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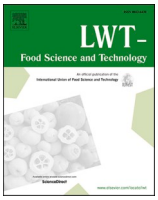

Fruit and vegetable by-products' flours as ingredients: A review on production process, health benefits and technological functionalities

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ABSTRACT

Fruits and vegetables are responsible for about 22% of food losses and wastes along the supply chain (not including the retail level). However, fruit and vegetable by-products (FVB) may be transformed into fibre-rich flours and bioactive compounds, mainly bound to the fibre, thus bringing value to the food industry due to health benefits and technological functionality. Therefore, these by-products have great potential to be applied in several food industries. The most common strategy is transforming these by-products into ingredients, and there are some processing strategies for transforming these by-products into dried ingredients - flours. Hence, this review aimed to unveil the most straightforward processes already available and discussed in the literature, allowing an easier implementation at an industrial level, thus achieving an actual application and valorisation of these by-products. The food products where these flours have been applied and the effects on the final products' physicochemical characteristics and health attributes are also critically reviewed.

1. Introduction

Given the importance of reducing food losses and waste, FAO and the United Nation Environment Programme are now measuring Food Loss Index and Food Waste Index to evaluate the progress towards the SDG Target 12.3. The wasted foods have been classified as food loss or food waste, but although there is no commonly agreed definition of food loss and waste, recently, FAO proposed clarification of concepts. Thus, food loss refers to losses that occur "along the food supply chain from harvest up to, but not including, the retail level" and food wastes occur "at the retail and consumption level" (FAO, 2019). Based on this definition, the studies on literature comprise food losses. The first report showed that 14% of food produced is lost from post-harvest up to, but not including the retail level. Fruits and vegetables incur the highest losses due to their highly perishable nature, since more than 20% of the fruits and vegetables produced worldwide are lost from post-harvest up to, but excluding, the retail level (FAO, 2019). However, FAO estimated that this percentage is much higher given the difficulty of measuring all the losses (FAO, 2019). Other studies point to around 50% of by-products generated by the fruit and vegetable in the forms of peels, cores, pomaces, unripe or damaged fruits and vegetables (Padayachee, Day, Howell, & Gidley, 2017).

The dietary fibre (D.F.) health benefits are well known. Both EFSA (European Food Safety Authority) and FAO recommend a minimum D.F. intake of 25 g/day. The U.S. Department of Health and Human Services recommends 33.6 g/day for men between 19 and 30 years and 28 g/day for women of the same age. However, the actual intake amount is still under the recommendations in E.U. countries (Stephen et al., 2017) and the USA (Hoy & Goldman, 2014). An FDA survey concluded that "consumers are not effective in modifying dietary habits as they try to be" (Anderson et al., 2009). Therefore, developing food products with increased fibre content is a better strategy for increasing D.F. intake. Flours obtained from fruit and vegetable by-products (FVB) are rich in fibre and can be used as a clean label fibre ingredient. Another advantage of using these fibres is their bound bioactive compounds such as phenolic acids and carotenoids (Acosta-Estrada, Gutiérrez-Uribe, & Serna-Saldívar, 2014). In this bound form, bioactive compounds can be effectively delivered in the gut since the fibre acts as a vehicle for their transport along the gastrointestinal tract, thus allowing their release in the gut after fibre fermentation by gut microbiota (Acosta-Estrada et al., 2014; Gómez & Martinez, 2018). Therefore, incorporating these food losses into a food product allows the addition of multifunctionality, besides reducing land use and contributing to the circular economy.

Additionally, fruit and vegetable by-products flours (FVBF) also have important technological functionalities, and they can be used as food

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Abbreviations

FVB	Fruit and vegetable by-products
FVBF	Fruit and vegetable by-products flour(s)
SDG	Sustainable Development Goals
D.F.	Dietary fibre
IDF	Insoluble dietary fibre
SDF	Soluble dietary fibre
TDF	Total dietary fibre
P.S.	particle size
WHC	water holding capacity
WRC	water retention capacity
WAC	water absorption capacity
SWC	swelling capacity
OHC	oil holding capacity
FAC	fat adsorption capacity
TPC	total phenolic content

ingredients, namely as thickeners, gelling agents, fillers, and water retainer agents, as well as in the production of edible films (Föste, Verheyen, Jekle, & Becker, 2020).

The present review aimed at analysing the health and technological functionalities of FVBF to evaluate their potential as ingredients. Processes to obtain these by-products flours are also discussed, focusing on an inexpensive and straightforward process to enable a profitable industrial application. Standardisation of the FVBF may help to speed up the laboratory-industry transition of this ingredient. Fibre concentrates obtained through a fibre extraction step, enzymatic pre-treated by-products and fibre powders obtained via freeze-drying or spray-drying were not included in this review. However, they may be occasionally mentioned in comparison with the processes of interest. These exclusion criteria were based on an economic point of view.

2. Production process

The production process of flours from FVB varies slightly between studies. However, a standard procedure is represented in Fig. 1, which also summarises the typical conditions for each step. This standard production process was developed during this work by summarising several studies in the literature, taking into consideration the steps that demonstrated to be essential for food safety and the best health and technological functionalities. Table 1 shows representative conditions associated with the main steps in the production of FVBF in literature.

2.1. Stabilisation step

Flour production typically starts with a washing or stabilisation step to inactivate microorganisms to ensure food safety and biological and chemical stability of FVBF. In some cases, there is also interest in enzyme inactivation.

The stabilisation normally involves heat treatments (Table 1) that may alter the chemical composition, and the nutritional and functional properties of the DF of the FVBF (Fernández-Ginés, Fernández-López, Sayas-Barberá, Sendra, & Pérez-Álvarez, 2003). A sterilisation treatment applied to onions by-products (autoclave at 115 °C for 17–31 min) decreased insoluble dietary fibre (IDF) and increased soluble dietary

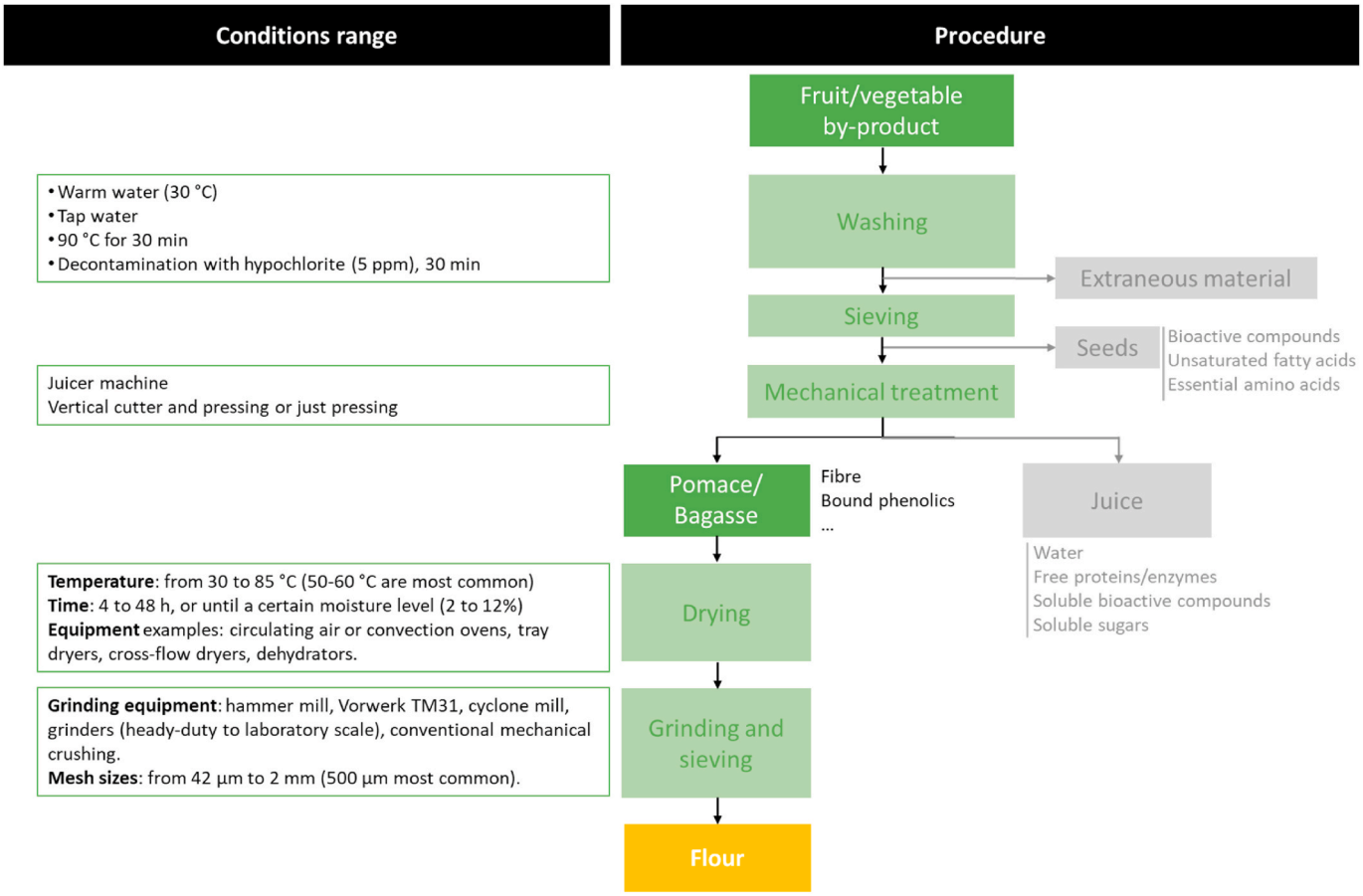

Fig. 1. Flow-chart of the most straightforward process to produce flours from fruit and vegetable by-products. This production process is a result of a compilation of several studies described and studied in literature.

Table 1
Processing conditions applied in the several steps of the production process of flours from fruit and vegetable by-products.

Fruit/vegetable by-product	Washing/ stabilisation	Separation of liquid and solid fraction	Drying	Grinding and sieving	Storage	Reference
Apple (gala) peels Banana (cavendish) peels Passion fruit (yellow) peels	0.005 g/L of chlorine active hypochlorite solution for 30 min.	Not performed, peels were directly dried.	60 °C until constant weight in circulating air oven.	In a Vorwerk TM 31 and sieving with mesh diameters of 200, 119, 59, 42 and 17.7 μm.	–	Espírito Santo et al. (2012)
Apple pomace from juice industry (pulp, peel, seed, and stems of mixed varieties)	Not performed.	Not performed.	55 °C, 5 h in a dehydrator	Grinding to 0.16 and 0.5 mm PS.	Packed in multilayer paper bags at room temperature.	Zlatanović et al. (2019)
Apple juice by-products	Wash twice with warm water (30 °C) after chopping and pressing	Chopping and pressing	60 °C, 30 min in an air tunnel drier.	Grinding to PS 0.5–0.6 mm.	–	Figuerola et al. (2005)
Apple pomace (pulp, peel, seeds and twigs from several varieties)	Not performed.	Squeezing of fresh fruit.	55 °C, 4–6 h in a Solaris dehydrator.	Grinding to PS < 300 μm.	Multilayer paper sack at room temperature.	Gorjanović et al. (2020)
Apple, carrot and orange pomaces	Warm water (30 °C) after juice removal.	Performed but not explained how.	60–70 °C until moisture of 2–3 g/100 g in a tray dryer.	Grinding and sieving with a 335 μm sieve.	Packed under vacuum at 4 °C for less than a week.	Kırbaş et al. (2019)
Blueberry and raspberry pomace	Not performed.	Not performed.	45 °C, 20 h in a convection oven.	In a hammer mill and sieving through a 0.80 mm sieve.	–	Šarić et al. (2019)
Carrot pomace	Not performed.	Not performed.	40 °C, 48 h in an air-oven.	Grinding to PS: 0.5 mm.	In a desiccator at room temperature	Chau et al. (2004)
Carrot pomace	Not performed.	Not performed.	60 °C in a convection oven.	In a cyclone mill with 2 mm screen size.	In polythene bags in a dry area.	Kaisangsri et al. (2016)
Carrot pomace	Washing and peeling.	Juice removal with a juicer.	50 °C.	In a laboratory grinder and sieving with mesh of 72 and 120.	–	Ahmad et al. (2016)
Carrot pomace	Not performed.	Not performed.	40 °C, 24 h in an air oven.	Grinding and sieving to PS < 425 μm	Packed in polyethylene bag at room temperature.	Lotfi Shirazi, Koocheki, Milani, and Mohebbi (2020)
Grapefruit, lemon and orange juice by-products (peels)	Wash with warm water (30 °C).	Not performed.	60 °C, 30 min in an air tunnel drier.	Grinding to PS 0.5–0.6 mm.	–	Figuerola et al. (2005)
Grape peels and seeds (wine industry by-products)	Not performed.	Pressing.	at 85 °C, 6 h in a forced-air circulation oven.	Milling.	–	D. Oliveira et al. (2013)
Grape skins (Chardonnay, Moscato and Pinot noir)	Not performed.	Not performed.	54 °C, 48 h in an oven.	Grinding to PS < 250 μm.	–	Marchiani et al. (2016)
Red wine grapes pomace (var. Cabernet Sauvignon)	Not performed.	Not performed.	60 °C until moisture below 12 g/100 g.	In a hammer mill.	In double plastic bags	Urquiaga et al. (2015)
White and red grape pomace (skins, seeds, stalks) Tomato peels Broccoli stems and leaves Artichoke external leaves	Not performed.	Not performed.	30–35 °C, 48 h in a dryer.	In a hammer mill.	At 4 °C.	Lucera et al. (2018)
Olive paste (cultivar Cellina di Nardò)	Not performed.	Not performed.	35 °C, 48 h.	In a hammer mill to a PS ≤ 500 μm.	–	Padalino et al. (2018)
Orange juice by-products (mainly composed of albedo, flavedo and pulp)	90 °C, 30 min.	Pressing (helical press).	50 ± 5 °C, 24 h.	Grinder-milling and sieves for PS < 0.417 mm.	–	Fernández-Ginés et al. (2003)
Passion fruit peels	Not performed.	Not performed.	60 °C until constant weight under air-flow.	In a Vorwerk TM 31 and sieving to PS < 17.7 μm.	In glass pots at 4 °C.	Espírito-Santo et al. (2013)
Peach palm (whole fruit)	Not performed.	Not performed.	60 °C, 48 h.	–	In high density metallised polyethylene bags	Santos et al. (2020)
Ripe mango peel	Washing with water.	Not performed.	50 °C, 18 h in a crossflow drier.	In a hammer mill and sieving through a 150 μm sieve.	–	Ajila et al. (2008)
Tomato peel	Not performed.	Not performed.	1st: dehydration of peels on trays in a hot-drier equipment. 2nd: conventional drying at a flow rate of 1.5 m/s at 60 °C.	Conventional mechanical crushing. PS ≈ 0.150 mm.	–	Wang et al. (2016)

h, hours. min, minutes. PS, Particle size.

fibre (SDF) contents improving the SDF:IDF ratio from 1:9, 1:6, 1:5, 1:4 or 1:3 (depending on the by-product) to 1:2 ratio in all cases. It is considered that the best ratios to achieve both SDF and ISD positive effects include 30–50% of SDF and 70-50% of IDF. These ratios are important to achieve both health and technological properties/benefits (Benítez et al., 2011). As previous studies in the literature have demonstrated, this ratio modification that occurs as a result of boiling is caused by the degradation of originally insoluble fibre such as cellulose into glucose and hemicelluloses into arabinose, xylose and galactose (Zia-ur-Rehman, Islam, & Shah, 2003).

Mild conditions (Table 1) are sometimes used to avoid or minimise changes in fibre profile, namely losses of pectins, pentosans and bioactive compounds (Figuerola, Hurtado, Estévez, Chiffelle, & Asenjo, 2005).

Decontamination with sodium hypochlorite solution followed by rinsing with water is applied in some studies (Espírito Santo et al., 2012; L. C. Oliveira, Alencar, & Steel, 2018). Previous studies comprising the microbiological evaluation before and after stabilisation with sodium hypochlorite solution proved the efficacy of this solution on FVB stabilisation by reducing the microbial counts into values that are classified as satisfactory according to food safety guidelines (Araújo-Rodrigues et al., 2021). Thus, if preserving the fibre profile using low temperatures on the stabilisation step is intended, sodium hypochlorite solution or other similar compounds is possibly the most efficient and necessary step to guarantee food safety. Nonetheless, more studies on this subject, with microbial counts and shelf-life, are required.

2.2. Separation of liquid and solid fractions

This step may not exist depending on the by-product. For instance, pomaces are already a solid fraction with no need for further juice removal. Nevertheless, for by-products with high water content (e.g. whole non-compliant fruits), a step aiming at separating liquid and solid parts is performed after the stabilisation, allowing a reduction of the drying time and the caramelisation extent of the free sugars during drying. This step is achieved by mechanical processing, using typically a juicer machine or a vertical cutter followed by pressing (Benítez et al., 2011; Campos et al., 2019). After this step, the by-product is transformed into a pomace with lower water content and follows to drying. This processing may also be performed to collect water-soluble compounds and thus present in the liquid part of the by-product, allowing a wider valorisation. For instance, bromelain is extracted from pineapple stems and peels juices after this mechanical step of removing the juice from the solid part (Campos, Ribeiro, Teixeira, Pastrana, & Pintado, 2020). Thereby, this step is very important to achieve a complete valorisation of the FVB beyond the flour created from the solid fraction of the by-product.

For a by-product that includes seeds (e.g. apple by-products), a seeds removal step is frequently included by sieving, intended to avoid toxic molecules and lipids susceptible to oxidation (Rabetafika, Bchir, Blecker, & Richel, 2014). Seeds can also be valorised as they are a potential source of bioactive compounds, proteins with essential amino acids and healthy lipids (unsaturated fatty acids) (Rabetafika et al., 2014).

Juice extraction may result in a concentration of pesticides residues in the fruit pericarp. Thus, before follow-up procedures, it should be necessary to verify if the level of these contaminants is under safety regulations (Šarić et al., 2019).

2.3. Drying

The final steps of flour production are drying and grinding. Table 1 indicates, when given by the authors, the temperature and time used in the drying step, the grinding process and the final particle size (P.S.).

The drying procedure usually intends a moisture reduction to a value below 10 g/100 g (Espírito Santo et al., 2012; Figuerola et al., 2005; Šarić et al., 2019), but some studies created flours with moisture values below 3 g/100 g (Chau, Chen, & Lee, 2004; Figuerola et al., 2005; Kırbaş, Kumcuoglu, & Tavman, 2019).

The recent review of Yang, Sombatngamwilai, Yu, and Kuo (2020) showed that different drying techniques such as convective dryers, circulating air ovens, air-jet, fluidised-bed dryers and microwave ovens affect the physical and chemical properties of the samples, influencing the flavour compounds, phytochemicals retention and colour.

FVBs' drying for flour production usually occurs under 65 °C to minimise losses of polyphenols, tannins, anthocyanins and proteins. In the case of air-drying, temperatures around 50–60 °C generate lower modifications on the D.F. profile, significantly lower losses of pectic substances, than higher temperatures (70–90 °C) as well as lower temperatures (30–40 °C) that demand longer drying time (Garau, Simal, Rossello, & Femenia, 2007). Additionally, higher air-drying temperatures (70–90 °C) result in lower water retention capacity (WRC) and fat adsorption capacity (FAC) (Garau et al., 2007). Regarding antioxidant activity, the same authors verified that orange by-products air-dried at 60 °C had higher protection factor values (Garau et al., 2007). Additionally, airflow velocity and humidity influence the quality of final products, namely, colour quality and bioactive compounds retention. In general, low temperature and humidity improve quality results, resulting in higher colour appeals and bioactive compounds content (Yang et al., 2020). Thus, drying can be managed to increase chemical quality and consequent health benefits of by-products' flours (related to phenolic compounds) and generally, temperatures between 50 and 60 °C are recommended.

2.4. Grinding

Grinding and P.S. affect the technological properties of the flour. Usually, the FVBF developed in the literature presents a P.S. of 500 μm (Table 1), facilitating the comparison between studies. It also might be in the range of the best P.S. for hydration properties.

Until a certain point, fibres' water holding capacity (WHC) increases with lower P.S. (Elleuch et al., 2011). The decrease of P.S. from 1127 to 550 μm increased WHC, WRC and swelling capacity (SWC), but further P.S. decrease leads to decreased hydration properties, which could be related to the SDF and IDF contents that are differently affected during the grinding process. Esposito et al. (2005) found different SDF and IDF content in the various fractions of wheat kernel when ground to distinct P.S. The fraction of the wheat kernel corresponding to the external layers had higher SDF at lower P.S. (0.9 g/100 g SDF for 0.5 mm P.S. and 2.5 g/100 g SDF for 0.18 mm P.S.) and a lower amount of IDF. The intermediate layers of the kernel had higher SDF and IDF for lower P.S. Finally, the internal layer of the kernel close to aleurone had a lower amount of IDF at lower P.S., but SDF was not affected by P.S. (Esposito et al., 2005). Nevertheless, P.S. lower than 500 μm increases antioxidant activity of flours due to increased availability of antioxidant compounds (Esposito et al., 2005). Micronisation of seeds, peels and calyxes increased phenolic, and flavonoid compounds content and antioxidant activity of persimmon flours, reducing the lipid oxidation of the final product (pork patties) during storage (Ramachandraiah & Chin, 2018). However, for higher levels of FVBF (75 g/100 g), the higher P.S. flour offered higher total phenolic content (TPC) and total flavonoids content in the final product (cookies) (Zlatanović et al., 2019). This could be due to a higher level of bound phenolics in the higher P.S. flour, thus resulting in greater thermal stability to heat treatment during cooking, increasing the final phenolics content.

2.5. Storage

In the research literature, flours are stored at freezing conditions until further analysis to avoid changes in technological functionality as well as TPC and antioxidant activity of flours (Fernández-López et al., 2009); or at room temperature, which is more realistic to further application in the food industry as ingredients. From the studies included in this work, only one (Fernández-López et al., 2009) has studied different storage conditions' effect on the same flour product enabling a useful comparison. Thus, further studies on FVBF storage conditions and shelf-life are missing in the literature.

A storage stability study conducted by Fernández-López et al. (2009) evaluated the effect of storage of orange juice by-products' flour (with 72 g/100 g TDF content) at room temperature in polyethylene and polyamide laminate bags (water vapour permeability 1.1 g m^{-2} 24 h^{-1} at 23 °C, nitrogen permeability 10 cm^3 m^{-2} 24 h^{-1} at 23 °C, carbon dioxide permeability 140 cm^3 m^{-2} 24 h^{-1} at 23 °C and oxygen permeability 30 cm^3 m^{-2} 24 h^{-1} at 23 °C) under vacuum and not vacuum conditions and, under light or absence of light. Moisture values increased by 42.8% during the ten months of storage independently of packaging type and storage conditions, especially in the last four months (41.3%). Consequently, WHC increased until six months and decreased in the last four months (Fernández-López et al., 2009). Oil holding capacity (OHC) slightly increased. L* increased, especially in the last four months and, a* and b* decreased during storage, especially in air packed samples under light exposure (possibly due to the loss of carotenoids via oxidation). TPC decreased until 6–7 months of storage and then increased to similar values in time 0 (Fernández-López et al., 2009), which could be related to the release of bound phenolics during storage.

Briefly, packaging conditions of FVBF should have a low water vapour permeability to avoid moisture values to increase, and light exposure must be avoided to increase the chemical stability of the FVBF.

3. Technological functionality of FVBF

The technological functionality of FVBF is related to texture, colour, or stability during shelf-life. These technological functionalities are associated with different molecule agents present in fruits and vegetables. Literature comprises studies on incorporating FVBF in several products, namely bakery, meat, dairy, and extruded products.

The DF is the responsible structure for texture related functionalities because of its WHC, SWC, WRC, water-solubility, OHC (Elleuch et al., 2011), FAC (Benítez et al., 2011; Garau et al., 2007), foam capacity and foam stability as well as solvent retention capacities (e.g. lactic acid, sodium carbonate, sucrose solvent capacities) (Ahmad, Wani, Wani, Masoodi, & Gani, 2016). Due to these texturising capacities, the addition of FVBF into liquid and semi-solid food products increases its viscosity, even in low doses. Incorporating 1 g/100 g of passion fruit peels flour increased the apparent viscosity of yoghurts because casein gel was more compact and overlaid the fibre. Oppositely, in the control yoghurts, exopolysaccharides were more frequent (Espírito-Santo et al., 2013).

SDF has technological functionalities such as thickening, gelling, reinforcing agent in tablets, filler, production of edible films and coatings, emulsifier, fat replacer and foam stabiliser (Föste et al., 2020). On the other hand, IDF is more useful for stabilising and texturising purposes, such as minimising shrinkage, retard staling, controlling moisture, and increasing food stability (Föste et al., 2020). Therefore, due to different SDF:IDF ratios, different fruits, vegetables, and cereals by-products present different WRC, SWC, FAC (Figuerola et al., 2005) and WHC values that result in different final product textures, even when there are low differences in TDF, SDF and IDF (Šarić et al., 2019). Studies comparing the application of several FVBF into the same final product demonstrated how the complexity of the flours and the different D.F. content, including SDF:IDF ratio, result in other texture effects. A study comparing blueberry and raspberry pomaces flours demonstrated that FVBF with slightly higher IDF content and slightly lower SDF content result in higher WAC and different results in the final product (see Table 2 for details) (Šarić et al., 2019). Another study comparing apple, carrot and orange pomaces' flours applied in cakes had different sensory scores. Carrot had the lowest overall acceptance scores mainly due to the texture and taste, which shows the influence of D.F. content (Kırbaş et al., 2019).

Bakery products have been the most targeted on the application of FVB, and a recent review paper on the subject concluded that the utilisation of FVB into baked products often results in a decrease in food acceptability, mainly due to flavour and appearance changes. The authors also pointed that FVB should be strategically selected to optimal composition and physical properties to avoid adverse effects (Gómez & Martinez, 2018). For instance, doughs' water absorption capacity (WAC) is a farinograph characteristic that can be decreased, increased, or not affected by adding an FVBF into a flour, depending on the fibre profile. FVBF richer in IDF is more likely to reduce water absorption of the product (Table 2). Increased WAC of dough may result in higher hardness of the final product (bakery products) due to more extensive gluten structure (Ajila, Leelavathi, & Prasada-Rao, 2008), which results in firmer final bakery products (Šarić et al., 2019). FVBF generally decreases dough stability and increases dough development time because fibre slows down the hydration rate and gluten development, but it also depends on the amount of FVBF incorporated (Ajila et al., 2008). Table 2 shows two studies where the incorporation of FVBF only affected overall quality scores at a higher level of FVBF incorporation (7.5 g/100 g of mango peel flour on biscuits (Ajila et al., 2008), and 75 g/100 g of apple pomace flour on cookies (Zlatanović et al., 2019)).

Similarly, in other food products, the incorporation of FVBF affects the texture differently depending on the type of by-product and amount of FVBF incorporated. Low doses of citrus by-products' flours into Bologna sausages increased hardness and decreased springiness (Fernández-Ginés et al., 2003). On the other hand, incorporating 10 g/100 g of tomato peel flour into low-fat sausages decreased hardness and springiness (Wang et al., 2016). These different results are unclear because one of the studies does not present the amount of D.F., which is proven to be the major agent affecting texture. Moreover, the studies comprise slightly different meat products. Thus, the formulation may also influence how FVBF affects the final product's texture (Table 2).

More in-depth knowledge about the effects of FVBF on food products would be achieved with future studies comprising the development of the same food product with different FVBF and using the same FVBF into various food products.

The production process leading to the by-product also may impact the texturising properties of the fibre. Juice production with enzyme treatments increased the SWC of the final fibre extracted from the pomace and decreased its water-binding capacity, which authors attributed to the loosening of cell wall structure and decreased pectin degree of methylation (Kosmala et al., 2010). Therefore, each FVBF nutritional composition, mainly D.F. composition, must be evaluated and its effects on the newly developed food product because, as mentioned previously, their functional properties (WRC, SWC, etc.) influence the texture effects on the final product.

Finally, it must be mentioned that FVBF may provide colour and stabilisation properties to the final product due to the presence of carotenoids and polyphenols. Carotenoids confer yellow, orange, and red colours to the products, and anthocyanins give red, purple and blue colours (Padayachee et al., 2017). When oxidised, polyphenols may provide a brownish colour to the flours. This oxidation may occur during drying due to enzymatic and non-enzymatic browning reactions (Ajila et al., 2008).

4. Health benefits of FVBF

Fruits and vegetables are constituted of macronutrients, such as water, carbohydrates, fibre, fats and proteins; micronutrients as

Table 2
Fruit and vegetable by-products' flours: composition, application and main effects on the final food product in terms of texture and bioactive compounds.

Fruit/vegetable by-product	Fibre profile, Bioactive compounds/ Biological activities	Developed product (applied flour dose)	Relevant outcomes in the food product	Reference
Apple (gala) Banana (cavendish) Passion fruit (yellow)	**Apple:** CH: 78.01 g/100 g TDF: 63.27 g/100 g **Banana:** CH: 63.06 g/100 g TDF: 51.19 g/100 g **Passion fruit:** CH: 74.33 g/100 g TDF: 65.08 g/100 g	Probiotic yoghurt (1 g/100 g)	↑ probiotic viability during shelf-life (for apple and banana by-products). ↑ short chain and polyunsaturated fatty acid contents of yoghurts. ↑ α-linolenic acid (by banana fibre).	Espírito Santo et al. (2012)
Apple pomace from juice industry (pulp, peel, seed, and stems of mixed varieties)	TDF: 42 g/100 g **TPC**: 7.0 mg GAE/g **TFC**: 25.0 mg QE/g **Antioxidant activity**: 9.4 mmol TE/100 g (DPPH) and 4.3 mmol TE/100 g (ABTS)	Cookies (25, 50, and 75 g/ 100 g)	↑ TDF ↑ TPC and total flavonoids content, especially for 0.5 mm PS flour at the 75 g/100 g level. ↑ antioxidant activity of cookies (0.65 in control sample and up to 3.58 mmol TE/100 g – ABTS; and 0.12 in control sample and up to 1.07 mmol TE/100 g - DPPH) ↓ appearance, structure, chewiness, taste and overall liking sensory scores especially at 75 g/100 g level. **Shelf-life**: pleasant apple taste and crunchy texture lasted for 12 months.	Zlatanović et al. (2019)
Apple juice by-products	**Royal Gala:** TDF: 78.2 g/100 g SDF: 14.33 g/100 g ISF: 63.9 g/100 g **Granny Smith:** TDF: 60.7 g/100 g SDF: 4.14 g/100 g ISF: 56.5 g/100 g **Liberty:** TDF: 89.8 g/100 g SDF: 8.20 g/100 g ISF: 81.6 g/100 g	Apple flour	**Royal gala:** WRC: 1.62 g water/g dw SWC: 6.59 ml water/g dw FAC: 0.95 g oil/g dw Hardness: 27 N (500 μm PS) and 0.3 N (200 μm PS) **Granny Smith:** WRC: 1.78 g water/g dw SWC: 6.89 ml water/g dw FAC: 1.45 g oil/g dw Hardness: 24 N (500 μm PS) and 0.6 N (200 μm PS) **Liberty:** WRC: 1.87 g water/g dw SWC: 8.27 ml water/g dw FAC: 0.60 g oil/g dw Hardness: 48 N (500 μm PS) and 5 N (200 μm PS)	Figuerola et al. (2005)
Apple pomace (pulp, peel, seeds and twigs from several varieties)	TDF: 35–45 g/100 g **WHC**: 4.7–6.4 g/g **OHC**: 1.3–1.6 g/g **TPC**: 4.3–8.1 mg GAE/g **TFC**: 12.2–34.6 mg QE/g **Antioxidant activity**: 3.4–10.0 mmol TE/100 g (ABTS) 2.6–4.5 mmol TE/100 g (DPPH)	Supplementation study on mice on a high-fat and sucrose diet (10 mg)	The flour supplementation: ↓ the body weight gain and blood glucose. Improved the glucose tolerance.	Gorjanović et al. (2020)
Apple pomace	TDF: 64.84 g/100 g SDF: 20.27 g/100 g IDF: 44.57 g/100 g	Cake (0, 5, 10, and 15 g/100 g)	**Increased pomace flour content:** ↑ apparent viscosity, elastic modulus (G′), and viscous modulus (G″), specific gravity and crumb hardness of the batter. ↓ specific volume of cakes. **Sensory analysis:** 5 g of pomace flour/100 g of cake level had similar sensory attributes scores to the control sample, except for *orange* pomace flour that had higher scores than the control sample. Carrot pomace cakes had the lowest score for overall acceptance. In general, the increased pomace flour content resulted in lower sensory scores.	Kırbaş et al. (2019)
Orange pomace	TDF: 82.22 g/100 g SDF: 13.42 g/100 g IDF: 68.80 g/100 g	Cake (0, 5, 10, and 15 g/100 g)		
Carrot pomace	TDF: 83.91 g/100 g SDF: 22.73 g/100 g IDF: 61.18 g/100 g	Cake (0, 5, 10, and 15 g/100 g)		
Carrot pomace	TDF: 63.5 g/100 g IDF: 50.1 g/100 g AIS: 67.4 g/100 g WIS: 56.3 g/100 g Monosaccharides: galactose, glucose, arabinose, mannose, rhamnose, fructose, xylose (traces)	Carrot flour	IDF and AIS had higher bulk density than cellulose. IDF, AIS and WIS had higher WHC than cellulose. IDF OHC < cellulose OHC, but WIS OHC > cellulose OHC. IDF, AIS and WIS have higher SWC than cellulose. IDF, AIS and WIS have higher glucose-adsorption capacity and inhibitory activity against amylase.	Chau et al. (2004)
Carrot pomace	TDF: 63.30 g/100 g	Extruded products (0, 5, 10 and 15 g/100 g)	5 g/100 g of carrot pomace flour increased expansion of the final product. Increased carrot pomace content: ↑ β-carotene content both in raw mixtures and in the extruded final products, especially for mixtures with higher moisture	Kaisangsri et al. (2016)

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Table 2 (*continued*)

Fruit/vegetable by-product	Fibre profile, Bioactive compounds/ Biological activities	Developed product (applied flour dose)	Relevant outcomes in the food product	Reference
			↑ β-carotene losses during extrusion ↓ EI of extrudates ↑WAI of products (only at moisture level of 15 g/ 100 g)	
Carrot pomace	TDF: 29.00 g/100 g	Mixed with wheat flour (0, 10, 15, and 20 g/100 g)	Increased carrot pomace content: ↑ TDF, ↓ protein ↑ WAC, OHC, WSI, SWC and water solvent retention capacity ↓ foaming capacity and stability especially for 120 mesh ↑ sucrose solvent retention capacity ↓ lactic acid and sodium carbonate solvent retention capacities	Ahmad et al. (2016)
Carrot pomace	TDF: 7.04 g/100 g	Barley-based extruded products (10, 17.5, and 25 g/100 g)	Increased carrot pomace flour: ↑ nutritional value ↓ EI and cell wall average size ↑ hardness and cell wall thickness	Lotfi Shirazi et al. (2020)
Blueberry pomace Raspberry pomace	TDF: 56.41 g/100 g SDF: 1.70 g/100 g IDF: 54.72 g/100 g TDF: 52.51 g/100 g SDF: 2.12 g/100 g IDF: 50.41 g/100 g	Cookies (30 g/100 g)	Fruit flour effect on cookies: ↑ fibre content. ↑ elastic and viscous moduli, producing harder dough and firmer cookies. Blueberry WAC (3.07 g/g) > raspberry WAC (2.10 g/g) and consequently blueberry flour created more rigid dough structure, higher water loss during baking, lower cookie thickness, higher spread ratio, more dense inner structure and higher cookie hardness.	Šarić et al. (2019)
Passion fruit peels	–	Yoghurt (1 g/100 g)	↑ thixotropy. ↑ apparent viscosity. ↑ sensory scores for odour, but the intensity of passion fruit flavour was weak. ↓ sensory scores for texture.	Espírito-Santo et al. (2013)
White and red grape pomace (skins, seeds, stalks) Tomato peels Broccoli stems and leaves Artichoke external leaves	**TPC:** White grape: 90.51 mg GAE/g dw Red grape: 107.40 mg GAE/g dw Tomato: 4.90 mg GAE/g dw Broccoli: 14.59 mg GAE/g dw Artichoke: 21.15 mg GAE/g dw **Antioxidant activity (ABTS):** White grape: 110.13 mg TE/g dw Red grape: 127.36 mg TE/g dw Tomato: 4.21 mg TE/g dw Broccoli: 23.70 mg TE/g dw Artichoke: 16.76 mg TE/g dw	Spreadable cheese (5 g/100 g)	↑ TPC (except for tomato peel) and antioxidant activity, especially in grapes and broccoli supplemented cheeses **Sensory analysis:** ↓ spreadability, solubility, juiciness ↑ fibrous, adhesiveness, graininess	Lucera et al. (2018)
Grape peels and seeds (wine industry by-products)	Crude fibres: 16.65 g/100 g **TPC**: 283.74 mg/100 g of dry flour.	Extruded cereal (10, 15 and 20 g/100 g)	Increased flour content: ↑ TPC and fibre content of cereal. ↓instrumental texture of cereal. Overall acceptance of the product was not different between the three products.	D. Oliveira et al. (2013)
Grape skins (Chardonnay, Moscato and Pinot noir)	**Moscato** TDF: 481.0 g/kg of dw SDF: 90.2 g/kg of dw IDF: 390.9 g/kg of dw **Chardonnay** TDF: 426.2 g/kg of dw SDF: 81.5 g/kg of dw IDF: 346.3 g/kg of dw **Pinot noir** TDF: 3455.5 g/kg of dw SDF: 62.9 g/kg of dw IDF: 285.0 g/kg of dw	Yoghurts (60 g/kg)	Grape skin flour effects on yogurts: ↓ protein, fat, and moisture contents ↑ CH content ↑ TPC (+55%) ↑ antioxidant activity during shelf-life (+80%) ↑ acidity (+25%) ↓ sensory scores for appearance, odour, taste, flavour, texture, and overall acceptability	Marchiani et al. (2016)
Red wine grapes pomace (var. Cabernet Sauvignon)	TDF: 47.70 g/100 g SDF: 3.54 g/100 g IDF: 44.20 g/100 g **TPC**: 41.11 mg GAE/g (gallic acid; caffeic acid; vanillic acid; protocatechuic acid; coumaric acid and ferulic acid) **Total anthocyanin content**: 1.49 mg cyanidin 3-glucose eq./g **Anthocyanins**: 0.366 mg/g **Flavonoids**: 0.160 mg/g **Antioxidant capacity**: 362.9 μmol trolox eq./g (ORAC)	Clinical trial (daily intake of 20 g of grape pomace flour) Clinical trial, daily intake for one burger (7 g/100 g)	**Health benefits:** Improved blood pressure, glycaemia, and postprandial insulin. **Health benefits:** Improved fasting glucose and insulin resistance, plasma antioxidant levels, and oxidative damage markers.	Urquiaga et al. (2015) Urquiaga et al. (2018)

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Table 2 (*continued*)

Fruit/vegetable by-product	Fibre profile, Bioactive compounds/ Biological activities	Developed product (applied flour dose)	Relevant outcomes in the food product	Reference
	α-tocopherol 53.51 μg/g **γ-tocopherol** 12.57 μg/g **δ-tocopherol** 0.68 μg/g			
Grapefruit juice by-products	**Ruby:** TDF: 62.6 g/100 g SDF: 4.57 g/100 g IDF: 56.0 g/100 g **Marsh:** TDF: 44.2 g/100 g SDF: 6.43 g/100 g ISF: 37.8 g/100 g	Grapefruit flour	**Ruby:** WRC: 2.09 g water/g dw SWC: 8.02 ml water/g dw FAC: 1.52 g oil/g dw Hardness: 45 N (500 μm PS) and 11 N (200 μm PS) **Marsh:** WRC: 2.26 g water/g dw SWC: 6.69 ml water/g dw FAC: 1.20 g oil/g dw Hardness: 49 N (500 μm PS) and 15 N (200 μm PS)	Figuerola et al. (2005)
Lemon juice by-products	**Eureka:** TDF: 60.1 g/100 g SDF: 9.20 g/100 g ISF: 50.9 g/100 g **Fino 49:** TDF: 68.3 g/100 g SDF: 6.25 g/100 g ISF: 62.0 g/100 g	Lemon flour	**Eureka:** WRC: 1.85 g water/g dw SWC: 7.32 ml water/g dw FAC: 1.30 g oil/g dw Hardness: 5 N (500 μm PS) and 2 N (200 μm PS) **Fino 49:** WRC: 1.74 g water/g dw SWC: 9.19 ml water/g dw FAC: 1.48 g oil/g dw Hardness: 6 N (500 μm PS) and 3 N (200 μm PS)	
Orange juice by-products	TDF: 64.3 g/100 g SDF: 10.28 g/100 g ISF: 54.0 g/100 g	Orange flour	WRC: 1.65 g water/g dw SWC: 6.11 ml water/g dw FAC: 1.81 g oil/g dw Hardness: 48 N (500 μm PS) and 13 N (200 μm PS)	
Orange juice by-products (mainly composed of albedo, flavedo and pulp)	TDF: 71.62 g/100 g	High dietary fibre powder	Extractable polyphenols (40.67 mg GAE/g of dw): - Hydroxycinnamic acids (caffeic acid, coumaric acid, ferulic acid) - Flavanones (narirutin, naringin, **hesperidin (20.69 mg/g)**, poncirin) - Flavones (diosmin, neodiosmin)	Fernández-López et al. (2009)
Orange juice by-products (mainly composed of albedo, flavedo and pulp)	–	Bologna sausage (0, 0.5, 1, 1.5 and 2 g/100 g)	The addition of citrus fibre: ↓ moisture content of sausages (only significant for 1.5 and 2 g/100 g) ↓ fat content (only significant for 1.5 and 2 g/100 g) ≈ protein content ↑ ash content (only significant for 1.5 and 2 g/100 g) ↑ fibre content (not significant for 0.5 g/100 g) ↓ nitrite content ↑ L*, a*, b*, C* and H* ≈ pH ↑ hardness and ↓ cohesiveness, springiness, gumminess, and chewiness	Fernández-Ginés et al. (2003)
Olive paste	–	Spaghetti (10 g/100 g)	↓ sensory quality, but the addition of 0.6 g/100 g transglutaminase increased sensory quality. ↑ PUFA/SFA ration ↑ polyphenols content	Padalino et al. (2018)
Peach palm (whole fruit)	TDF: 13.21 g/100 g CH: 77.18 g/100 g	Extruded corn-based breakfast cereal (0–50 g/100 g)	Peach palm flour effects on extruded BCP: ↓ moisture and digestible CH contents ↑ fat, TDF and carotenoids contents.	Santos et al. (2020)
Ripe mango peel	TDF: 51.2 g/100 g SDF: 19.0 g/100 g IDF: 32.1 g/100 g **TPC**: 96.2 mg GAE/g mango peel powder **Total carotenoids**: 3092 μg/g mango peel powder	Biscuits (2.5, 5, 7.5 and 10 g/100 g)	The addition of mango peel powder in dough: ↑ WAC and dough development time ↓ dough stability The addition of mango peel powder in biscuits: ↑ TDF, SDF and IDF ↑ polyphenols (from 540 to 4500 μg GAE/g) ↑ carotenoids (from 17 to 247 μg/g) ↓ L* (due to browning), a* and b* ↓ diameter and thickness only for 15 g/100 g and 20 g/100 g formulations ↑ breaking strength ↓ crust colour scores in sensory evaluation ↓ crust appearance and texture scores only from 10 g/100 g of mango peel ≈ taste/flavour ↓ overall quality from 7.5 g/100 g of mango peel	Ajila et al. (2008)
Tomato peel	SDF: 5.72 g/100 g ISD: 62.63 g/100 g	Low-fat sausages (10 g/100 g)	Tomato peel powder: ↓ hardness ↓ springiness ↓ chewiness ↑ stability of polyunsaturated/saturated fatty acid ratio during storage (48 days)	Wang et al. (2016)

PS, particle size. CH, carbohydrates. TDF, total dietary fibre. IDF, insoluble dietary fibre. SDF, soluble dietary fibre. AIS, alcohol-insoluble solid. WIS, water-insoluble solid. WHC, water holding capacity. OHC, oil holding capacity. WRC, water retention capacity. WAC, water absorption capacity. SWC, swelling capacity. FAC, fat adsorption capacity. a_w, water activity. dw, dry weight. GAE, gallic acid equivalents. TE, trolox equivalents. TPC, total phenolic content. TFC, total flavonoid content.

vitamins and minerals; and are also rich in bioactive compounds, mainly carotenoids, phenolic acids, flavonoids and phytosterols (Ajila et al., 2008; Gómez & Martinez, 2018).

The health benefits of FVBF are related to their fibre and bound bioactive compounds content that has been proven to exert several health benefits such as antioxidant activity, gut microbiota improvement, satiety increase, lower energy intake and consequently, reduction of the risk of chronic diseases such as type-2 diabetes, obesity, cancer and cardiovascular diseases (Acosta-Estrada et al., 2014; Fardet, 2010). Table 2 presents the bioactive compounds and antioxidant activity of FVBF and the final product developed (when applicable). Usually, the use of FVBF in food products increases bioactive compounds content, such as TPC and carotenoids (Ajila et al., 2008; Kaisangsri et al., 2016; Marchiani et al., 2016; D.; Oliveira, Marques, Kwiatkowski, Monteiro, & Clemente, 2013; Santos et al., 2020), resulting in increased bioactivities of the food product, being antioxidant activity the most studied (Marchiani et al., 2016; Zlatanović et al., 2019). Although the magnitude of the increase in bioactive compounds may not be proportional to the biological effect (Di Nunzio et al., 2020), studies have been demonstrating that the use of fibre from by-products may induce several positive effects on health, namely on host gut microbiota (Nissen et al., 2021).

The bioactive compounds present in the FVBF are also advantageous in terms of stability and shelf-life of the final product and indirect health benefits. A probiotic yoghurt with 1 g/100 g of apple and banana by-products flours had higher probiotic viability during shelf-life. It improved short-chain and polyunsaturated fatty acids contents, maybe due to synergistic effect between the type of fibre and the probiotic strain on the conjugated linoleic acid (CLA) content (Espírito Santo et al., 2012).

4.1. Dietary fibre and phytochemicals

The most significant bioactive compound in FVBF is D.F., but phytochemicals are also frequently evaluated in these flours, namely carotenoids and phenolic compounds such as anthocyanins and flavonoids (Table 2). Herewith, antioxidant activity is often present and analysed (Gorjanović et al., 2020; Lucera et al., 2018; Urquiaga et al., 2015; Zlatanović et al., 2019).

D.F. itself provides several well-known health benefits. Adequate DF intake reduces the risk of developing chronic diseases such as coronary heart disease, stroke, hypertension, diabetes, obesity, and gastrointestinal disorders. Moreover, DF intake improves serum lipid concentrations, blood pressure and blood glucose levels in diabetes; supports weight loss and enhances immune function (Anderson et al., 2009).

Phytochemicals are bioactive non-nutritional chemical compounds responsible for the most beneficial properties of fruits, vegetables, and whole grains. Phenolic compounds are the most studied phytochemicals in foods. These compounds occur in food as free, soluble conjugated (glycosides) and insoluble forms called bound phenolics, mostly bound to fibre (Acosta-Estrada et al., 2014). In general, this group of compounds has several health benefits such as antioxidant, antimicrobial, antiviral and anti-inflammatory properties (Acosta-Estrada et al., 2014); and improve plasma lipids and vascular function, possibly decreasing cardiovascular disease risk (Padayachee et al., 2017). Still, these bioactivities are not commonly studied on the FVBF included in this work (Table 2), which lacks literature and is an opportunity to deepen knowledge about these flours.

Most of the free and soluble conjugated forms of phenolic compounds are released in the juice during the production of by-products flours. However, the bound phenolics are covalently bound to cell wall structures such as cellulose, hemicellulose, lignin, pectin and rod-shaped structural proteins (Acosta-Estrada et al., 2014). The health functionality of D.F. was recently deeply revised by Padayachee et al. (2017), emphasising the interaction between fibres and phytonutrients. The authors concluded that the fibres play a key role in transporting polyphenols through the upper gastrointestinal tract to the colon, where the microflora release and metabolise these compounds. *In vitro* antioxidant assays demonstrated that the bound phenolics have higher antioxidant activity than free and soluble conjugated phenolics (Acosta-Estrada et al., 2014).

Tocols (vitamin E isomers) are antioxidants present in plants and foods of plant origin and have been highlighted as beneficial to human health, including the prevention of chronic diseases. However, they have not been much analysed in FVBF. Urquiaga et al. (2015) verified the presence of α-, γ- and δ-tocopherols in grape pomace flour, corresponding to approximately 0.16 g/100 g of the TPC (see Table 2).

Phytosterols have not been thoroughly analysed in fruits and vegetable by-products. However, some studies indicate that dried and ground fruit and cereals by-products can have around 4.5 mg of free phytosterols per g of raw material and 48 mg/g of phytosterols in the lipid fraction (Jiang & Wang, 2005). The major phytosterols found in peach, mango (peels and remnants of pulp) and cereals (brans, germs, and hulls) by-products were β-sitosterol, β-campesterol, avenasterol, and stigmasterol (Amaya-Cruz et al., 2015).

It is well known that fruits and vegetables are a source of vitamins and minerals, including their by-products. However, studies comprising vitamins and minerals content in FVBF are scarce. As shown in Table 2, only one study included an evaluation of vitamin content (vitamin E) (Urquiaga et al., 2015). This topic also needs to be improved on FVBF development.

4.2. Preclinical and clinical trials with FVBF

Due to the demonstrated synergistic effect between fibre and other bioactive molecules such as phenolic compounds (Espírito Santo et al., 2012), it is expected FVBF will have better health benefits than the extracted purified fibre.

Although there are few studies on the health benefits of FVBF, results demonstrate great potential for this product to be applied in food products providing health benefits. The daily intake of 20 g of grape pomace flour consumed in bread, biscuits or directly mixed with water during lunch improved blood pressure, glycaemia and postprandial insulin. It was also verified that antioxidant defences increased and oxidative protein damage decreased, indicating attenuation of oxidative stress (Urquiaga et al., 2015). The daily consumption of a 100 g burger with 7 g of grape pomace flour improved fasting glucose and insulin resistance, plasma antioxidant levels, and oxidative damage markers (Urquiaga et al., 2018). The same flour reduced premature death, changed Tumor Necrosis Factor-alpha (TNF-α) and interleukin 10 (IL-10) levels, and increased plasma antioxidant activity in atherogenic diet-fed mice (a model of lethal ischemic heart disease.), thus contributing to a decreased inflammation and consequently the progression of atherosclerosis, reduced coronary heart disease and improved cardiovascular outcomes (Rivera et al., 2019). Mice supplemented with apple pomace flour lowered the increase of body weight gain and blood glucose and improved glucose tolerance (Gorjanović et al., 2020). A study aiming to distinguish the effect from fibre and polyphenols, fed rats with apple pectin (P), high polyphenol freeze-dried apple (P.L.) or both and it was found different effects on plasma and liver cholesterol and triglyceride concentrations (Aprikian et al., 2003). Plasma cholesterol and triglyceride contents were lower in rats fed with P plus P.L. and plasma triglyceride content was also low in rats fed with P.L. Liver cholesterol and triglyceride were lower in rats fed with P and in rats fed

with both P and P.L. Sterol excretion was higher in rats fed with P. Authors concluded that the combination of P and P.L. in feed was more effective on health benefits than when fed separately (Aprikian et al., 2003). These studies suggest an interaction between D.F. and phytochemicals and that complex FVBF may be more effective on health benefits delivery than purified compounds separately ingested.

5. Conclusion and future perspectives

Reducing food losses and wastes in a circular economy strategy has critical environmental (reduction of pollution) and economic (economic valorisation of by-products) implications and supports the Sustainable Development Goals of the United Nations. FVBF is a viable and low-cost solution to valorise and incorporate FVB into various food products. In fact, several studies have demonstrated that these flours can be successfully incorporated into the bakery, dairy, meat and extruded products.

Thermal treatments applied to the by-products improve their SDF: IDF ratio and release bound bioactive compounds. Thus, FVBF must be produced differently for different applications, i.e., if FVBF is going to be incorporated into a product with a mild production process as dairy products, FVBF can be produced with application of temperature and inducing lower P.S. On the other hand, if FVBF is intended to be applied in an extruded product, the flour must have been produced under as mild as possible conditions to assure the bound compounds are protected and released during the food product production.

Given the importance of fibre in human health and the fibre content of FVBF, the use of these by-products is an excellent opportunity to improve the nutritional content of food products regarding fibre content. Additionally, it provides several other health benefits related to their significant amount and diversity of stable bioactive compounds because they are mostly linked to fibre. Nonetheless, more clinical studies must be performed on the final developed product to assure efficacy.

Although FVBF has been diversely developed, ingredients produced in the presented straightforward method are shown in few studies. The main limitation in literature is that studies vary a lot in conditions of each step of the production process of flours, i.e. rarely two studies have similar conditions during the procedure. The following steps for effective FVBF valorisation comprise studies on:

- Food safety regarding pesticides and other contaminants from agriculture;
- Vitamins and minerals analysis, including processing effects on their contents (drying temperature, final moisture content, grinding, storage type and time);
- Storage conditions and shelf-life studies comprising both food safety, micronutrients, and bioactive compounds stability;
- More in-depth knowledge about the effects of FVBF on texture and sensory quality of food products would be achieved with future studies comprising the development of the same food product with different FVBF and using the same FVBF into various food products.

Declaration of competing interest

The authors of this article declare that they have no conflicts of interest of any kind.

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References

Acosta-Estrada, B. A., Gutiérrez-Uribe, J. A., & Serna-Saldívar, S. O. (2014). Bound phenolics in foods, a review. *Food Chemistry, 152*, 46–55. https://doi.org/10.1016/j.foodchem.2013.11.093

Ahmad, M., Wani, T. A., Wani, S. M., Masoodi, F. A., & Gani, A. (2016). Incorporation of carrot pomace powder in wheat flour: Effect on flour, dough and cookie characteristics. *Journal of Food Science & Technology, 53*(10), 3715–3724. https://doi.org/10.1007/s13197-016-2345-2

Ajila, C., Leelavathi, K., & Prasada-Rao, U. J. S. (2008). Improvement of dietary fiber content and antioxidant properties in soft dough biscuits with the incorporation of mango peel powder. *Journal of Cereal Science, 48*(2), 319–326. https://doi.org/10.1016/j.jcs.2007.10.001

Amaya-Cruz, D. M., Rodríguez-González, S., Pérez-Ramírez, I. F., Loarca-Piña, G., Amaya-Llano, S., Gallegos-Corona, M. A., et al. (2015). Juice by-products as a source of dietary fibre and antioxidants and their effect on hepatic steatosis. *Journal of Functional Foods, 17*, 93–102. https://doi.org/10.1016/j.jff.2015.04.051

Anderson, J. W., Baird, P., Davis, R. H., Jr., Ferreri, S., Knudtson, M., Koraym, A., et al. (2009). Health benefits of dietary fiber. *Nutrition Reviews, 67*(4), 188–205. https://doi.org/10.1111/j.1753-4887.2009.00189.x

Aprikian, O., Duclos, V., Guyot, S., Besson, C., Manach, C., Bernalier, A., … Demigné, C. (2003). Apple pectin and a polyphenol-rich apple concentrate are more effective together than separately on Cecal fermentations and plasma lipids in rats. *Journal of Nutrition, 133*(6), 1860–1865. https://doi.org/10.1093/jn/133.6.1860

Araújo-Rodrigues, H., Santos, D., Campos, D. A., Ratinho, M., Rodrigues, I. M., & Pintado, M. E. (2021). Development of frozen pulps and powders from carrot and tomato by-products: Impact of processing and storage time on bioactive and biological properties. *Horticulturae, 7*(7), 185.

Benítez, V., Mollá, E., Martín-Cabrejas, M. A., Aguilera, Y., López-Andréu, F. J., & Esteban, R. M. (2011). Effect of sterilisation on dietary fibre and physicochemical properties of onion by-products. *Food Chemistry, 127*(2), 501–507. https://doi.org/10.1016/j.foodchem.2011.01.031

Campos, D. A., Coscueta, E. R., Valetti, N. W., Pastrana-Castro, L. M., Teixeira, J. A., Picó, G. A., et al. (2019). Optimisation of bromelain isolation from pineapple by-products by polysaccharide complex formation. *Food Hydrocolloids, 87*, 792–804. https://doi.org/10.1016/j.foodhyd.2018.09.009

Campos, D. A., Ribeiro, T. B., Teixeira, J. A., Pastrana, L., & Pintado, M. M. (2020). Integral valorisation of pineapple (Ananas comosus L.) by-products through a green chemistry approach towards added value ingredients. *Foods, 9*(1), 60.

Chau, C.-F., Chen, C.-H., & Lee, M.-H. (2004). Comparison of the characteristics, functional properties, and in vitro hypoglycemic effects of various carrot insoluble fiber-rich fractions. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 37*(2), 155–160. https://doi.org/10.1016/j.lwt.2003.08.001

Di Nunzio, M., Picone, G., Pasini, F., Chiarello, E., Caboni, M. F., Capozzi, F., … Bordoni, A. (2020). Olive oil by-product as functional ingredient in bakery products. Influence of processing and evaluation of biological effects. *Food Research International, 131*, 108940. https://doi.org/10.1016/j.foodres.2019.108940

Elleuch, M., Bedigian, D., Roiseux, O., Besbes, S., Blecker, C., & Attia, H. (2011). Dietary fibre and fibre-rich by-products of food processing: Characterisation, technological functionality and commercial applications: A review. *Food Chemistry, 124*(2), 411–421. https://doi.org/10.1016/j.foodchem.2010.06.077

Espírito Santo, A. P., Cartolano, N. S., Silva, T. F., Soares, F. A. S. M., Gioielli, L. A., Perego, P., … Oliveira, M. N. (2012). Fibers from fruit by-products enhance probiotic viability and fatty acid profile and increase CLA content in yoghurts. *International Journal of Food Microbiology, 154*(3), 135–144. https://doi.org/10.1016/j.ijfoodmicro.2011.12.025

Espírito-Santo, A. P., Lagazzo, A., Sousa, A. L. O. P., Perego, P., Converti, A., & Oliveira, M. N. (2013). Rheology, spontaneous whey separation, microstructure and sensorial characteristics of probiotic yoghurts enriched with passion fruit fiber. *Food Research International, 50*(1), 224–231. https://doi.org/10.1016/j.foodres.2012.09.012

Esposito, F., Arlotti, G., Bonifati, A., Napolitano, A., Vitale, D., & Fogliano, V. (2005). Antioxidant activity and dietary Wbre in durum wheat bran by-products. *Food Research International, 38*, 1167–1173. https://doi.org/10.1016/j.foodres.2005.05.002

FAO. (2019). *The State of Food and Agriculture 2019. Moving forward on food loss and waste reduction*. Rome. Licence: CC BY-NC-SA 3.0 IGO.

Fardet, A. (2010). New hypotheses for the health-protective mechanisms of whole-grain cereals: What is beyond fibre? *Nutrition Research Reviews, 23*(1), 65–134. https://doi.org/10.1017/S0954422410000041

Fernández-López, J., Sendra-Nadal, E., Navarro, C., Sayas, E., Viuda-Martos, M., & Alvarez, J. A. P. (2009). Storage stability of a high dietary fibre powder from orange by-products. *International Journal of Food Science and Technology, 44*(4), 748–756. https://doi.org/10.1111/j.1365-2621.2008.01892.x

Fernández-Ginés, J. M., Fernández-López, J., Sayas-Barberá, E., Sendra, E., & Pérez-Álvarez, J. (2003). Effect of storage conditions on quality characteristics of Bologna sausages made with citrus fiber. *Journal of Food Science, 68*, 710–714. https://doi.org/10.1111/j.1365-2621.2003.tb05737.x

Figuerola, F., Hurtado, M.a. L., Estévez, A. M.a., Chiffelle, I., & Asenjo, F. (2005). Fibre concentrates from apple pomace and citrus peel as potential fibre sources for food enrichment. *Food Chemistry, 91*(3), 395–401. https://doi.org/10.1016/j.foodchem.2004.04.036

Föste, M., Verheyen, C., Jekle, M., & Becker, T. (2020). Fibres of milling and fruit processing by-products in gluten-free bread making: A review of hydration properties, dough formation and quality-improving strategies. *Food Chemistry, 306*, 125451. https://doi.org/10.1016/j.foodchem.2019.125451

Garau, M. C., Simal, S., Rossello, C., & Femenia, A. (2007). Effect of air-drying temperature on physico-chemical properties of dietary fibre and antioxidant capacity of orange (Citrus aurantium v. Canoneta) by-products. *Food Chemistry, 104*(3), 1014–1024.

Gómez, M., & Martinez, M. M. (2018). Fruit and vegetable by-products as novel ingredients to improve the nutritional quality of baked goods. *Critical Reviews in Food Science and Nutrition, 58*(13), 2119–2135. https://doi.org/10.1080/10408398.2017.1305946

Gorjanović, S., Micić, D., Pastor, F., Tosti, T., Kalušević, A., Ristić, S., et al. (2020). Evaluation of apple pomace flour obtained industrially by dehydration as a source of biomolecules with antioxidant, antidiabetic and antiobesity effects. *Antioxidants, 9*(5). https://doi.org/10.3390/antiox9050413

Hoy, M. K., & Goldman, J. D. (2014). *Fiber intake of the U.S. Population what we eat in America, NHANES 2009-2010. Food Surveys Research Group Dietary Data Brief No. 12*.

Jiang, Y., & Wang, T. (2005). Phytosterols in cereal by-products. *Journal of the American Oil Chemists' Society, 82*(6), 439–444.

Kaisangsri, N., Kowalski, R. J., Wijesekara, I., Kerdchoechuen, O., Laohakunjit, N., & Ganjyal, G. M. (2016). Carrot pomace enhances the expansion and nutritional quality of corn starch extrudates. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 68*, 391–399. https://doi.org/10.1016/j.lwt.2015.12.016

Kırbaş, Z., Kumcuoglu, S., & Tavman, S. (2019). Effects of apple, orange and carrot pomace powders on gluten-free batter rheology and cake properties. *Journal of Food Science & Technology, 56*(2), 914–926. https://doi.org/10.1007/s13197-018-03554-z

Kosmala, M., Kołodziejczyk, K., Markowski, J., Mieszczakowska, M., Ginies, C., & Renard, C. M. G. C. (2010). Co-products of black-currant and apple juice production: Hydration properties and polysaccharide composition. *Lebensmittel-Wissenschaft und -Technologie- Food Science and Technology, 43*(1), 173–180. https://doi.org/10.1016/j.lwt.2009.06.016

Lotfi Shirazi, S., Koocheki, A., Milani, E., & Mohebbi, M. (2020). Production of high fiber ready-to-eat expanded snack from barley flour and carrot pomace using extrusion cooking technology. *Journal of Food Science & Technology, 57*(6), 2169–2181. https://doi.org/10.1007/s13197-020-04252-5

Lucera, A., Costa, C., Marinelli, V., Saccotelli, M. A., Del Nobile, M. A., & Conte, A. (2018). Fruit and vegetable by-products to fortify spreadable cheese. *Antioxidants, 7*(5), 61.

Marchiani, R., Bertolino, M., Belviso, S., Giordano, M., Ghirardello, D., Torri, L., … Zeppa, G. (2016). Yogurt enrichment with grape pomace: Effect of grape cultivar on physicochemical, microbiological and sensory properties. *Journal of Food Quality, 39*(2), 77–89. https://doi.org/10.1111/jfq.12181

Nissen, L., Casciano, F., Chiarello, E., Di Nunzio, M., Bordoni, A., & Gianotti, A. (2021). Colonic in vitro model assessment of the prebiotic potential of bread fortified with polyphenols rich olive fiber. *Nutrients, 13*(3), 787.

Oliveira, L. C., Alencar, N. M. M., & Steel, C. J. (2018). Improvement of sensorial and technological characteristics of extruded breakfast cereals enriched with whole grain wheat flour and jabuticaba (Myrciaria cauliflora) peel. *Lebensmittel-Wissenschaft und -Technologie, 90*, 207–214. https://doi.org/10.1016/j.lwt.2017.12.017

Oliveira, D., Marques, D., Kwiatkowski, A., Monteiro, A., & Clemente, E. (2013). Sensory analysis and chemical characterisation of cereal enriched with grape peel and seed flour. *Acta Scientiarum. Technology, 35*, 427–431. https://doi.org/10.4025/actascitechnol.v35i3.13176

Padalino, L., D'Antuono, I., Durante, M., Conte, A., Cardinali, A., Linsalata, V., et al. (2018). Use of olive oil industrial by-product for pasta enrichment. *Antioxidants, 7*(4), 59.

Padayachee, A., Day, L., Howell, K., & Gidley, M. J. (2017). Complexity and health functionality of plant cell wall fibers from fruits and vegetables. *Critical Reviews in Food Science and Nutrition, 57*(1), 59–81. https://doi.org/10.1080/10408398.2013.850652

Rabetafika, H. N., Bchir, B., Blecker, C., & Richel, A. (2014). Fractionation of apple by-products as source of new ingredients: Current situation and perspectives. *Trends in Food Science & Technology, 40*(1), 99–114. https://doi.org/10.1016/j.tifs.2014.08.004

Ramachandraiah, K., & Chin, K. B. (2018). Effect of particle size of persimmon by-product powders on their physicochemical properties and antioxidant activities in porcine patties. *Journal of Food Process Engineering, 41*(1), Article e12610. https://doi.org/10.1111/jfpe.12610

Rivera, K., Salas-Pérez, F., Echeverría, G., Urquiaga, I., Dicenta, S., Pérez, D., et al. (2019). Red wine grape pomace attenuates atherosclerosis and myocardial damage and increases survival in association with improved plasma antioxidant activity in a murine model of lethal ischemic heart disease. *Nutrients, 11*(9). https://doi.org/10.3390/nu11092135

Santos, I. L., Schmiele, M., Aguiar, J. P. L., Steel, C. J., Silva, E. P., & Souza, F.d. C.d. A. (2020). Evaluation of extruded corn breakfast cereal enriched with whole peach palm (Bactris gasipaes, Kunth) Flour. *Food Science and Technology, 40*, 458–464.

Šarić, B., Dapčević-Hadnađev, T., Hadnađev, M., Sakač, M., Mandić, A., Mišan, A., et al. (2019). Fiber concentrates from raspberry and blueberry pomace in gluten-free cookie formulation: Effect on dough rheology and cookie baking properties. *Journal of Texture Studies, 50*(2), 124–130. https://doi.org/10.1111/jtxs.12374

Stephen, A. M., Champ, M. M. J., Cloran, S. J., Fleith, M., van Lieshout, L., Mejborn, H., et al. (2017). Dietary fibre in Europe: Current state of knowledge on definitions, sources, recommendations, intakes and relationships to health. *Nutrition Research Reviews, 30*(2), 149–190. https://doi.org/10.1017/S095442241700004X

Urquiaga, I., D'Acuña, S., Pérez, D., Dicenta, S., Echeverría, G., Rigotti, A., et al. (2015). Wine grape pomace flour improves blood pressure, fasting glucose and protein damage in humans: A randomised controlled trial. *Biological Research, 48*(1), 49. https://doi.org/10.1186/s40659-015-0040-9

Urquiaga, I., Troncoso, D., Mackenna, M. J., Urzúa, C., Pérez, D., Dicenta, S., et al. (2018). The consumption of beef burgers prepared with wine grape pomace flour improves fasting glucose, plasma antioxidant levels, and oxidative damage markers in humans: A controlled trial. *Nutrients, 10*(10). https://doi.org/10.3390/nu10101388

Wang, Q., Xiong, Z., Li, G., Zhao, X., Wu, H., & Ren, Y. (2016). Tomato peel powder as fat replacement in low-fat sausages: Formulations with mechanically crushed powder exhibit higher stability than those with airflow ultra-micro crushed powder. *European Journal of Lipid Science and Technology, 118*(2), 175–184. https://doi.org/10.1002/ejlt.201400579

Yang, H., Sombatngamwilai, T., Yu, W.-Y., & Kuo, M.-I. (2020). Drying applications during value-added sustainable processing for selected mass-produced food coproducts. *Processes, 8*(3), 307.

Zia-ur-Rehman, Z., Islam, M., & Shah, W. H. (2003). Effect of microwave and conventional cooking on insoluble dietary fibre components of vegetables. *Food Chemistry, 80*(2), 237–240. https://doi.org/10.1016/S0308-8146(02)00259-5

Zlatanović, S., Kalušević, A., Micić, D., Laličić-Petronijević, J., Tomić, N., Ostojić, S., et al. (2019). Functionality and storability of cookies fortified at the industrial scale with up to 75% of apple pomace flour produced by dehydration. *Foods, 8*(11). https://doi.org/10.3390/foods8110561