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*Review*

# Physical properties of shortbread biscuits enriched with dried and powdered fruit and their by-products: a review

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A b s t r a c t. Fruit fortification is a promising strategy for improving the nutritional and functional properties of shortbread biscuits, as fruit contains various bioactive compounds that provide potential health benefits. This study aimed to investigate the contemporary patterns in incorporating dried and powdered fruit and their by-products into shortbread biscuits, with a focus on alterations in their physical properties such as geometrical characteristics, weight, colour and texture. Moreover, the methods used for obtaining fruit powders were discussed. The research was based on the analysis of papers published within the last six years, retrieved from Scopus, Web of Sciences, and Google Scholar databases. It has been found that drying and size reduction are crucial processes that determine the quality of fruit powders. Most importantly, the selection of the type, particle size, and quantity of the additive, as well as its processing conditions, are critical factors in achieving the desired physical characteristics of the final product. The addition of various fruits and their by-products affects the weight and geometric characteristics of the resulting biscuits. The colour of the fortified biscuits undergoes significant changes, with the brightness level typically being reduced and redness increasing. In particular, depending on the type of additive used, it can cause an increase or a decrease in shortbread hardness.

K e y w o r d s: dried and powdered fruit, physical properties, cookie texture, colour, spread ratio

## INTRODUCTION

Cereals and their products are basic foods and are also one of the crucial and oldest components of human diets. Globally, they contribute more than 50% of the energy intake to the human diet (Laskowski *et al.*, 2019). Wheat, which is one of the most significant cereals, gets processed into various types of food for consumption because of its ease of processing (Ubbor *et al.*, 2022). For example, baked goods are frequently purchased by most consumers, this is independent of their age or social status (Dziki *et al.*, 2021; Marcinkowska-Lesiak *et al.*, 2018). One of these baked products is biscuits, a popular, easily accessible, convenient, ready-to-eat, and often low-cost snack (Ikuomola *et al.*, 2017; Szpicer *et al.*, 2021). Biscuits are a good energy source rather than playing a meaningful role in providing nutrition. Indeed, due to their high fat and sugar content, they are a matter of public interest in terms of general health. A high consumption of these ingredients is often related to the risk of developing civilization diseases, including diabetes, cardiovascular problems, and obesity (Nogueira *et al.*, 2018). In considering the challenges posed by the task of dealing with nutritional insufficiencies, various forms of food enrichment may offer at least a partial solution to this problem (Poniedziałek *et al.*, 2020). Various popular fruits provide a source of energy, nutrients, and active substances, such as polyphenols, vitamins, minerals, and fibre (Karasawa *et al.*, 2018). Fruit consumption performs an essential role in both cardiovascular disease and cancer prevention (Karasawa *et al.*, 2018; Swallah *et al.*, 2020; Zhao *et al.*, 2015). Various studies in recent



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years have provided information concerning the health-promoting effects of the bioactive compounds in fruit. They are considered to be antioxidants (Nowak *et al.*, 2022; Żołnierczyk *et al.*, 2021), anti-aging (Dhalaria *et al.*, 2020; Kopustinskiene *et al.*, 2021), anticancer (Kitic *et al.*, 2022; Kowalska, 2021), antimicrobial (Kitic *et al.*, 2022; Nowak *et al.*, 2022; Szymański *et al.*, 2022), anti-inflammatory (Baradaran Rahimi *et al.*, 2020; Gugliandolo *et al.*, 2019), hepatoprotective (Tabeshpour *et al.*, 2020; Tian *et al.*, 2021) neuroprotective (de Mello e Silva *et al.*, 2022; Kowalska, 2021), and antidiabetic (Khalid *et al.*, 2022; Żołnierczyk *et al.*, 2021). Due to their various beneficial properties, fruit have been increasingly utilized to enhance the nutraceutical and functional value of shortbread biscuits. The formulation of biscuits is also influenced by cultural traditions and the availability of local ingredients (Giuffrè *et al.*, 2022), including regional fruits (Mashau *et al.*, 2022; Saeed *et al.*, 2022) and their derivatives (Pinto *et al.*, 2023). The growing interest in incorporating fruit into product formulas has led to an increase in the use of flours made from locally available crops (Mashau *et al.*, 2022). The integration of regional ingredients into cookie formulations is aligned with the non-waste technologies movement, which is centred around decreasing food wastage and encouraging environmentally sound practices within the food sector. This study aimed to investigate the contemporary patterns in augmenting shortbread biscuits with fruit and their by-products, focusing specifically on alterations in their physical properties. The papers from the last six years received particular attention, with the use of Scopus, Web of Sciences and Google Scholar databases.

## PRODUCTION OF FRUIT AND FRUIT BY-PRODUCT POWDERS

Shortbread biscuits are produced with little or no added water. Fruit and fruit by-products (FBP) are usually characterized by their high water content. Therefore, using them in a higher proportion in a biscuit recipe requires their dehydration and size reduction. Drying extends their shelf life and allows them to be crushed into a powder (Santos *et al.*, 2022). The powders prepared in this way can be used as an additive not only in biscuits but also with various types of food such as bread (Różyło *et al.*, 2019), pasta (Wójtowicz *et al.*, 2019), ice cream (Utpott *et al.*, 2020), gelatine desserts and extruded cereals (Bakmohamadpor *et al.*, 2021) or edible films (Rojas-Bravo *et al.*, 2019). Such powders are concentrates of many bioactive compounds with unique compositions (Santos *et al.*, 2022). They are also rich in dietary fibre (Najjar *et al.*, 2022; Pathania and Kaur, 2022). Fibre has many health benefits. Among other things, it binds bioactive compounds and allows them to be released in the gut during the fermentation process by gut microbiota (Gómez and Martinez, 2017). Size reduction additionally increases the bioavailability of active compounds (Becker *et al.*, 2017). Therefore, if the dehydration and size reduction of fruit and FBP is properly carried out it, this facilitates the attainment of good quality powders with many applications, especially in the food industry.

### Drying

The process of the dehydration of fruit and FBP can be carried out using various methods. Drying is most frequently used for this purpose. This method of food preservation allows for the attainment of material with a long shelf-life and reduces transport weight. Moreover, it decreases the water content in the raw material up to a level which allows for a proper size reduction to be performed. Many methods are used to dry fruit and FBP, which are then added to biscuits, these include air-drying (De Albuquerque *et al.*, 2016), vacuum drying (Tańska *et al.*, 2016), freeze-drying (Antoniewska *et al.*, 2019) and others (Karam *et al.*, 2016). However, the best quality dried material is usually obtained as a result of freeze-drying (Demirkol *et al.*, 2018) followed by vacuum drying (Michalska *et al.*, 2017) and air-drying (Barbosa *et al.*, 2015). Many previous studies have indicated that an adequate drying method should be precisely selected depending on the processed raw material and phytochemicals targeted to be extracted (Michalska *et al.*, 2017; Papoutsis *et al.*, 2017). Demirkol and Tarakci (2018) dried grape (*Vitis labrusca* L.) pomace powder using freeze-drying and air-drying methods. They found that the powder obtained using freeze-drying had the highest content of phenolic compounds as compared to pomace dried using hot air. Hot air drying also yielded favourable results if the process temperature did not exceed 80°C. Additionally, the freeze-dried powder was the brightest one and had the highest proportion of red colour compared to the product obtained by convective drying, whereas the powder obtained by hot air drying was the most yellow. Other authors (Michalska *et al.*, 2017) studied the impact of different drying techniques on the properties of powder obtained from blackcurrant pomace. They showed that the powder obtained during freeze-drying was characterized by the highest values of brightness, redness, and yellowness, as well as the highest content of phenolic compounds, as compared to the product obtained using hot air drying and the microwave-vacuum method. Moreover, an increase in the drying temperature contributed to the degradation of the phenolic compounds and a decrease in the antioxidant activity of the powder. Barbosa *et al.* (2015) studied the impact of various dehydration methods on the properties of orange juice powder and found that air-drying resulted in a much darker product as compared to freeze-drying and spray drying. Also, the colour components responsible for the yellowness and redness of the powder were present in significantly higher concentrations after convective drying as compared with the other dehydration methods. However, the best colour retention was found for the freeze-dried powder. Additionally, the highest content of vitamin C was noted in powder produced using the spray drying and freeze-drying methods. The studies conducted by Lee *et al.* (2012) also revealed that the highest quality Citrus "Hallabong" fruit powder in terms of colour and vitamin C content was obtained from freeze-dried fruit. On the other hand, freeze-drying is the most energy-consuming process and should be used in particular for valuable raw materials with a high nutraceutical potential (Duan *et al.*, 2016; Dziki, 2020). It is important to note that both freeze-drying and vacuum-drying can be carried out at a low temperature and with a limitation in the concentration of oxygen, thus maximizing the preservation of bioactive compounds in food (Schulze *et al.*, 2014). The loss of flavonoids, phenolics, flavonols and flavones as well as catechins is very low as compared with the loss of these components during hot-air drying (Zhang *et al.*, 2005). It should also be emphasized that the moisture content of freeze-dried food is usually very low (2-4%). As a consequence, fruit and FBP are very brittle and easy to grind (Oyinloye *et al.*, 2020). In order to obtain dried material with such a low moisture content using air-drying, the temperature of the air must be at the level of 80-90°C. Such a high temperature has a negative influence on the quality of the sensitive compounds such as vitamins and phenolic compounds (Sousa *et al.*, 2017). On the other hand, food that has been air-dried at a lower temperature (30-40°C) usually has a high water activity and a shortened shelf life. Moreover, the size reduction step is difficult as a result of the increased plasticity of such materials. Therefore, obtaining powders from fruit and FBP, and freeze-drying in particular, is recommended (Sousa *et al.*, 2017). Fruit powder can also be obtained directly by spray-drying (Tze *et al.*, 2012). However, this technique has a limitation mainly with regard to juice drying. In addition, a high drying temperature decreases the content of sensitive bioactive (Shishir *et al.*, 2017).

Grinding

Dry grinding is a basic and very important process used to obtain powders from fruit and FBP. Such powders are condensed sources of fibre, minerals, vitamins and many phytochemicals with a proven antioxidant activity (Karam *et al.*, 2016) and thus they are essential for the human diet (Andrés *et al.*, 2004). Besides their composition, the properties of the powders are determined to a substantial extent based on the estimation of the particle size and particle-size distribution. However, at present there are only a limited number of papers in the literature studying the effect of size reduction on the overall quality of fruit and FBP powders. The ground fruit and FBP used for biscuit fortification usually have particles below 500 µm (Santos *et al.*, 2022). On the other hand, more fine grinding usually increases the extractability of bioactive compounds and, as a consequence, enhances the antioxidant capacity of fruit powders (Zhang *et al.*, 2014). The size reduction efficiency depends on many factors. Most particularly, the moisture content of the plant materials determines the ease with which they may be ground. Plant raw materials with a high moisture content are less susceptible to size reduction, especially during impact grinding because water acts as a plasticizer. Consequently, a lower yield of fine particles is obtained and the grinding energy requirements are increased (Jung *et al.*, 2018). Additionally, the mechanical properties of foods have an important influence on the results of grinding (Oyinloye and Yoon, 2020). During the air-drying process, a significant shrinkage and collapse of the fruit structure is observed. Consequently, the dried product is harder and less brittle than the freeze-dried fruit (Qing-guo *et al.*, 2007). Shrunken fruit are also reduced in terms of their poor appearance and density (Karam *et al.*, 2016). These changes have a negative influence on the grinding results. A more dense and hard structure in the dried raw materials requires more energy for size reduction and produces particles which are less fine as compared with materials that have a softer structure (Oyinloye and Yoon, 2020). The grinding technique applied also influences the particle size of dried fruit. Different mills may be used to obtain fruit powders. However, impact mills are most often applied for these purposes (Gao *et al.*, 2020). Ultra-fine grinding (micronization) most particularly, allows for powders with very fine particles (below 10 µm) to be obtained. In this process, such methods as jet milling, ball milling and vibration milling are usually employed (Karam *et al.*, 2016). Zhang *et al.* (2020) studied the grinding process of dried *Lycium ruthenicum* Murray fruit using different size reduction methods. The results showed that the fruit ground using superfine-grinding were characterized by smaller particle sizes than the fruit powdered using shear-breaking and ball-milling. Most importantly, such superfine-ground fruit powders showed a higher content of phenolic compounds and antioxidant capacity than other powders. Other authors have found that the ultra-fine grinding of lychee juice by-products promotes the release of bound phenolic compounds from the food matrix (Xiong *et al.*, 2021). In another study (Liu *et al.*, 2020), the authors analysed the effects of drying and size reduction methods on the physicochemical properties of hawthorn fruit powder. They showed that a combination of freeze-drying and jet milling was the most effective technique for reducing the hawthorn fruit and allowed for the attainment of powder with a higher water solubility index, a higher phenolic content, and a more natural colour as compared to the powders obtained using freeze-drying and shear pulverization. A similar study was conducted by Gao *et al.* (2019). They studied the properties of coarse and superfine powders obtained from dried downy rose-myrtle berries (*Rhodomyrtus tomentosa* (Ait.) Hassk). These fruit are a rich source of anthocyanin and can be used both as a functional food additive or as a food colorant (Liu *et al.*, 2012). Superfine grinding resulted in a brighter and more vividly yellow powder as compared with coarse grinding. Most importantly, the total amount of phenolics and anthocyanins released from the fine powders was higher than that released from the coarse powders. This tendency was observed both before and after gastrointestinal digestion. It should be also highlighted, that superfine grinding increased the bioaccessibility of ground rose-myrtle berries.

It is also worth emphasizing that during intense grinding, due to friction, the temperature of the ground material may rise to over 90°C ( *et al.*, 2016). With the increase in temperature, there may be a decrease in the solubility of the powder, as well as a loss of some nutrients or other active substances (Ghodki and Goswami, 2016). Therefore, it is important to control the temperature during the plant material grinding process and avoid excessive heating (Ghodki and Goswami, 2015). Kaur and Srivastav (2018) studied the influence of cryogenic grinding on the physicochemical properties of mango (*Mangifera indica* L.) peel powder and found that this process allows for the attainment of better quality FBP powder in terms of bioactive compounds and antioxidant activity. In cryogenic grinding, the material to be ground is frozen to a very low temperature, which is typically below the glass transition temperature of the material, this makes it more brittle and easier to grind. However, this process is expensive and rarely used for fruit powder production. In summary, drying and size reduction are crucial processes which determine the quality of powdered fruit and FBP. These processes are also energy-intensive, therefore the methods used to dry and grind fruit and FBP should be precisely selected. Figure 1 summarises the most common methods of obtaining fruit and fruit-by-product powders.

## PHYSICAL PROPERTIES OF BISCUITS ENRICHED WITH FRUIT AND FBP

The physical characteristics of biscuits primarily depend on the attributes and amounts of the main ingredients, including flour, fat, and sugar (Ashwath Kumar and Sudha, 2021). Fruit and FBP incorporation may also modify the texture, dimensions and colour of the product, which has become a matter of interest for researchers in recent years. The influence of fruit supplementation concerning the modification of the physical properties of shortbread biscuits is reported in the following section and summarized in Table 1. By analysing the literature reports concerning the possibility of using dried and powdered fruit to enrich biscuits, it may be observed that a relatively small number of the studies concern the use of fruit, and it is mainly by-products which are used for this purpose.

### Geometrical characteristics and weight

The size, shape, and spread of biscuits are influenced to a great extent by the physicochemical component parameters and production conditions (Nakov *et al.*, 2020; Mohamed *et al.*, 2017). In order for the biscuits to be considered good quality, they should have a large diameter (Zarroug *et al.*, 2021). Studies have indicated that there is a close negative relationship between the gluten level and the diameter of the biscuits (Korese *et al.*, 2021). Additionally, it was found that the higher the gluten content, the less the biscuit dough spreads during baking. The spread ratio (spread factor) is determined by calculating the width or diameter of the biscuits divided by their thickness, therefore it may be expressed as a percentage or without specifying the unit used (Rocha Parra *et al.*, 2019; Yang *et al.*, 2022). A high spread ratio is a desirable feature of biscuit quality, which depends on the spreading speed and

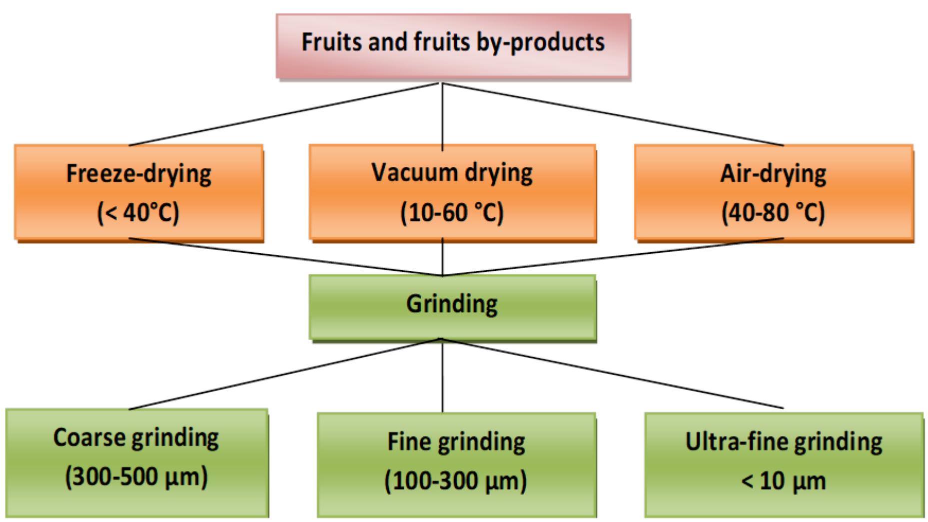


**Fig. 1**. Most common methods for making flour from fruits and fruit by-products (FBP).

**Table 1.** Effect of fruit powder enrichment on physical properties of shortbread cookies

| Raw material and the level of wheat flour replacement | Obtaining powders | W | D | T | Wd | V | SR | L | H | F | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Apple endocarp (5, 10, 15%) | Endocarp of apple was dehydrated using a lyophiliser at -40°C and 0.998 mbar for 96 h, ground using a knife mill, and sifted through a 35-mesh granulometric sieve (0.425 mm). | - | - | \| | - | - | ↑ | ↓ | - | - | (de Toledo *et al*., 2017) |
| Apple peel (4, 8, 16, 24, 32%) | Peels were blanched in hot water for 30 s to prevent enzymatic darkening, washed, and dried at 60°C for 48 h. They were then finely ground into particles smaller than 0.5 mm. | - | - | ↓ | \| | ↓ | - | ↓ | - | - | (Nakov *et al*., 2020) |
| Apple pomace (15, 30%) | Pomace was dried using a forced convection oven at 50°C for 24 h and then ground to three particle sizes (362, 482, 840 μm). | \| | ↓ | - | ↓ | - | - | ↓ | ↑ | - | (Rocha Parra *et al*., 2019) |
| Apple pomace (5, 10, 15, 20, 25%) | Pomace was dried through convective dryers at 58-60°C and ground into a fine powder. | - | - | ↓ | \| | - | ↑ | ↓ | - | - | (Usman *et al*., 2020) |
| Banana flour cv. Luvhele, Mabonde; unripe (10, 15, 20, 30%) | Pulp pieces were then air-dried in the oven at 70°C for 12 h, milled to obtain flour, and sifted through a 100 mesh sieve separately for each cultivar. | ↑ | ↓ | ↑ | - | - | ↓ | ↓ | ↑ | ↑ | (Mashau *et al*., 2022) |
| Banana flour cv. Muomva red; unripe (10, 15, 20, 25%) | Banana fingers were peeled, cut into 5 mm pieces, exposed to citric acid (10 g $L^{-1}$), left for 10 min, drained, and then dried in a forced-air oven at 70°C for 12 h. Then the material was ground into homogeneous flour. | ↑ | \| | \| | - | - | \| | ↓ | ↑ | ↑ | (Mabogo *et al*., 2021) |
| Bergamot pulp flour (*Pastazzo*) (2.5, 5, 10, 15%) | Bergamot fruits were processed by removing the flavedo and juice. *Pastazzo* was pressed and dried at 45°C with a tangential air flow dryer until 12.6% moisture content was reached and finely powdered (30 μm) | - | - | - | - | - | - | ↑ | ↑ | - | (Laganà *et al*., 2022) |
| Cactus peel (2.5, 5, 7.5, 10%) | Peel was dried at 45°C in a hot air oven until constant weight, ground using a coffee grinder, and sieved. | ↑ | - | ↑ | - | - | ↓ | ↓ | - | - | (Sh El-Shahat *et al*.) |
| Camu-camu co-product (5, 10, 15, 20%) | Seeds, peels, and residual pulp were dried at different temperatures using a forced-air oven and then ground to 16 mesh using a knife mill. | - | - | - | - | - | - | - | ↑ | - | (das Chagas *et al*., 2021) |
| Chiku fruit pomace (4.5, 7, 9.5, 12%) | Fruit slices were mashed and the juice extracted through a muslin cloth. The remaining pomace was blended with water, passed through a muslin cloth, dried for 6 h at 58±2°C, ground, and sieved through a 180 μm sieve. | - | ↓ | \| | - | - | \| | ↓ | ↓ | - | (Asadi *et al*., 2021) |

**Table 1.** Continuation

| Raw material and the level of wheat flour replacement | Obtaining powders | W | D | T | Wd | V | SR | L | H | F | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Date palm fruit (10, 20, 30, 40, 50%) | Fruit pulp with peel was dried at 75°C for 6-8 h in an oven, milled by hand, and passed through a 0.35 mm mesh sieve to achieve a fine powder. | ↑↓ | ↑ | ↑↓ | - | - | ↑ | - | ↓ | - | (Peter *et al*., 2017) |
| Dragon fruit (30, 40, 50, 60%) | Fruit was prepared by washing, peeling, and slicing it thinly. After being dried at 70°C for 48 h, the material was crushed into 300 mm particles and sieved. | ↑ | ↓ | ↓ | - | ↓ | ↑ | - | - | - | (Pawde *et al*., 2020) |
| Goji berry by-product (10, 20, 30, 40%) | Waste left after goji concentrate extraction was stored at −18°C and dehydrated at 70°C for 10 h to reduce moisture content to below 13%. The resulting by-product was ground to pass through a 0.85 mm screen. | - | ↓ | ↓ | - | - | ↑ | - | ↓ | ↓ | (Bora *et al*., 2019) |
| Grape peels (5, 10, 15%) | Grape skins were dried for 6 days at room temperature and kept in plastic bags until use. Then, they were ground and sieved to obtain particles between 400 and 750 µm in diameter. | - | - | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | ↓ | (Kuchtová *et al*., 2018) |
| Grape pomace (2, 4, 6, 8%) | Leftover skin and seeds were separated from the pulp and treated as industrial waste. The pomace was then dried at 60°C for 12 h in a hot air oven and pulverized to obtain powder. | \| | \| | - | - | - | \| | ↓ | - | - | (Theagarajan *et al*., 2019) |
| Grape seeds (5, 10, 15%) | Grape seeds were dried for 6 days at room temperature and kept in plastic bags until use. Then, they were ground and sieved to obtain particles between 400 and 750 µm in diameter. | - | - | ↓ | ↓ | ↓ | ↑ | ↓ | ↓ | ↓ | (Kuchtová *et al*., 2018) |
| Kinnow mandarin peel and pomace (5, 10, 15, 20%) | Peel and pomace were dried for 48 h at 45°C using a cabinet drier before being milled, scalded, and passed through a 0.5 mm sieve. | - | ↓ | ↑ | - | - | ↓ | ↑ | - | - | (Yaqoob *et al*., 2021) |
| Kiwi edible portion and peel (5, 10, 15, 20%) | Kiwi fruit edible portion and peel was dried in an oven at 55°C for 16-18 h until the moisture content was ≤ 10 % and ground into a powder. | - | \| | ↑ | - | - | ↓ | ↓ | ↑ | - | (Mohamed *et al*., 2017) |
| Melon peels (5, 10, 15%) | Melon peels were dehydrated using a lyophiliser at -40 °C and 0.998 mbar for 96 h, ground using a knife mill, and sifted through a 35-mesh granulometric sieve (0.425 mm). | - | - | ↑ | - | - | ↓ | ↓ | - | - | (de Toledo *et al*., 2017) |
| *Parinari curatellifolia* peel (5, 10, 15, 20%) | Peels were dried at 60°C for 4 h in an oven and ground into fine flour using a miller, followed by passing the flour through a 250 µm sieve mesh. | ↓ | ↑ | ↓ | - | - | ↑ | ↓ | ↑ | - | (Ramashia *et al*., 2021) |

**Table 1.** Continuation

| Raw material and the level of wheat flour replacement | Obtaining powders | W | D | T | Wd | V | SR | L | H | F | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Passion fruit epicarp (3, 6, 9%) | Passion fruit epicarp was dried in an air flow oven at 60°C until it reached a constant weight. Then, it was ground and sifted through a 100-mesh screen. | - | ↓ | ↓ | - | - | \| | ↓ | ↑ | - | (Ning *et al.*, 2021) |
| Pineapple central axis (5, 10, 15%) | Central axis of pineapple was dehydrated using a lyophiliser at -40°C and 0.998 mbar for 96 h, ground using a knife mill, and sifted through a 35-mesh granulometric sieve (0.425 mm). | - | - | ↓ | - | - | ↑ | ↓ | - | - | (de Toledo *et al.*, 2017) |
| Raspberry pomace flour (10, 15, 20%) | Pomace was dried in a convection oven at 50°C for 24 h and then ground into flour using a food mill with a particle size of 0.2 mm. | - | - | - | - | - | - | ↓ | ↑↓ | ↑ | (Tarasevičienė *et al.*, 2021) |
| Red currant pomace flour (10, 15, 20%) | Pomace was dried in a convection oven at 50°C for 24 h and then ground into flour using a food mill with a particle size of 0.2 mm. | - | - | - | - | - | - | ↓ | ↑↓ | ↓ | (Theagarajan *et al.*, 2019) |
| Sea buckthorn by-product powder (5, 10, 15, 20%) | Leftover waste from crushed berries was processed into flour with particles ranging from 40 to 75 µm in size after being dried, ground, and sifted. | - | - | - | - | - | - | - | \| | \| | (Janotková *et al.*, 2021) |
| Strawberry pomace flour (10, 15, 20%) | Pomace was dried in a convection oven at 50°C for 24 h and then ground into flour using a food mill with a particle size of 0.2 mm. | - | - | - | - | - | - | ↓ | ↓ | ↓ | (Theagarajan *et al.*, 2019) |
| *Zizyphus lotus* fruit powder (15, 30, 45, 100%) | Fruit edible parts were manually separated from seeds, sun-dried for 120 h, ground, passed through a 75-µm sieve. | \| | \| | ↑ | - | - | \| | ↓ | ↑ | ↑ | (Zarroug *et al.*, 2021) |

W – weight, D – diameter, T – thickness, Wd – width, V – volume, SR – spread ratio, L – lightness, H – hardness, F – fracturability; ↑ – increase, ↓ – decrease, | – no significant difference compared to the control, - – not determined.

settling time. Both of these parameters are closely related to the viscosity of the dough (Baumgartner *et al.*, 2018). Moreover, the spread ratio of biscuits is negatively correlated with their hardness (Chauhan *et al.*, 2016). The weight and diameter variations in baked goods are often reported in terms of the percentage (%) of the initial weight. This parameter is typically determined by measuring the weight of the baked goods prior to baking and again one hour after baking (de Toledo *et al.*, 2017).

Zarroug *et al.* (2021) investigated the impact of Tunisian *Ziziphus lotus* fruit powder on the nutritional and physical properties of biscuits. The inclusion of sun-dried and milled fruit produced no significant effect on the weight, diameter and spread ratio of shortbreads. However, the incorporation of *Ziziphus lotus* powder led to an increase in the thickness of the biscuits. In particular, biscuits with 100% fruit flour were found to be 22% thicker than those made with 100% wheat flour. Other authors (Pawde *et al.*, 2020) have suggested the use of powdered dragon fruit, which has significant nutraceutical and health-promoting qualities, as a functional additive in biscuits. The weight of shortbreads increased gradually with the addition of the powder, as compared to the control. The diameter of the cookies decreased, this was likely due to the higher spreading ratio caused by the addition of dragon fruit. As the percentage of dried and crushed fruit in the recipe increased, the thickness of the product decreased. The substitution also resulted in a reduction in volume, while increasing the density of the cookies. Hydrophilic substances, such as the fibres in dragon fruit, contributed to a decrease in the diameter of the cookie and the fluidity of the dough.

A study conducted by Mashau *et al.* (2022) involved substituting wheat flour with unripe banana flour derived from two varieties, Luvhele and Mabonde, in biscuits. The incorporation of banana flour resulted in an increase in the weight of the biscuits, which was significant at levels higher than 10% supplementation. This increase was attributed to the high fibre content and bulk density (quotient of the mass of the flour and its volume) of unripe banana powder. The diameter of the biscuits decreased with the addition of fruit flour, as compared to the control. The thickness of the enriched products was higher, and it increased with the increase in the levels of supplementation. The spread ratio of the fortified biscuits was found to be lower than that of the control (except for the biscuits with Mabonde variety of powder with a 10% incorporation level where a significant difference was noted). In their study, Mabogo *et al.* (2021) reported comparable results with the use of unripe banana flour (*cv*. Muomva red) as an enriching agent for biscuit production, this resulted in an increase in the weight of the biscuits. However, even with a 25% supplementation level, there were no significant changes observed in the diameter, thickness, and spread ratio.

Many papers in recent years have been focused on enriching biscuits with FBP. Apples are among the most frequently consumed fruit worldwide, and the growing demand for apple processing has resulted in an increase in by-products such as apple pomace and peel (Awasthi *et al.*, 2021). The research conducted by Rocha Parra *et al.* (2019) has indicated that the incorporation of dried apple pomace decreased the spread ratio of biscuits as compared to the control. The obtained results may be linked to the higher levels of dietary fibre present in this additive. Dietary fibre has a higher capacity to bind water, which may contribute to a reduction in the spread ratio (Kaur *et al.*, 2019). The apple pomace, which was dehydrated and crushed to three particles sizes (362, 482 and 840 μm), was used as a substitute to wheat flour in biscuit production. Of particular interest is the fact that in the products with the smallest particles the spread ratio was not affected by the amount of additive. However, in biscuits with larger particles (482 and 840 μm), a higher spread ratio was observed in products containing 15% pomace as compared to 30% (Rocha Parra *et al.*, 2019). In another study (Usman *et al.*, 2020) the width and thickness of the biscuits decreased with the increase in the content of dried and In this case, additive incorporation weakened the starch and gluten network, this was related to the width and thickness of the final product, and was also associated with the dilution of the concentration of storage proteins. It is worth noting that the spread factor increased by 20% in biscuits containing 25% apple pomace powder as compared to the control. In another study (Nakov *et al.*, 2020), the addition of apple peel powder to biscuits was also found to decrease their thickness. However, the width of the apple peel biscuits did not show any significant difference as compared to the control. de Toledo *et al.* (2017) introduced flour from pineapple, apple, and melon by-products into biscuit production. The percentage of weight variation in the fruit powder-enriched biscuits was analysed and found not to differ significantly from the control, the 15% apple endocarp supplementation was an exception as it produced a significantly lower degree of weight variation. The weight variability was demonstrated by the weight loss observed during baking, this suggests that biscuits enriched with 15% apple endocarp offered the most favourable production conditions. In turn, the highest increase in diameter variation was observed in products enriched with pineapple central axis. The authors indicated that this could be the result of the presence of bromelain, which may affect the peptide bonds of gluten. Apple endocarp flour significantly improved the thickness of the shortbread biscuits, while the pineapple flour significantly reduced it. Interestingly, the researchers found no substantial differences in the thickness of the biscuits between various concentrations of each additive. The study found that biscuits enriched with pineapple central axis produced the highest expansion factor, especially those containing 15% by-product concentration. On the other hand, biscuits with melon peels had the lowest expansion factor, but there were no significant differences found among the different by-product concentrations used. Furthermore, the expansion factor of the apple endocarp powder biscuits decreased as the concentration of fruit by-product powder increased.

The processing of kinnow mandarins yields a substantial quantity of by-products, consisting of peel (30-40%), pomace and seeds. These by-products amount to 50% of the fresh fruit mass, causing an unfavourable element in the overall economics of their processing (Mahawar *et al.*, 2020). Yaqoob *et al.* (2021) conducted an analysis on the impact of the use of dried and ground kinnow peel and pomace, as well as the supercritical kinnow peel liquid extract in biscuits. The thickness of the biscuits was only found to increase considerably with the use of kinnow pomace powder, a 30% increase for biscuits supplemented with 10% peel was noted as compared to the control. The inclusion of peel and kinnow pomace resulted in a notable reduction in biscuit diameter, which led to a decrease in the spread ratio of the biscuits. The main focus of industrial passion fruit production is on producing juice and nectar (Coelho *et al.*, 2017). According to Ning *et al.* (2021) the use of passion fruit epicarp flour in biscuits has resulted in a reduction in the diameter of shortbreads, regardless of the percentage of the additive used. However, the thickness of the products remained unaffected except for a 9% concentration of passion fruit epicarp flour, which caused a decrease in thickness. A slight but statistically significant decrease in the thickness of the biscuits, amounting to 4.76%, as compared to the unenriched product, was observed. The authors attributed this effect to a reduction in the gluten content due to the substitution of wheat flour with fruit powder. By contrast, the addition of passion fruit epicarp showed no significant effect concerning the spread ratio of the biscuits. Another by-product that may be used to enrich biscuits is berry pomace. During the processing of goji berries, a significant amount of waste is generated, it amounts to approximately 10 kg per 90 kg of goji juice obtained (Cruz-Chamorro *et al.*, 2023). In a recent study (Bora *et al.*, 2019), it was observed that the inclusion of goji berry waste obtained through the concentrate extraction of fruit led to a thickness reduction. The research revealed a noteworthy rise in the spread ratio upon the incorporation of goji berry pomace at inclusion levels of 20, 30, and 40%. The biscuits were enriched with a 40% pomace powder which resulted in a spread factor increase of 6% as compared to the control sample.

Another research experiment utilized cactus pear peel as an ingredient in shortbread biscuits (Sh El-Shahat *et al.*, 2017). Despite the fact that this by-product accounts for approximately 40-45% of the total weight of the fruit and is known to contain fibre and various bioactive compounds, it is commonly discarded, in much the same way as other fruit peels (Hernández-Carranza *et al.*, 2019). The incorporation of cactus peel flour at a concentration of 7.5% did not lead to any significant change in the weight, length, thickness and spread ratio of the biscuits. Minimal differences in the physical parameters were reflected in the high scores obtained during a sensory analysis of the biscuits with the addition of 7.5% dried and ground cactus peel (Sh El-Shahat *et al.*, 2017). The fruit of *Parinari curatellifolia* originate from a tree which is mainly found in Southern Africa and it requires immediate processing due to its high perishability, particularly in rural areas with limited refrigeration facilities (Benhura *et al.*, 2015). Ramashia *et al.* (2021) conducted a study to investigate the effect of *Parinari curatellifolia* fruit peel flour on the physical properties of biscuits. The results showed that the addition of peel powder increased both the diameter and the spread ratio of the products, while their weight and thickness decreased. The study highlighted the potential of the *Parinari curatellifolia* peel powder as a functional ingredient in baked goods.

The presented results indicate that FBP affects both the geometric characteristics and weight of the biscuits in different ways. These changes were found to be influenced by various factors such as the chemical composition and the percentage of additive used, the particle size of the fruit powder and the recipe of the biscuits.

## Colour changes

The colour of food products, particularly shortbread biscuits, plays a crucial role in determining the degree of consumer acceptance. This attribute is influenced by several factors, including the baking process and the ingredients used (Laganà *et al.*, 2022; Tarasevičienė *et al.*, 2021). In order to objectively evaluate the colour of the biscuits and allow for a comparison to be made between the different products, a colour space scale such as CIELab may be employed (Mota *et al.*, 2020). CIELab incorporates three main parameters: $L^*$, $a^*$, and $b^*$, which indicate the lightness (brightness), and the position between red (positive values) and green (negative), and also the position between yellow (positive) and blue (negative), respectively (Sujka *et al.*, 2022). Chroma ($C^*$), which is also known as the relative saturation, is a quantitative attribute of colourfulness owing to its ability to quantify the degree of deviation of a given hue (hue angle) from a grey colour with equivalent lightness. The equations below illustrates the relationship between $C^*$, $a^*$, $b^*$ and hue ($h°$) (Meléndez-Martínez *et al.*, 2003):

$$C^* = \sqrt{a^{*2} + b^{*2}}, \quad (1)$$

$$h^\circ = arctan \frac{b^*}{a^*}. \quad (2)$$

In recent years, researchers have shown considerable interest in investigating the impact of incorporating fruit additives on the colour attributes of shortbread biscuits. In a study conducted by Zarroug *et al.* (2021), it was demonstrated that the dark colour of the biscuits could mainly be attributed to the incorporation of *Ziziphus lotus* fruit powder as the principal ingredient, with the degree of discolouration being directly proportional to the quantity of the powder utilized. Biscuits formulated with 100% fruit powder in place of wheat flour displayed a colour profile akin to that of chocolate, which was primarily due to the presence of natural pigments from the *Ziziphus lotus* fruit, including polyphenols, in addition to the more pronounced caramelization and Maillard reactions occurring in the fortified products. The surface colour of the cookies was evaluated using a 9-point hedonic scale by a panel of 15 semi-trained assessors, and the results were consistent with the colorimetric measurements. The ratings for colour, taste, and aftertaste were found to increase with increases in the content of *Ziziphus lotus* fruit powder in the biscuits. Banana powder can also lead to a reduction in the brightness of the final product. Specifically, incorporating unripe banana flours into biscuits caused a darker coloration as the level of the additive increased as compared to the control (Mabogo *et al.*, 2021; Mashau *et al.*, 2022). In a study conducted by Mashau *et al.* (2022) it was found that biscuits fortified with unripe banana powder exhibited a more reddish hue ($a^*$) and a less yellowish hue ($b^*$) than the unfortified biscuits. By contrast, the biscuits enriched with unripe banana (Mabogo *et al.,* 2021) exhibited a lower degree of redness, as well as a lower degree of yellowness as compared to the control. The observed difference may be attributed to the treatment of the fresh fruit with citric acid to prevent oxidative browning, as well as inherent variations in fruit colour among the different varieties used.

In other studies (Rocha Parra *et al.*, 2019), it was found that biscuits fortified with apple pomace powders of different particle sizes exhibited a darker colouration, increased redness, and a decreased yellowness as compared to the control. The addition of 30% fruit powder resulted in a darker colour as compared to the 15% apple pomace supplementation. The biscuits enriched with the smallest particle size (362 μm) of powder had the darkest colour, with a 33% decrease in the $L^*$ value as compared to the control. It is interesting to note that there was no significant correlation observed between the particle size and the $L^*$ value which was mainly influenced by the browning reaction associated with the sugar content of the product. In addition, a decrease in particle size led to an increase in redness and a tendency towards reddish values. The products containing 15% apple pomace had a higher value of yellowness as compared to those with 30% of the additive, thereby indicating an increased tendency towards yellow values. Despite the observed colour changes, the sensory evaluation of cookies fortified with 15% pomace that were assessed using a 9-point hedonic scale did not exhibit any significant differences from the control in terms of appearance. Furthermore, there was no significant variance in terms of the sensory results concerning the powder particle size utilized. These outcomes provide further support for the hypothesis that the non-traditional colour of the final product is unlikely to impact its acceptability to consumers. As reported in the study by Usman *et al.* (2020), the fortification of biscuits with dried and milled apple pomace powder also resulted in a noticeable decrease in brightness, as evidenced by a significant reduction in the colour value of the biscuits as determined by a colour meter. The findings of Nakov *et al.* (2020) showed that the addition of dried and milled apple peel to the biscuit formula resulted in a decrease in both lightness and yellowness. By contrast, the redness values increased with increasing levels of powder, with the exception of the lowest enrichment level (4%), where the value of parameter $a^*$ was positive and did not differ significantly from the control sample. According to a study conducted by de Toledo *et al.* (2017) the pineapple, melon, and apple by-product flours also resulted in a lower level of biscuit brightness. Moreover, with the exception of the products containing 15% apple endocarp, the values of $C^*$ were not significantly different from those of the control. In addition, the colour of the fortified biscuits was closer to yellow. As the pH value increased, the products became brighter, and the value of the hue angle indicated a more yellow tone. A sensory evaluation, comprising a preference ranking test and an acceptance test, demonstrated that cookies fortified with 15% apple, pineapple, and melon by-products did not exhibit any notable differences in appearance compared to each other or the control. In their study, Tarasevičienė *et al.* (2021) investigated the impact of substituting wheat flour with raspberry, red currant, and strawberry pomace powders at various levels. The results showed that the control biscuits had the highest $L^*$ value, while biscuits with 20% strawberry pomace flour had the lowest. Furthermore, the enriched biscuits had a more intense red colour (with the exception of those containing 10% raspberry pomace) and a less intense yellow colour than the control. In a study by Laganà *et al.* (2022), it was observed that shortbreads fortified with Pastazzo bergamot fruit powder had a reduced baking time requirement to achieve their optimal colour, potentially leading to reduced manufacturing costs and thermal exposure. The upper surface of the fortified biscuits had a higher brightness level compared to the control, while no significant differences in terms of $L^*$ were observed on the lower surface. The addition of Pastazzo also resulted in a decrease in the redness of the shortbreads, particularly on the bottom side of the biscuits. Moreover, there was an increase in the yellowness and $C^*$, primarily on the lower surface of the baked products . The findings of another study conducted by Ning *et al.* (2021) revealed that products enriched with passion fruit flour exhibited a lower brightness and yellowness, and a higher redness as compared to the control sample. The total colour difference (ΔE) between the control and the enriched biscuits demonstrated a positive correlation with the concentration of passion fruit powder. These colour alterations may be attributed to multiple factors, including the darker shade of passion fruit flour as compared to wheat flour, and the chemical reactions that occurred during the baking process. According to a sensory evaluation on a 9-point hedonic scale, the change in the colour of the biscuits enriched with passion fruit powder resulted in lower ratings for their appearance as compared to the control. However, the difference was statistically significant only at 6 and 9% levels of supplementation, while no significant difference was observed at the 3% level. Ramashia *et al.* (2021) demonstrated that the incorporation of Parinari curatellifolia powder led to a decrease in the lightness and yellowness of the biscuits, while the redness values decreased. In a separate investigation, it was found that the addition of chiku fruit pomace powder led to a decline in the brightness, yellowness, hue angle, and colour intensity of the biscuits (Asadi *et al.*, 2021). The authors have suggested that the colour variations observed in the baked products may be attributed to both the ingredients utilized and the parameters of the production process. The ratings for the colour of chiku pomace biscuits, were obtained through an organoleptic analysis using a 9-point hedonic scale, they were lower in fortified cakes in comparison with the control. However, the difference was not statistically significant at the 4.5% supplementation level. Moreover, in previous research conducted by other authors (Mohamed, 2017), the incorporation of dried and ground edible portions and kiwi peels led to a gradual decrease in lightness, this was accompanied by an increase in the redness and yellowness parameters, which was dependent on the percentage of the various supplements used. In turn, Sh El-Shahat *et al.* (2017) performed studies which demonstrated that the biscuits fortified with cactus peel powder exhibited darker, redder, and less yellow colouration as compared to the unfortified ones. Other authors (Yaqoob *et al.*, 2021) investigated the effect of kinnow peel and pomace powder and also kinnow pomace extract supplementation on the colour properties of biscuits at different levels of wheat replacement. Interestingly, the brightest colour of the final products was observed in the pomace-supplemented products (the $L^*$ value increased by approximately 11% as compared to the control). Furthermore, the pomace reduced the redness and yellowness of most of the analysed components. The higher red intensity and yellowness in the peel powder as compared to the pomace powder biscuits most likely occurred due to the higher pigment concentration in the kinnow peel as compared to the pomace. The appearance/colour scores of cookies that were enriched with pomace and kinnow peel powders did not show a significant difference when compared to the scores of the control, this was determined using a sensory analysis which had a 9-point consumer scale. The findings produced by both the sensory and instrumental analyses suggest that the incorporation of certain fruit additives into biscuits which may cause changes in colour does not necessarily impact the overall consumer acceptance of the final product.

It was proven conclusively that fortifying biscuits with powders originating from diverse fruit and their by-products usually influences their colour to a significant extent. The existing research predominantly indicates that the incorporation of powders causes a reduction in the brightness level of the end product. Remarkably, the natural pigments in the additives used, the size of the particles, and the pH value were recognized as pivotal factors that impact the colour of the final product.

## Texture

Texture properties such as hardness and crispness, play a crucial role in determining the overall quality of biscuits, which influences their degree of acceptability to consumers (Fontana *et al.*, 2022; Mohamed, 2017). These properties are affected by a number of factors, including the quality of the flour used, the quantity and the type of sugar added, the lipid content, the additives used, the type of fat employed in the recipe and the water content. The maximum force necessary to induce deformation or fracture in a biscuit is the typical expression of its hardness (Fontana *et al.*, 2022; Szpicer *et al.*, 2021). It is also a critical indicator of the freshness and palatability of biscuits. Moreover, maintaining an appropriate level of hardness in biscuits is essential in order to prevent breakage during transportation (Theagarajan *et al.*, 2019). As yet, there is no clear definition of hardness in biscuits. This parameter is commonly assessed through a three-point bending test (Bora *et al.*, 2019; Mohamed, 2017) with the compression force (Barak *et al.*, 2014), cutting force (Dziki *et al.*, 2022) and fracture stress (Ning *et al.*, 2021) all being assessed. In the context of biscuit analysis, fracturability (crispness or brittleness) refers to the force required to induce the initial fracture or breakage of the biscuit during compression testing. This parameter is typically determined by subjecting the biscuit to increasing levels of force until the first peak force is reached, at which point the biscuit fractures or breaks (Korese *et al.*, 2021).

The use of various fruits and FBP powders for enriching biscuits significantly affects the texture of shortbreads. Zarroug *et al.* (2021) showed that the textural properties of shortbread biscuits were altered through the incorporation of *Ziziphus lotus* powder. Increasing the proportion of dried fruit increased both the hardness and fracturability of the biscuits. The findings of the instrumental analysis were corroborated by a decline in the sensory evaluation with regard to the texture quality of the cookies relative to the control. Mashau *et al.* (2022) conducted a study that investigated the effect of replacing wheat flour with unripe banana flour from two different varieties concerning the textural properties of crisp biscuits. The results indicated that the enriched biscuits were firmer than the control, with a maximum increase of up to 37% being observed for the Mabonde variety at a 10% supplementation level. This may be attributed to the interaction between the wheat and banana powder proteins, which results in the increased compressibility of the biscuits. Supplementation with unripe banana flour also resulted in higher texture fracturability values as compared to the control, which may be related to a higher protein content in the dough, resulting in a looser matrix. Furthermore, the study found that the type and amount of ingredients used, as well as the baking conditions, had a greater impact on the fracturability and hardness of the Mabonde powder biscuits than the Luvhele powder biscuits, thereby indicating better shape retention during transportation. Other studies (Mabogo *et al.*, 2021) have corroborated an increase in the hardness and fracturability of shortbreads when wheat flour is substituted with banana flour (obtained from the Muomva red variety). Other authors have determined the hardness of biscuits fortified with powdered passion fruit epicarp flour based on fracture stress (Ning *et al.*, 2021). The results showed an increase in the hardness of the biscuits with the percentage of this fruit powder used in the biscuit recipe. The greatest increase (56%) was observed when 9% of the additive was used. The proposed additive may have reduced the starch and gluten content and increased the fibre concentration in the baked products, which could have affected their texture. However, the fracture distance did not change significantly due to the effects of enrichment. The results obtained from a texture analysis were in agreement with the outcomes of the sensory analysis. The addition of 9% passion fruit epicarp flour resulted in lower ratings for appearance, aroma, texture, and overall acceptability, with significant differences occurring in comparison with the control. On the other hand, the texture ratings of cakes enriched with 3% and 6% additives did not show any significant difference as compared with the non-enriched products. In another paper (Rocha Parra *et al.*, 2019) the authors studied the impact of dehydrated apple pomace powder with varying particle sizes on the texture of enriched biscuits. It was observed that the biscuits supplemented with the pomace were significantly harder, this was indicated by the maximum breaking force measured during the three-point bending test as compared to the biscuits without supplementation. The results also showed that the hardness of the biscuits with pomace was the highest for those composed of the smallest pomace particles. These associations are probably related to the formation of a more compact dough structure under the influence of fine particles, which may increase hardness. Additionally, these results confirmed that the rheological parameters of dough have a substantial impact on the hardness of the final product. They found positive correlations between the elastic and viscous moduli of the dough and biscuit hardness and also the breaking force was negatively correlated with biscuit spread during baking. The results showed that there were no significant differences in the sensory evaluation of the texture of the fortified cookies as compared to the control. Additionally, it was found that particle size did not have a significant effect on cookie texture as determined using sensory evaluation. Nevertheless, some evaluators reported that the cookies containing the smallest particles had a firmer and more compact texture, while others noted that those enriched with pomace containing the largest particles had a slightly gritty texture, which however, was not regarded as unfavourable. It is notable that the taste ratings of the fortified cookies were significantly higher than those of the cookies without the additive. (Rocha Parra *et al.*, 2019). Other researchers partially replaced wheat flour with dried and powdered Pastazzo of bergamot fruit (Citrus bergamia) (Laganà *et al.*, 2022). Based on the results of a three-point bending test, shortbread biscuits made solely from wheat flour were found to be softer than those enhanced with bergamot Pastazzo flour. The hardest biscuits were obtained with 15% supplementation (approximately 55% harder than the control). Furthermore, the hardness of the products fortified with 5%, 10%, and 15% of the added powder did not differ significantly from each other. The researchers attributed these findings to the possible stiffening of the gluten network, which is associated with the additional fibre from the fruit powder used. In a separate investigation, it was found that the incorporation of camu-camu FBP powder resulted in biscuits that were generally significantly harder than the control (by approximately 32 for 20% product supplementation), this was attributed to a lower gluten content in the fortified biscuits (das Chagas *et al.*, 2021). However, a non-significant increase in hardness was observed for baked goods in which 5% of the wheat flour was replaced with the applied powder. This hindered the production of viscoelastic dough with desirable properties.

In contrast to the previously described studies, the results of Tarasevičienė *et al.* (2021) demonstrated that the addition of redcurrant and strawberry pomace powder at 10, 15, and 20%, and raspberry pomace supplementation at 15 and 20%, decreased the hardness of the biscuits. Only when substituting wheat flour with 10% raspberry pomace, was the opposite trend observed. It is worth noting that biscuits containing 20% strawberry flour were the softest, with a reduction in hardness of approximately 79% as compared to the control, this was potentially due to the moisture retention of the fibrous raw material. Furthermore, increasing the levels of raspberry and strawberry pomace resulted in softer products. From a consumer standpoint, this observation may be advantageous, as indicated by the results of the sensory evaluation conducted using a 9-point hedonic scale. The fortified cookies containing 20% strawberry pomace received the highest scores from the panellists in terms of colour, aroma, and texture, with scores of 7.83, 7.83, and 7.33 points, respectively. Conversely, increasing the addition level of redcurrant pomace made the products harder. Biscuits containing 20% of this powder were approximately 44% harder than those with 10% supplementation. Additionally, the products containing 20% raspberry pomace were the most brittle, whereas products with 20% strawberry pomace were the least (also compared to the control). This indicates that fruit powders, depending on their chemical composition, may interact to varying degrees with the other components of biscuits, which can lead to either a strengthening or a weakening of the biscuit texture, and thus affect consumer acceptability.

In a separate investigation (Bora *et al.*, 2019), the addition of goji berry pomace resulted in a reduction in biscuit hardness and fracturability. The observed increase in the softness of the baked goods may be attributed to the presence of fibre, which inhibited starch gelatinisation during baking and protein aggregation during dough mixing. Similar trends were found in studies conducted by Asadi *et al.* (2021). The incorporation of dried and powdered chiku fruit pomace (*Manilkara zapota* L.) in the wheat biscuits resulted in a gradual decrease in biscuit hardness depending on the amount of the additive that was added to the biscuit mixture. The maximum decrease was approximately 39% when 12% of the wheat flour was replaced with dried and ground chiku pomace. Despite a decline in the sensory ratings for colour, flavour, aroma, and the overall acceptability of the cookies with increasing proportions of chiku pomace powder, there were no significant differences in the texture ratings between the enriched samples and the control. It is notable that, among the chiku pomace-enriched cookies, the cookie with a 7% supplement attained the highest overall acceptance score in terms of the organoleptic evaluation. In another study, the inclusion of both the dehydrated and the powdered edible portion and peel powder of kiwi also resulted in a reduction in biscuit hardness (Mohamed, 2017). However, the results of the statistical analysis demonstrated that significant differences were only observed for additions of 20% of the kiwi edible portion powder and 15-20% of the kiwi fruit peel powder. A study conducted by Kuchtová *et al.* (2018) enriched biscuits by incorporating dried and ground grape peels and seeds (from 5 to 15%). The inclusion of both types of preparations resulted in a linear reduction in biscuit hardness (up to approximately 24% for peels and 31% for seeds, in comparison with the control). Additionally, there was a decrease in the crispness of the products when 10% grape seeds and 15% grape peels were added. It is noteworthy that the sensory evaluation of the texture of the biscuits gradually decreased on a 5-point scale as the amount of grape seeds increased, this was likely due to the coarse texture of the cakes enriched with the seeds. This effect may be related to the particle size of the red grape seeds and can be addressed by reducing their size before adding them to the dough. Moreover, the addition of grape skins up to a level of 5% in the cookie recipe did not have a negative impact on their overall acceptability. In another studies (Peter *et al.*, 2017), the breaking strength was used as an indicator of biscuit hardness. The results revealed that an increase in enriched biscuit softness occurred as compared to the control. Some fruit powders may have no significant effect on the textural parameters of shortbread biscuits, which is advantageous in terms of the potential to introduce highly acceptable biscuits to the market. As reported by Janotková *et al.* (2021), the incorporation of sea buckthorn by-product powder did not result in a significant influence on the hardness and crispness of biscuits. Additionally, the brittleness of the biscuits remained unaffected by enrichment with this FBP. Based on the sensory evaluation of a group of panellists using a 1 to 10 line-marking scale, the control cookies were rated as both the hardest and the most brittle ones. However, with increasing levels of powdered sea buckthorn by-product in the recipe, the cookies became less hard. The instrumental analysis supported this finding, although the texture evaluation did not reveal any statistically significant differences in the hardness and brittleness values, in contrast to the sensory evaluation.

To summarize this chapter, it may be concluded that various fruit powders have a different impact on the texture of biscuits. The addition of dried fruit powders generally increases the hardness and fracturability of biscuits, with smaller particle sizes resulting in harder biscuits. The observed changes in texture are most likely due to the interactions of the additives used, the added fibre in particular produced a substantial effect when it interacted with the other biscuit ingredients.

## EFFECTS OF PACKAGING AND STORAGE ON THE PHYSICOCHEMICAL PROPERTIES OF BISCUITS

Biscuits are recognized for their extended shelf life in comparison with other baked goods due to their low water content, this results in a low water activity (Lee and Kang, 2018; Mabogo *et al.*, 2021). However, due to their hygroscopic nature, biscuits can rapidly absorb moisture during storage (Romani *et al.*, 2016; Stellamaris, 2018). Although there is no well-defined moisture threshold for biscuits, they must maintain their crunchiness and firmness, which are important sensory characteristics that are influenced by the water level and activity of the product (Célia *et al.*, 2022; Paciulli *et al.*, 2018). Moreover, water migration and the interactions of various ingredients with water are also altered during biscuit storage, leading to a loss of crispness over time. Residual (bound) moisture has a significant impact on biscuit stability during storage, as even biscuits with a minimal moisture content can undergo hydrolysis and enzymatic reactions (Takeungwongtrakul and Benjakul, 2017). Additionally, biscuits are high in fat content, and exposure to oxygen can result in lipid oxidation, causing flavour and aroma changes that can negatively affect product quality, which ultimately leads to rancidity and staleness (Paciulli *et al.*, 2023). These changes can cause a reduction in consumer acceptance, particularly if the changes in taste and aroma are substantial (Čukelj *et al.*, 2017). Moreover, the research conducted by Antoniewska *et al.* (2019) demonstrated that the antioxidant properties of biscuits enriched with freeze-dried Japanese quince fruit depended on both the storage time and the percentage of fruit additive. The hydrogen peroxide value method was used to measure the content of primary lipid oxidation products, and the biscuits enriched with 0.5, 1, and 1.5% additive powder with antioxidant properties showed lower levels of hydrogen peroxide as compared to the control. However, it is interesting to note that higher concentrations of Japanese quince powder, particularly at 6 and 9%, resulted in higher hydrogen peroxide values as compared to the non-enriched cakes, this was possibly due to the pro-oxidant effect of some antioxidant plant ingredients. The study further revealed a decrease in the amount of hydroperoxides in the fat contained in the biscuits after 12 weeks of storage in all samples. Simultaneously, an increase in the anisidine value, which indicates the content of carbonyl compounds, was observed, this was possibly caused by the oxidation of unsaturated fatty acids found in the lipid fraction of the biscuits. This phenomenon may have been induced by the concentrations of oxidants present in the biscuits, phenolic compounds and other compounds with antioxidant potential, initially reduced the amount of hydroperoxides but eventually ceased to effectively protect the fat from oxidation after prolonged storage. Paciulli *et al.* (2018) investigated how the physicochemical properties and oxidative stability of gluten-free biscuits enriched with chestnut flour at 50, 80, and 100% levels changed during storage. They found that the moisture content of the biscuits increased, and there was a slight increase in water activity during the 60-day storage period, which depended on the level of chestnut flour incorporation. Biscuits containing 50% chestnut flour showed the highest water activity in all storage periods as compared to other samples, which may be related to the competition between sugars and fibre for water in the final product. However, the highest increase in water activity (from 0.39 to 0.44) during storage was recorded for gluten-free biscuits without the addition of chestnut flour, thereby indicating that the proposed supplement may have a positive impact on the improved preservation of bakery products. The hardness of the biscuits increased significantly during storage, especially after 15 days, which was directly related to the increase in water content. Only the product containing 100% chestnut flour showed hardness stability during storage. Furthermore, the existence of the relationship between the water-binding capacity and the distance at rupture of the analysed biscuits confirmed the influence of the hygroscopic fibre particles and sugars on the preservation of enriched foods. Interestingly, the colour of both the enriched and the control biscuits (the values of the $L^*$, $a^*$, and $b^*$ parameters) did not change during the 60-day storage period. It was found that the optimum balance between texture stability, antioxidant activity, and ease of dough handling was achieved with 50% added chestnut flour. De Pilli *et al.* (2019) tested the effect of the added filling using partially osmo-dehydrated cherry halves of the Lapins and Ferrovia varieties on the shelf life of the biscuits, they were additionally protected with an edible coating containing vegetable oil emulsion, egg white, as well as humectants and gelling agents. The results showed that the total storage time significantly influenced the water content of the different parts of the biscuit (both the coated biscuit part and the cherry filling). Interestingly, the variety used only affected the water content of the fruit part of the biscuit. During the storage period of the biscuits, a decrease in the moisture content was observed, which was more consistent in the case of the Lapins variety, thereby confirming the migration of water from the components with a higher water content to the components with a lower water content and the air space of the plastic bags. Due to differences in the structure of the fruit tissues, Lapins cherries underwent a more rapid dehydration process as compared to the Ferrovia variety, which may be explained by the lower water content of the former variety. After 15 days, the moisture content of the biscuits containing both varieties of the cherries became steadier. In addition, the storage time and variety of cherry used influenced the breaking strength of the biscuits. After storage, the products containing cherries of the Lapins variety were more resistant to breaking than those of the Ferrovia variety, which may be due to the lower moisture content of the Lapins cherry filling during storage. Furthermore, it was shown that the storage time had a significant effect on reducing the colour angle for biscuits enriched with both cherry varieties, which may be attributed to the oxidation of the fruit pigments.

In order to prevent or restrict the degradation of biscuits during storage, it is critical to utilize suitable packaging materials with high barriers to environmental factors such as steam, oxygen, and light. Balestra *et al.* (2019) conducted a study comparing the physicochemical properties of biscuits made with sunflower oil and packaged in a traditional metalized oriented polypropylene layer and paper, this was compared to packaging with polylactic acid replacing the polypropylene layer, and packaging containing ethylene vinyl acetate mixed with polypropylene. The biscuits were stored at 35°C and 50% relative humidity for 105 days. The study revealed that the texture quality of the biscuits was not significantly influenced by the packaging material. However, there were significant variations in the moisture content, water activity, and lipid oxidation product levels between the biscuits packaged in traditional and innovative materials. The use of polypropylene vinyl acetate packaging was found to be the most effective one in maintaining product quality, as shown by the lower levels of hydration and oxidation when compared with traditional packaging and packaging containing lactic acid. This type of packaging provides a valuable alternative to standard materials for more sustainable and eco-friendly industrial solutions to preserve biscuits and other food products. Additionally, the shelf life of food products, including biscuits, can be extended by supplementing the biscuit mixture with processed fruit that have antioxidant or antimicrobial properties, as demonstrated by Catana *et al.* (2018) using dried chokeberries. Biscuits enriched with both chokeberry and cinnamon or chokeberry and ginger were found to have a 72-day shelf-life (packed in polypropylene film) based on their peroxide index as well as sensory and microbiological analyses. Initially, the firmness and crispness of the cookies enriched with chokeberry were similar. However, after a storage period of 72 days, the biscuits containing chokeberry and ginger were found to be 1.28 times crisper and 1.84 times harder than those containing chokeberry and cinnamon. This disparity may be linked to differences in the composition of the cookies, resulting in differences in their water and lipid content. In their study, Yaqoob *et al.* (2021) reported a gradual increase in water content during the 75-day storage period of biscuits enriched with dried and milled pomace and kinnow peels. This increase may be attributed to the high pectin content in these additives, which enhances water-binding capacity. It is noteworthy that the content of free fatty acids increased during the storage period, but the control containing the artificial antioxidant butylated hydroxyanisole (BHA) showed the highest amount. This finding suggests that natural antioxidant substances present in the fruit may aid in improving the stability of the fat composition and in the control of rancidity. The peroxide value in all of the biscuits showed a significant change during storage, this may be related to the increase in water content. It is important to note that a sensory evaluation revealed that the enriched biscuits did not exhibit any significant changes during the 30-day storage period, in contrast to the control. However, with further storage, biscuits supplemented with kinnow pomace powder received lower ratings in terms of their overall acceptability. By contrast, the ratings of biscuits with crust did not change significantly, thereby indicating the greater potential of this additive in terms of biscuit preservation as compared to pomace. To summarize this chapter, the physicochemical properties of biscuits during storage are influenced by the type, processing method, and the amount of fruit supplement used, and especially by the storage conditions applied. Furthermore, due to the hygroscopic nature of biscuits, it is essential to select appropriate storage packaging that can enhance shelf life by safeguarding against detrimental environmental factors, while also being eco-friendly.

## CONCLUSIONS

1. The careful selection of the type, particle size, and quantity of fruit and fruit by-products, as well as the most appropriate processing conditions, is critical to achieving the desired physical characteristics of the final product.

2. The incorporation of dried and powdered fruit during biscuit manufacturing has an influence over the weight, shape, and colour of the final product. This generally leads to a decrease in brightness and also to an increase in redness.

3. The use of different fruit powders results in different texture characteristics in the final product, and the observed variations in biscuit texture are likely due to interactions between the added fruit powders, particularly fibre, and the other biscuit ingredients. The incorporation of dried *Ziziphus lotus*, maracuja, apple pomace, bergamot by-product, and camu-camu co-product powders generally increases biscuit hardness and fracturability, whereas some fruit powders, such as strawberry, raspberry, red currant, goji berry, date palm fruit, chiku fruit pomace, kiwi edible portion and peel, and grape peel and seeds, increase biscuit softness. The addition of sea buckthorn by-product powder has no significant effect on textural parameters.

4. Despite their low water content and extended shelf life, biscuits are still susceptible to moisture absorption and lipid oxidation, which can have adverse effects on their quality and on consumer acceptance. In order to prevent degradation during storage, it is necessary to use the appropriate packaging materials. One innovative solution is the utilization of metalized orientated polypropylene material with an ethylene vinyl acetate additive.

5. Future work on this topic should focus on determining the impact of powder production conditions and particle-size distribution on the properties of biscuits. To date, only a few studies have addressed this issue.

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