powder derives from fruits, it is also associated with a particular flavor that might have an impact on the sensory characteristics of pomace-containing products. The addition of 10% mango peel powder produced acceptable biscuits with an improved taste and flavor that was attributed to the pleasantness of the underlying base material. Higher levels of mango peel powder (20%) led to a slightly bitter taste because of the high polyphenol content (108). In general, it was observed that a replacement of wheat flour up to 5% did not change the sensory scores significantly (120; 110; 111; 117; 112). With addition of fruit pomace powder, the fruity taste and smell of the products increased, whereas much higher levels of replacement resulted in a more pronounced bitter and sour product character (121; 109; 114; 119). In the studies of Srivastava et al.(115) and Uysal et al.(122), the overall sensory scores decreased with higher amounts of fiber incorporation.

4.2.3. Application as fat replacement

Besides its utilization as wheat flour replacement, it is also possible to replace other high energy ingredients such as sugar or fat by fruit pomace in brittle bakery products. For instance, PEM was used to substitute 10, 20 or 30% of the shortening in a cookie formulation. Min et al.(116) observed that PEM could not provide the same level of gas retention since cookies with

PEM were reduced in diameter and height. Penetration force was reduced, and cookies exhibited a lower fracturability, which was explained by the higher availability of water in the PEM cookies. The change of cookie surface color was not significant. Özboy-Özbaş et al.(123) used apricot kernel flour (AKF) and resistant starch (RS) for fat replacement in cookies. Spread ratios of cookies increased up to 20% replacement but then decreased when more than 30% shortening was replaced by the AKF/RS mixture. Cookie hardness decreased with replacement of more than 10%. In color measurements, b* (an indicator for the yellow contribution to product color) decreased with increasing amounts of AKF and RS. Sensory scores of fat reduced cookies were not significantly different from the control and were all acceptable.

4.2.4. Influence on content of dietary fiber and polyphenols

Fruit pomace powder is usually characterized by a high DF content since it contains mainly cell wall compounds and seeds of pressed fruits, and the incorporation of such materials increases the DF content of the products. For example, an increase from 6.5-20.7% was observed when 20% of the wheat flour in biscuits was replaced with the same amount of mango peel powder (108). Incorporation of 10% white grape pomace resulted in an 88% increase in total DF compared to control biscuits (114).

Next to the DF enhancement, fruit pomace powder incorporation in brittle bakery products also contributes to a higher content of polyphenols, which remain associated with cell wall components after juice extraction. Twenty percent mango peel powder increased the polyphenol content in biscuits from 0.54-4.5 mg/g and the carotenoid content from 17-247 µg/g (108). Mildner-Szkudlarz et al.(114) observed a six-fold increase in the antioxidant activity coming from the incorporation of 30% white grape pomace. Nevertheless, the high contents of polyphenols in fruit pomace usually decrease during thermal processing of powder and baking of biscuits (114; 119).

5. Application of fruit pomace in extruded products

High-temperature, short-time extrusion is a common process for manufacturing snack products, usually with corn as the main ingredient, and frequently implemented so as to produce highly expanded products with distinct crispiness. Since fruit pomace powders are high in DF and polyphenols, their application in extruded products is a promising opportunity to fortify cereal snacks with health beneficial ingredients. Table 3 summarizes studies of extruded products with fruit pomace as ingredient. The high contents of SDF in most fruit pomace powders are responsible for changes in product characteristics such as water absorption index (WAI), water solubility index (WSI), texture, expansion, starch digestibility, and sensory properties. Additionally, the high shear and thermal stress may affect polyphenol content and antioxidant activity of the final product.

Incorporating fruit pomace in the extruder feed mixture lowers its starch content. The lower starch content in pomace-containing extrudates then leads to a lower water absorption (124-126), which affects starch gelatinization. The WAI is additionally influenced by the competition between starch and fruit pomace fiber for water, with the fiber showing the higher water binding capacity (124). The high water affinity of fiber also explains why no significant differences were found in the WAI of corn flour extrudates and extrudates fortified with pineapple pomace (127), or those fortified with other fruit pomace (orange peel, grape seeds, tomato pomace (128)). The WSI, on the other hand, describes the amount of soluble components in extrudates and points to the degradation of molecular compounds during extrusion (e.g., starch dextrinization). Altan et al.(124) observed that the presence of pomace in cereal extrudates resulted in an increased WSI, whereas other studies observed a decrease of WSI with pomace addition. This could have been caused by reduced starch damage through the extrusion process (125), or by the high content of DF coming with the pomace (127).

With the use of pomace, the radial expansion of extrudates decreased and the bulk density increased, because of a lower extensibility, a lower gas holding capacity and reduced starch conversion in the base matrix (125; 129; 127). Struck et al.(20) noted that fiber particles cause rupture of cell walls before the gas bubbles fully expand (similar to the effects in bread, but in a system undergoing much more rapid expansion). For example, the addition of 28% apple pomace to corn flour resulted in 46-57% reduction of radial expansion but in insignificant changes in overall volumetric expansion, which was explained by the higher longitudinal expansion of apple pomace extrudates because of the alignment of fiber in the direction of extrusion (130).

Differences in expansion and bulk density directly influence the texture of pomace fortified cereal extrudates; a less porous structure with smaller cell sizes has been identified as responsible for decreased crispiness and increased brittleness (20). Apple pomace in corn flour extrudates exhibited substantially higher crushing forces because, at pomace levels from 17-28%, cell wall thickness was reduced by 32-44% and average cell wall diameter by 62% (130). Selani et al.(127), however, found no difference in hardness between reference and pineapple pomace extrudates.

Since DF and starch interact with each other and compete for matrix water, pomace also influences *in vitro* starch digestibility of extrudates. In general, extrusion processing increases starch digestibility due to the high shear and thermal stresses during production, and the resulting starch gelatinization and dextrinization. The addition of grape pomace reduced *in vitro* starch digestibility in barley extrudates, presumably because of the lower susceptibility of starch to amylase degradation as the granules are entrapped within a viscous protein-fiber-starch network. Another explanation was the reduced starch gelatinization because of the competition for water (131). Karkle et al.(125) observed increased levels of resistant starch with increasing apple pomace level. It was also suggested that nonstarch polysaccharides such as pectin reduce the availability of starch for digestive enzymes and therefore reduce starch digestibility (13).

The use of fruit pomace usually results in extrudates with a sweet and fruity taste (132; 133). However, the application of more than 30% defatted blackcurrant seeds in cornmeal extrudates decreased overall sensory acceptability, whereas 10% produced the best results (134). The method of processing fruit by-products was also shown to influence sensory characteristics, since extrudates with blackcurrant pomace from nonenzymatic treated press residues had higher sensory scores than extrudates with blackcurrant pomace that experienced conventional enzymatic treatment before pressing (126).

As regards nutritional benefits, a number of studies showed that total phenolic content and antioxidant activity of fruit pomace decreased during extrusion processing (124; 133-136). High screw speed resulted in reduced antioxidant activity during extrusion because of the destruction of antioxidants under high shear stress (124). The influence of extrusion processing on individual phenolic compounds was also studied; flavonoids have been recognized as extremely thermolabile (134), and anthocyanin retention was shown to depend on processing conditions such as barrel temperature, screw speed and feed moisture (137; 138).

6. Conclusions

Enhancing the fiber content of bakery products has been an important theme of the cereal science literature, with fruit pomace from a great diversity of sources regularly studied in a range of bakery products, and offering additional benefits alongside increases in dietary fiber. The current review has surveyed the usage of fruit pomace in bread, cakes and muffins, cookies and biscuits, and extruded products. Prominent themes include the generally damaging effects of fiber on the aerated structure of cereal-based food products and ways to alleviate these, acceptable levels of fiber incorporation, and associated benefits in terms of flavor and increases in beneficial bioactive compounds. In general, fruit pomace can be included at significant levels in cereal-based products while maintaining consumer acceptability, enhancing the healthiness of the products and potentially conferring distinctiveness, while also offering valuable diversion of pomace from waste back into the food chain.

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Table 1

Use of fruit pomace as ingredient in soft bakery products

Application	Fruit pomace	Amount of pomace used in	Reference
Wheat flour Replacement	Apple	5, 10 or 15% apple pomace in cakes	(62)
		up to 32% apple skin powder in muffins	(87)
		50% powered apple pomace in muffins	(85)
	Grape	10, 15 or 20% wine grape pomace in muffins	(67)
		10, 20 or 30% grape by-product in muffins	(91)
	Mango	20, 40 or 60% mango pulp fibre waste in muffins 10, 20 or 30% dry mango pulp fibre waste in muffins	(89)
	Melon	2.5, 5 or 7.5% melon skin and rinds powders in cakes	(102)
	Orange	10 or 15% dietary fibre-rich orange bagasse in muffins	(90)
Fat replacement	Melon	5, 10 or 15% melon skin and rinds powders in cakes	(102)
	Peach	2, 3, 4, 5 or 10% peach dietary fibre in muffins	(101)
Sugar replacement	Apple	30% fibre, water and rebaudioside A in muffins	(107)
		30, 60 or 100% fibre, water and rebaudioside A in muffins	(9)

Table 2
Use of fruit pomace as ingredient in brittle bakery products

Type of pomace	Pomace processing prior to use	Pomace application	Reference
Mango peels	Washing with water, drying at 50 °C in cross-flow drier for 18 h to 10% moisture, powdering with a hammer mill, sieving through 150 µm sieve.	Replacement of 5, 7.5, 10, 15 or 20% wheat flour in biscuits	(108)
Apple pomace	Grinding in meat grinder, drying on drum dryer at 162.8 °C surface temperature, further drying in a cabinet dehydrator at 55 °C for 3 h, subsequent milling.	Replacement of 30, 40 or 50% oatmeal in cookies	(120)
	Freezing at -24 °C. Drying: (a) Convective forced air drying at 40 °C; (b) Impingement drying at 110 °C, or (c) Freeze drying at -55 °C and 17.33 Pa. Grinding with laboratory mill fitted with a 0.5 mm screen, vacuum packaging, frozen storage (-24 °C).	Replacement of 15 or 20% wheat flour in cookies	(118)
	Convective drying at 40 °C for 8 h, milling in grinder mill, sieving to obtain a particle size of 160-270 µm.	Replacement of 5, 10 or 15% wheat flour in biscuits	(111)
	Drying, grinding to pass through a 50 mesh sieve. Mixing with distilled water for 1 h, 3 min homogenization with an ultrasonic homogenizer, autoclaving at 121°C for 10 min. Treatment with Viscozyme at 40 °C for 1 h, boiling for 5 min, filtering and freeze drying to obtain the further used pectin-enriched material (PEM).	Replacement of 10, 20 or 30% shortening with PEM gels in cookies	(116)
	Drying in a double-drum drier at 162.8 °C, 80 psi, 2.5 rpm, or freeze drying. Grinding to <20 mesh with Wiley Mill.	Replacement of 40% wheat flour in the crust, and of 40% oats in the filling of Oriental moon cookies	(85)

Citrus peels	Chopping, drying at 40 °C for 14 h, milling in grinder mill, sieving to obtain particle size of 160-270 μm.	Replacement of 5, 10 or 15% wheat flour in biscuits	(110)
Grapefruit peels	Chopping, drying at 40 °C for 14 h, milling in grinder mill, sieving to obtain particle size of 160-270 μm.	Replacement of 5, 10 or 15% wheat flour in biscuits	(109)
Orange peels	Drying in forced-air convection oven at 80 °C for 12 h to 9% moisture, milling to particle size <4.2 mm, extrusion at barrel temperatures of 83, 100, 125, 150 or 167 °C with moisture content 22, 25, 30 or 38%, and screw speed 126, 140, 160, 180 or 194 rpm.	Replacement of 5, 15 or 25% wheat flour in sugar-snap cookies	(117)
	Washing, pressing in helical press, drying at 50 °C for 24 h, milling in grinder mill to particle size <0.2 mm.	Replacement of 5, 15 or 25% wheat flour in biscuits	(112)
Guave bagasse	Frozen storage at -18 °C, drying at 55 °C until constant weight.	Incorporation of 5, 10 or 15% in cookies	(17)
White grape pomace	Freeze drying to 2-4% moisture, sieving to separate skins from seeds, milling to particle size <150 μm.	Replacement of 10, 20 or 30% wheat flour in wheat biscuits	(114)
Grape marc extract (GME)	Freeze drying, crushing, homogenization, mixing with ethanol and citric acid, centrifugation, concentration of supernatant in vacuum evaporator.	Replacement of 125 mL water by 225 mL GME and 50 mL water	(119)
Raspberry pomace	Pomace obtained in dry form, used in crumbled or non-crumbled form.	Replacement of 25 or 50% wheat flour in cookies	(121)
Apricot kernel flour	Washing of kernels, air drying at 30 °C for 2 wks, cracking, soaking in warm water for 1 h, drying for 2 h, grinding in coffee grinder.	Replacement of 10, 20, 30, 40 or 50% shortening in low-fat cookies	(123)
Pomegranate	Washing, cutting, drying at 40 °C for 5-6 h,	Replacement of	(115)

peel powder	powdering in blender, sieving through 250 µm sieve.	2.5, 5, 7.5 or 10% wheat flour in biscuits

Table 3
Use of fruit pomace as ingredient in extruded products

Type of pomace	Pomace application	Reference
Grape pomace	0, 2, 6, 10 or 12.7% in barley flour	(127,131,132)
Apple pomace *Rosehip pomace*	0, 10, 15 or 20% in corn grits	(133)
Defatted black currant seeds	0, 10, 30 or 50% in cornmeal	(134)
Black currant pomace	27-28% black currant pomace, 38-39% mixture of barley flour, oat flour and oat bran, and 14-15% potato starch	(126)
Bilberry extract	2% in maize	(137)
Apple pomace	0, 17, 22 or 28% in corn flour	(125, 130)
	22-28% in pregelatinized starch and other ingredients	(129)
Blueberry pomace	30% in white sorghum	(135,136)
Pineapple pomace	0, 10.5 or 21% in corn flour	(127)
Cranberry pomace	30, 40 or 50% in corn starch	(138)
Orange peel, grape seeds, tomato pomace	3-7% in rice grits, durum clear flour, defatted hazelnut flour	(128)