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Implementation of Sustainable Development Goals in the dairy sector: Perspectives on the use of agro-industrial side-streams to design functional foods

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A R T I C L E I N F O

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Bioactive compounds

A B S T R A C T

Background and objectives: From 2017 to 2020, global milk production ranged from 610,724 to 643,769 thousand tons, but the dairy industry still faces issues related to its carbon footprint and sustainability. According to the United Nations Sustainable Development Goals (SDGs), by 2030, food processors, governmental bodies, and consumers should take actions regarding food production patterns and consumption to decrease the generation of by-products and side-streams and increase their circularity by developing nutritious-rich products. Dairy products have traditionally been manufactured without bioactive ingredients to boost consumers' health and well-being. To achieve the sustainability goals and the need to reformulate traditional dairy foods to make them more nutritious and reduce their carbon footprint, it is paramount to implement integrated approaches that embody the "farm to fork" ethos.
Scope and approach: This review integrates concepts of food science, technology, nutrition, circular economy, and sustainability to provide an overview of the technological applications of dietary fibre, polyphenols, functional lipids, and carotenoids obtained from agro-industrial side-streams in dairy food formulations.
Key findings and conclusions: Dairy processors can use bioactive ingredients and extracts obtained from agro-industrial side-streams to design potentially functional food models and tentatively market these products with nutritional claims or even with a health claim in case the bioactivity is verified in human intervention trials. This approach will increase the nutritional value of traditional dairy foods and contribute to circularity within food systems, reducing food waste, and enhancing human health.

1. Introduction

From 2017 to 2020, global milk production ranged from 610,724 to 643,769 thousand tons. India, the European Union (EU), the United States, China, Russia, Brazil, and New Zealand were the largest producers, with roughly 88% of worldwide production (European Commission, 2021). In the EU, fresh dairy products accounted for 38,016, 38,335, and 39,045 thousand tons in 2018, 2019, and 2020, respectively (Statista, 2021). Fresh milk, butter, yoghurt, fermented milks, and milk powder are the most traditional and the most produced dairy foods. However, considering rising consumer demands and expectations for more nutritious dairy foods, food companies of differing sizes have invested in developing dairy foods with added ingredients that may boost consumers' health: so-called "functional foods".

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Consumers have placed an increasing focus on their digestive health, optimising the intake of dietary fibre, practising weight management, increasing the consumption of bioactive compounds (i.e., phenolics), and reducing sugar/carbohydrate intake (Fidelis & Granato, 2021; Leme et al., 2021). Furthermore, issues such as the impact of production unit operations, animal welfare, and clean labels play a decisive role in purchasing and re-purchasing foods (Asioli et al., 2017). To accommodate all these needs while maintaining product quality and profitability is not an easy task for dairy food processors; however, thousands of new products are launched worldwide every year.

Products with nutritional and health claims (European Council, Regulation EC No 1924/2006), i.e., food products that have beneficial nutritional properties due to nutrients or other added substances, such as dietary fibre, lipids, phenolic compounds, and carotenoids, play an essential role in the current scenario of dairy processors. For example, some multinational companies have added rolled, white wheat flakes, rolled oats, red wheat bran, psyllium, chicory root extract, inulin/fructooligosaccharides, berry purees, among other ingredients to increase the content of dietary fibre of dairy foods. In contrast, extracts from vegetables and fruits (tomato, herbs, edible flowers, carrots, sweet potato, etc) have been added to dairy foods to increase the content of carotenoids and phenolic compounds. Several academic studies have attempted to develop dairy food models with added bioactive ingredients (Dabija, Codina, Gatlan, & Rusu, 2018; Escher et al., 2019; Simonetti, Perna, Grassi, & Gambacorda, 2021)

Experimental research that focuses on the addition of bioactive compounds in dairy foods is varied and provides insights into how food science and technologies, circular economy, and sustainability can serve as a cross-sectional platform to design nutritious and bioactive-rich ingredients to be added to dairy foods, which may boost consumer's health and wellbeing. However, designing functional foods using agro-industrial side-streams that are sources of bioactive compounds is not straightforward and may take years to reach the market. Accordingly, this review bridges the gap in the literature and focuses on the technological applications of dietary fibre, lipids, polyphenols, and carotenoids obtained from agro-industrial side-streams, aiming to contribute to the approaches outlined by the United Nations (UN) Sustainable Development Goals (SDGs) regarding circularity, responsible production and consumption, sustainability, and nutrition.

2. Envisaging an integrative and circular production of functional dairy foods considering the United Nations SDGs

By 2050, the global population is estimated to be approximately 10 billion. Consequently, food producers will face constant pressure to keep pace with demands for food. Although food production exceeds demand, unequal distribution and food loss and waste within supply chains may account for 30% of total food production not being consumed (Kusumowardani et al., 2022). Food waste and loss impact the access to safe and healthy foods in some regions, increase prices, and cause greenhouse gas (GHG) emissions. Thus, it is widely accepted that food production (including food waste and loss) and supply systems are two of the main factors that impact climate change (Qin & Horvath, 2022). The linear economy in food companies follows the "take, make, use, dispose" approach, generating a considerable amount of food waste and GHG, which directly impact environmental degradation and climate change. Conversely, the circular economy in food companies employs a more resource-efficient approach, whereby waste valorisation and cost reduction are two pillars used to mitigate the use of natural resources without jeopardising consumption (Miranda, Monteiro, & Rodrigues, 2021). Companies that adopt the circular economy concept follow the "make, use, reuse, remake, and recycle" approach, thus decreasing the production of waste and side-streams. The circularity of food systems has attracted interest from policymakers, scholars, and entrepreneurs, where the development and establishment of sustainable-oriented innovations are considered critical factors to sustainable food production. According to Campi, Duenas, and Fagiolo (2021), transforming food systems from a linear to a circular concept, and achieving sustainability in food chains, is a growing challenge at the international policy level. Several obstacles hinder the complete implementation of sustainable innovations in food systems such as energy recovery, GHG, resource efficiency, side-streaming reuse, and the correct treatment of waste (Tseng, Chiu, Chien, & Tan, 2019).

Considering the SDGs contained in the *Agenda 2030* (United Nations, 2015), global food systems play a crucial role in the sustainability and nutrition of Goal 2 (zero hunger), Goal 3 (good health and wellbeing), and Goal 12 (responsible consumption and production). These integrated Goals are inseparable, and they encompass economic, social, and environmental dimensions. The dairy sector, which involves farmers, industry, and cooperatives, needs to improve its sustainability credentials by embracing various technologies, including primary production patterns, the feeding of cows and overall animal production, manure handling, the processing of milk and its derivatives, and selecting/designing the packaging material of final products (Rotz, Montes, & Chianese, 2010). Therefore, implementing the SDGs in the dairy sector requires adopting "greener" technologies, optimised supply chain management, and product design (Mozas-Moral, Fernandez-Ucles, Medina-Viruel, & Bernal-Jurado, 2021). These actions will bring about changes in the demand for products and how business is conducted, which will, eventually, meet the aims of the *Agenda 2030*.

Considering that small and medium-sized enterprises are often very traditional and conservative, the manufacture of new products frequently represents a challenge. However, governmental incentives and consumer demands for clean labels and healthier options (e.g., protein-rich, zero sugar, zero fat, and probiotic/prebiotic-added options) have boosted the development of functional products to replace their traditional counterparts. Arguably, new technologies have been tested and improved to manufacture these products, and considerable investment in research & development is now a global reality. In practice, the need to be more sustainable, and the demand for improved/optimised dairy foods, have boosted the fourth industrial revolution: Industry 4.0 (Boz, 2021). This concept is intended to improve efficiency; improve the safety and quality of products and services; reduce costs, losses, and waste; and improve logistics, traceability, quality control, and the prediction of sensory and consumer preferences. In addition, consumers are increasingly conscious of how foods are produced and how the ingredients used in formulations affect the environment and health (Asioli & Grasso, 2021). This shift in how foods are made, and the interactions between food processors, policymakers, and consumers, are the basis for the Society 5.0 concept. This paradigm encompasses using technology for more sustainable, resilient, and equitable food systems, which has changed the innovation scenario, focusing on an all-inclusive value chain in various food sectors, including the dairy industry (Boz, 2021).

The practical implementation of integrated "farm to fork" approaches, in combination with SDGs and the concepts of Industry 4.0/Society 5.0 in dairy processing, will ultimately lower carbon footprints, use/reuse side-streams from agro-industry to reformulate traditional dairy foods, and enable faster changes in primary production and food processing units (Iriondo-DeHond, Miguel, & Del Castillo, 2018). Therefore, tackling food companies regarding sustainable management, the efficient use of natural resources and the decreased production of food losses, allied to better utilisation of agro-industrial side-streams and by-products, are vital elements to be considered. These by-products include seeds, leaves, stalks, rind, skin, and pomace. One plausible way to implement these concepts in dairy companies is by using agro-industrial side-streams as sources of extractable and non-extractable bioactive compounds (Stubler, Heinz, & Aganovic, 2020; do Campi et al., 2021), such as dietary fibre, carotenoids, polyunsaturated fatty acids (PUFAs) and phytosterols/stanols, and phenolic compounds.

Fig. 1 shows one example of different integrative approaches, such as

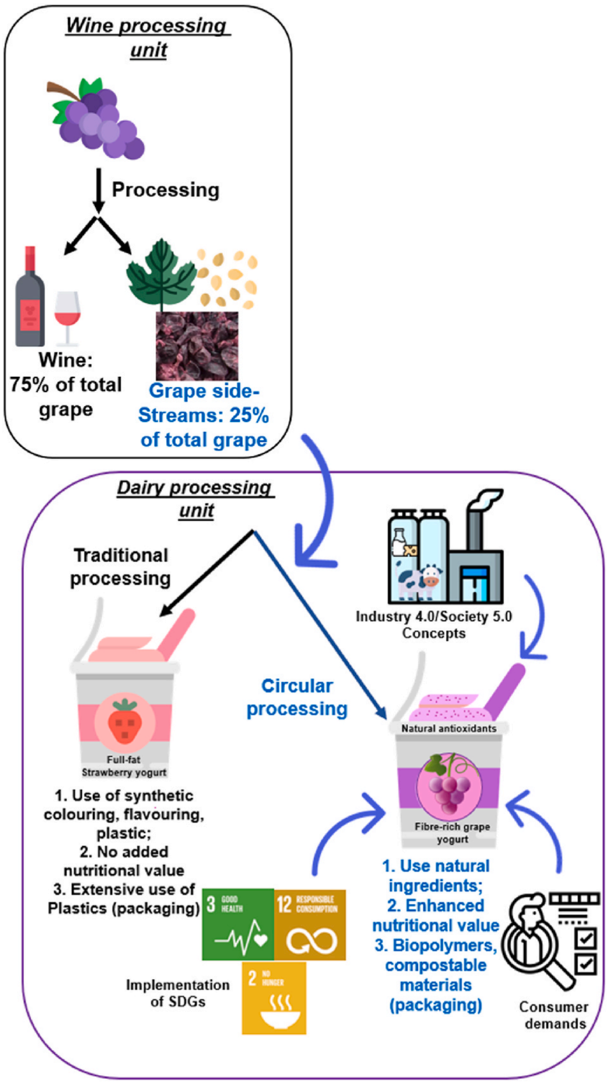

Fig. 1. Example of implementing different integrative concepts, namely Sustainable Development Goals (SDGs), Industry 4.0, Society 5.0, and consumer demands and expectations for the sustainable and circular processing of yoghurt with added grape pomace, source of fibre and natural antioxidants.

SDGs, Industry 4.0, Society 5.0, and consumer demands to develop new sustainable dairy foods. Taking the wine industry as an example, approximately 25–30% of side-streams are generated by this sector, which is composed of grape skin, stalks, leaves, and seeds. To produce a more sustainable and "natural" grape yoghurt, grape skin flour can be added to replace synthetic colouring and antioxidant compounds, as well as enhancing levels of fibre and antioxidants. A similar approach has been adopted by researchers using olive (Ribeiro, Bonifácio-Lopes, et al., 2021) pomace as ingredients in different dairy foods.

Agro-industrial side-streams generated from fruit, cereal and vegetable processing industries are highly diverse, mainly due to the different varieties utilised and the wide range of the processes employed (Tlais, Fiorino, Polo, Filannino, & Di Cagno, 2020). As these materials are sources of bioactive compounds, the extraction technologies applied for their recovery and stabilisation are of great value (Sagar, Pareek, Sharma, Yahia, & Lobo, 2018). Previous review papers have focused on technologies designed to extract bioactive compounds (Sagar et al., 2018), the use of herbal extracts in dairy products (Granato et al., 2018), the use of different fruit and vegetable parts in food products (Tlais et al., 2020), and the challenges associated with the sensory properties of new products, including ingredients obtained from agro-industrial side-streams, and consumer perceptions and emotions regarding these sustainable and novel dairy foods (Iriondo-DeHond et al., 2018). However, no single review paper was found concerning the integrative and sustainable use of agro-industrial side-streams as sources of various bioactive compounds to manufacture potentially functional dairy foods.

3. Functional dairy foods: from raw materials and technologies to human intervention studies

The global functional food market was valued at US$ 178 billion in 2019, while in 2020 and 2021, this figure reached US$ 258.8 and 281.4 billion, respectively (Statista, 2021; Fortune Business Insights, 2021). The compound annual growth rate (CAGR) is estimated to be approximately 10%, and forecasts project a value of US$ 530 billion in 2028 (Fortune Business Insights, 2021). The main drivers for the rising demand for healthy and nutritious diets are evolving lifestyles, increased income, and the awareness of the health benefits of functional foods. In short, food companies have adopted technologies and optimised their processes, not only to keep up with market demand but also to obtain a "clean label" distinction by decreasing energy consumption, using less plastic in packaging materials and synthetic ingredients in the formulation, and increasing the use of "nature-based" ingredients (Noguerol, Pagan, Garcia-Segovia, & Varela, 2021).

The development of potentially functional dairy foods is not simple; it requires compliance with local legislation (e.g., Food and Drug Administration - FDA, European Food Safety Authority - EFSA). It should be economically and logistically feasible, and products should interest a large consumer cohort. Considering this complex, multifaceted activity, in Fig. 2, we use a concept modified from Fidelis and Granato (2021) to describe a general approach to recovering bioactive compounds (e.g. fibre-rich fractions, and water-soluble and lipophilic compounds) from agro-industrial side-streams using various technologies (i.e., ultrasound, maceration, enzyme/microwave-assisted extraction) that are usually employed, while drying technologies (e.g., conventional drying, spray-drying, and freeze-drying) are used to increase the chemical and microbiological stability of bioactive-rich extracts (Pap et al., 2021). These bioactive-rich extracts can be incorporated into dairy foods to enhance their bioactivities and manufacture more nutritious dairy foods. In a complementary approach, Fig. 3 outlines the analyses to assess the chemical composition, bioactivities, and toxicological safety of the bioactive-rich extracts recovered from agro-industrial side streams. Some *in vitro* chemical and enzymatic-based systems should be used to assess bioactivity (e.g., antioxidant, antidiabetic, antimicrobial, and anti-hypertensive activities). At the same time, cell-based assays can be used to evaluate the possible harmful (e.g., cytotoxic) or protective effects of bioactive-rich extracts on human cells and tissues (e.g., endothelial cells, erythroblasts, hepatocytes, and pancreas cells, among others) (do Carmo, Granato, & Azevedo, 2021). Suppose the extracts show a nontoxic profile on human cells (i.e., no significant changes in cell viability at a physiologically relevant concentration). In that case, it is reasonable to assume a relative safety of the extracts to be further used in the prototyping and optimization of the dairy food formulation (Granato et al., 2022). Finally, as shown in Fig. 4, testing food formulations and prototypes is of paramount importance to assess how bioactive-rich ingredients affect the proximate composition, bioactivity, microbiological (e.g., shelf life), and sensory properties of dairy foods. If a dairy processor envisages potential health claims about their products, further efficacy testing should be performed under strict scientific rigour; randomised placebo-controlled intervention studies are considered the "gold standard" (Alongi & Anese, 2021). Evidence that dairy foods are beneficial should be formally demonstrated in clinical trials. A placebo control group (e.g., not consuming the bioactive-rich ingredient) is usually used to compare the outcomes with the group receiving the food containing the bioactive ingredient(s). Finally, human intervention studies can demonstrate an unequivocal association between the consumption of a functional dairy food (i.e., cause) and the health

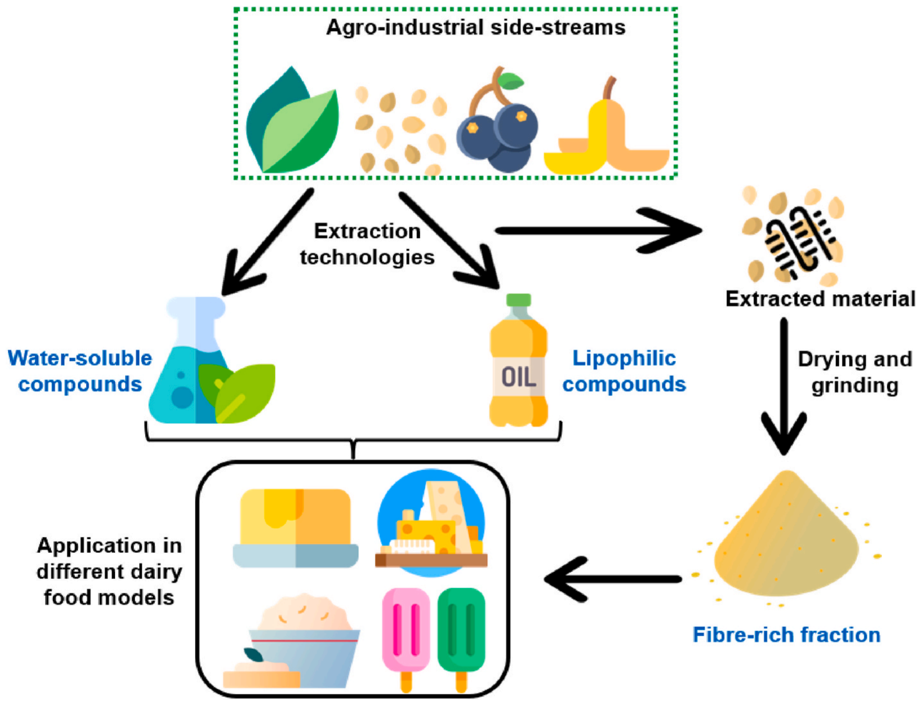

Fig. 2. General strategy to develop new potentially functional ingredients, namely extractives (lipophilic and water-soluble compounds) and dietary fibre from agro-industrial side streams and manufacture different dairy foods containing bioactive ingredients.

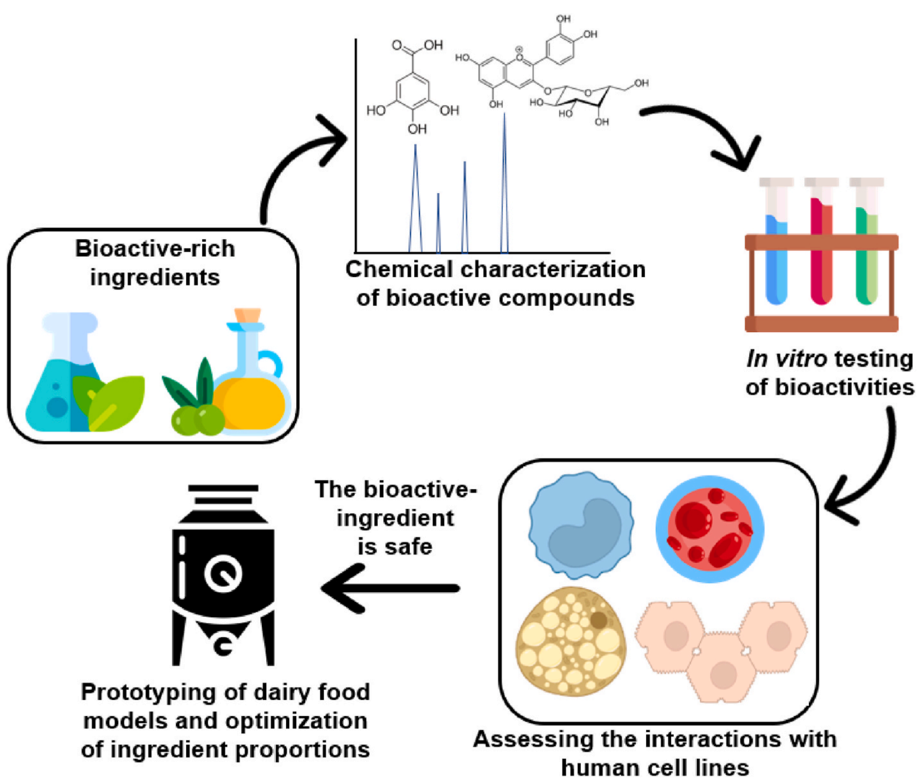

Fig. 3. Overview on the steps to be considered when using bioactive-rich ingredients in the manufacture of potentially functional foods: from analysing qualitative and quantitatively the chemical composition, assessing their bioactivities using *in vitro* systems, and evaluating their effects (e.g. cytotoxicity or cytoprotective properties) on targeted human cell lines.

benefits (i.e., effect) (Moon et al., 2022).

To align the SDGs, nutritional demand, and innovation, the development of dairy foods with added bioactive ingredients extracted from agro-industrial side-streams are compiled and discussed below, focusing on carotenoids, phenolic compounds, dietary fibre, and functional lipids.

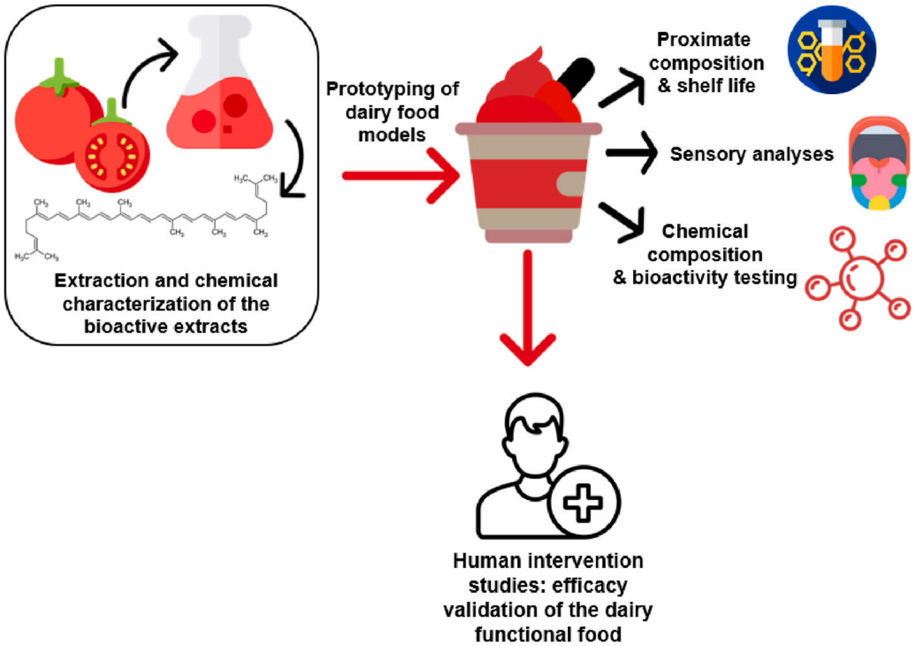

Fig. 4. Summary of practical steps to assess the efficacy of a potentially dairy functional food: extraction and characterisation of the bioactive-rich ingredient to be incorporated in the dairy food model, determination of the proximate composition, shelf life studies, chemical characterisation of the food by different approaches, *in vitro* bioactivity testing, and validation of the functionality using a human intervention study.

3.1. Dairy foods added with carotenoid-rich extracts

Carotenoids, some of the most widely distributed natural molecules in the plant kingdom, are usually known for their colouring properties, red, orange, and yellow hues, having a decisive effect on the health of the eye and vision, but also assuming essential roles as antioxidants and disease prevention (Ngamwonglumlert & Devahastin, 2019). Due to these properties, many of the crucial carotenoids are incorporated in foods, especially dairy products. Some carotenes are naturally present in the milk of some cattle but not in the milk of sheep and goats. Thus, carotenes are partially responsible for the yellow colour that high-fat dairy products made from these milks usually display (Fox & Guinee, 2022). Carotenoids can be extracted from plants using various techniques and solvents, being water, ethanol, and acetone, some of the most popular (Table 1). The extraction techniques range from simple macerations to ultrasound, being the former the most common, especially when incorporation imparts colour. High energetic extractions destroy the double bonds in the tails of carotenoid molecules and thus reduce their colour intensity. Still, other types of modern types extractions exist, namely enzyme assisted extraction, which detaches the carotenoids through the enzymatic reaction from the substrate (Jalali-Jivan, Fathi-Achachlouei, Ahmadi-Gavlight, & Jafari, 2021); microwave-assisted extraction that uses microwaves that induce vibration of water molecules, thus detaching carotenoids (Leema, Jothy, & Dharani, 2022); ultrasound-assisted extraction that uses ultrasonic pulses to extract carotenoids (Ordóñez-Santos, Esparza-Estrada, & Vanegas-Mahecha, 2021); simultaneous saccharification and co-fermentation (SSCF) that ferments and saccharifies the extract for the obtention of carotenoids and other molecules (Liu, Natalizio, Dragone, & Mussatto, 2021); deep eutectic solvents (Stupar et al., 2021), among others.

As seen in Table 1, in terms of incorporation in dairy products, many carotenes are added in accessible forms, using their colouring properties to improve the colour of dairy products and incorporated for their functionalising properties. In other cases, they are added encapsulated or in emulsions to extend the functionalisation over a more extended period and stabilise them. Due to being biological molecules and having colouring properties, carotenoids are prone to losing these properties over time, and some techniques are used to protect them and stabilise their structures. As shown in Table 1, zeaxanthin has been added to yoghurt in nanoemulsions and encapsulated forms. However, the incorporation of these extracts in foods is usually made using freeze-dried extracts or dried materials (e.g., pulp, seeds, and peels) because of the high price of the technology to protect these molecules and the difficulty of performing these stabilising procedures on large molecules like carotenoids.

Due to being allowed as food colourants in the EU, some carotenoids have been systematically extracted, standardised, and used in many foods, including dairy products. Nine allowed additives are a mixture of carotenoids that are partially responsible for their colours. Examples are E100 (curcumin) which has a yellow colour, mainly from the carotenoid with the same name, the carotenes (E160), which are further derived in E160a (carotenes), E160b (annatto, bixin, norbixin), E160c (paprika extract, capsanthin, capsorubin), E160d (lycopene), and E160e (β-apo-8′-carotenal). Lutein (E161b) and canthaxanthin (E161g) are pure carotenoids allowed in foods within the EU. These food colourants use different carotenoids extracted from plant sources in most dairy foods (EFSA, 2008; Sharma, Segat, Kelly, & Sheehan, 2019).

Due to the widespread use of these molecules as colourants, functionalising agents or food additives, many clinical trials have been performed or are currently recruiting volunteers for future endeavours. These studies aim specifically at further investigating and/or confirming the beneficial effects of specific carotenoids in illnesses or understanding the impact of their intake on different metabolic conditions, such as ocular diseases (NCT03750968), cognitive disorders (ACTRN12621000038897) and multiple sclerosis (lutein and zeaxanthin), and cardiovascular diseases (lycopene, astaxanthin; IRCT20191018045149N1, IRCT20201227049857N1).

Overall, carotenoids are molecules with many applications in the food industry, with their potential being discovered some time ago, leading to the widespread application as food colourants. They are safe for human health and the interest in further researching them has strengthened. Still, due to the many human trials being carried out with carotenoids, science allows more insight into their effects on the body's regular metabolism and many illnesses. With the implementation of sustainability and circular economy in many industries, using plant

Table 1
Incorporation of different carotenoids in dairy products.

Dairy Food	Plant Source	Extract Type	Extraction Technology	Added/analysed Carotenoids	Added Quantity	Incorporation Type	Incorporation Purpose	Reference
Milk-based beverage	*Mauritia flexuosa* fruit	Ethanol 80:20	Ultrasound	N.d.	N.d.	Free	Colour, Functional	Best et al. (2020)
Milk fat	*Solanum lycopersicum* (tomato)	Acetone, Petroleum ether, water	Maceration	Lycopene	30–150 mg/kg	Free	Functionalisation, shelf-life extension	Siwach, Tokas, and Seth (2016)
Ice-cream	*Solanum lycopersicum* (tomato)	100% Ethanol	Maceration	Lycopene, phytoene, phytofluene, β-carotene, cis-lycopene, and lutein	500–2000 mg/kg	Free	Colour	Rizk, El-Kady, and El-Bialy (2014)
Ice-cream	–	–	Bought solution	Lycopene	15 g/100 g	Free	Functionalisation	Chernyshova et al. (2019)
Yoghurt	*Lycium barbarum* Goji berries	100% Water	Infusion	Zeaxanthin	362 µg	Nanoemulsions	Functionalisation	Campo et al. (2019)
Yoghurt	*Carica papaya* Papaya fruit *Curcumis melo* Melon	Lyophilized fruit	–	β-cryptoxanthin – lycopene, and β-carotene	–	Free	Functionalisation	Gies, Descalzo, Servent, and Dhuique-Mayer (2019)
Yoghurt	*Daucus carota* carrot	Wastes	–	β-carotene	2.5–5 g/100 g	Encapsulated	Functionalisation	Šeregelj et al. (2021)
Yoghurt	*Daucus carota* carrot	Crushed carrots	–	–	0–20% w/w	Free	Functionalisation	Kiros, Seifu, Bultosa, and Solomon (2016)
Yoghurt	Tagetes (genus) Marigold flower	–	Bought solution	Astaxanthin	1.5 mg/120 g	Free	Functionalisation	Domingos et al. (2014)
Cheese	–	–	Bought solution	Lutein	16–32 mg/L	Free	Colour	Sobral et al. (2016)
Cheese	*Zea mays* (Corn)	Acetone	Maceration	Lutein	1–6 mg/28 g	Free	Functionalisation	Jones, Aryana, and Losso (2005)

Note: N.d = not detected.

residues as sources of carotenoids seems like a promising road to further utilise these molecules.

3.2. Dairy foods added with polyphenol-rich extracts

Phenolic-rich plant extracts have been investigated extensively as food ingredients for creating fortified foods or functional foods. This aspect has made a considerable challenge for food scientists and the food industry regarding the suitability of these biomolecules and their influence on the final products' microbiological, physicochemical, and sensory aspects. These parameters influence the consumers' perception and, finally, the economic impact of these products on the market (Cutrim & Cortez, 2018). Phenolic compounds derived from natural sources are attractive biomolecules because of their antioxidant and anticancer properties, beneficial effects on cardiovascular and neurodegenerative diseases, and antimicrobial potential. However, many phenolic compounds are problematic due to their low water solubility, disagreeable oral perception, and interactions with milk proteins. Therefore, specialised delivery systems such as microencapsulation have been developed to increase the molecule's shelf life, avoid its degradation, increase its bioavailability, and reduce its adverse sensorial effects on foods (Cutrim & Cortez, 2018). Polyphenolic nanocarriers can be categorised into polysaccharide- and protein-based delivery systems using substances such as biofilms, cyclodextrins, nano micelles, polymeric and gelatine nanoparticles, food protein nanoparticles like soybean, whey, casein, zein nanoparticles, chitosan, lipid nanocarriers and protein-polysaccharide complex nanoparticles, while most commonly used for the delivery of plant polyphenols remain food-protein nanoparticles and chitosan, gathering strong evidence of improving the intestinal absorption of polyphenols (Milinčić et al., 2019).

Another issue related to phenolic enriched dairy products is that generally, the food industry focuses on using phenolic enriched extracts and not pure compounds. These extracts are mainly sourced from traditionally used medicinal plants or edible plants with a long history of being used locally or internationally. One of the trends is to use widely accepted foods, such as goji berry, passion fruit or blueberries, as sources of phenolics. At the same time, local producers are more confident in using local resources like elderflower, Aronia berries or different fruit syrups. In any case, these extracts contain phenolic antioxidants and colourants (such as anthocyanins), which modify the sensory properties and the final acceptance of the product (Granato et al., 2018). Another recent trend in food science and nutrition is the use of food by-products, mainly of plant origin, as sources of new functional ingredients, this being as well present in the field of dairy products. Iriondo-DeHond et al. (2018) showed in their analysis that over 18 years (2000–2018), among the reviewed studies, 88% of the used side-streams are from plant materials, most of the by-products originating from the fruit industry (43%), wine companies (19%), and vegetable processors (13%). Regarding fruits and vegetable by-products, most of the research focused on citrus and tomato side-streams as functional ingredients in dairy products, showing the efforts that have been made towards the valorisation, especially of by-products from food groups that present the highest losses during production, storage, and transportation.

An important aspect that should be covered when dealing with phenolic-rich extracts is their purpose in the design of the novel product: they can be used either for *"technical"* issues such as improving the stability, shelf life, safety, sensory quality, and nutritional value, among others or can be used for their *health-promoting effects*, aiming to finally create a functional dairy product (Iriondo-DeHond et al., 2018; Salehi, 2021). Finally, it is essential to mention that polyphenol-rich extracts improve the functionality and the nutritional value of several classes of dairy products, such as yoghurt, ice cream, butter, cheese, and dairy desserts. In some cases, unique products can be created where phenolics can originate from different sources, having other functions for the same dairy product (Caleja et al., 2016; Da Silva, Matumoto-Pintro, Bazinet, Coullard, & Britten, 2015; Kandylis, Dimitrellou, & Moschakis, 2021;

Lee, Jeewanthi, Park, & Paik, 2016; Peker & Arslan, 2016). For example, the incorporation of grape-derived products in dairy products increase phenolics and the amounts of fermentable dietary fibres, with a recognised prebiotic effect, i.e. gut microbiota modulation *in vivo*. Furthermore, the positive effects of grape derivatives phenolic compounds on dairy products are extended to their incorporation in cheese, fermented milks, and ice creams. They refer to improving the product's overall antioxidant capacity, microbiological status, and sensory properties (Raikos, Ni, Hayes, & Ranawana, 2019)

Phenolics' low bioavailability is one factor that influences their health applications and nutritional and food technological relevance. Many efforts have been dedicated to investigating the bioavailability of phenolics from different herbal-based food matrices; however, there is still a need of understanding how dairy model systems change the bioavailability of these compounds. Oksuz, Tacer-Caba, Nilufer-Erdil, and Boyacioglu (2019) investigated the *in vitro* changes in the bioaccessibility of sour cherry (*Prunus cerasus*) phenolics when ingested with dairy food matrices and observed that phenolics remained highly stable in the dairy food matrix, while anthocyanins showed the opposite behaviour.

Many randomised clinical trials based on polyphenol-rich diets explore relevant aspects of their bioavailability, effects on cardiovascular health and metabolic syndrome, and other chronic diseases (Condezo-Hoyos, Gazi, & Perez-Jimenez, 2021). The efficacy of dairy foods added with polyphenols has to be assessed using primary *in vitro* data and pre-clinical trials (i.e. animal testing) and using randomised clinical trials so that any health claim can be justified and validated.

The extensive application of phenolic-rich extracts from different plant-based side-streams in the food industry has encouraged producers to incorporate them into dairy products and extend the possible valorisation of several food waste matrices, consequently potentially reducing their environmental impact (see Table 2). New perspectives are opened in the dairy industry to develop novel and innovative products with added functional properties, driven by the consumer's demands for healthier food products and ecological technologies in food processing.

In most cases, research on the utility of polyphenols in the production of dairy products has focused on their modulation of microbiota and their antioxidant properties. In contrast, interactions between milk proteins and polyphenols have been mainly studied using model systems (Lamothe, Azimy, Bazinet, Couillard, & Britten, 2014). However, these interactions need to be comprehensively understood (e.g., gelation properties of milk proteins after the interaction with polyphenols). Nonetheless, some studies in the literature document the influence of polyphenol-protein interaction on the bioactive properties of phenolics (e.g., enhanced antioxidant properties of epigallocatechin gallate complexes of α-casein, β-casein, α-lactalbumin and β-lactoglobulin compared to individual antioxidant activity; masking the radical scavenging activity and the antioxidant activity of tea catechins due to covalent/noncovalent interactions with milk proteins) (Yildirim-Elikoglu & Erdem, 2018). In a recent study of our group (Liu, Natalizio, et al., 2021), conjugates of whey protein isolate (WPI) and different polyphenols found in foods (naringenin, apigenin, quercetin, and epigallocatechin gallate) were prepared via free-radical grafting. Experimental data showed that the conjugation of WPI with the polyphenols increased their thermal stability and antioxidant capacity while reducing their hydrophobicity.

Therefore, a particular focus should be on the effects of polyphenolic-enriched extracts on the newly developed products' sensory characteristics. At the same time, further research is needed to focus on the bioavailability of these molecules considering polyphenol-milk protein interactions and health aspects after consuming the fortified products. Further evaluation of the gut microbiota modulation, production of bioactive metabolites, changes in bioactivity after digestion and derived health benefits using physiologically relevant experimental models are some targets of future research in the field.

Table 2
Polyphenols in dairy products: aspects to be considered when designing polyphenol-based dairy products.

Positive factors	Negative factors	Considerations
Improvement in the phytonutrient profile		Along with polyphenols, the extract can also deliver other compounds such as fibres, fatty acids, other polysaccharides.
Increased antioxidant capacity		Increase in the daily intake of dietary antioxidants
Modulation of intestinal microbiota		Polyphenols that are not absorbed are metabolised by the colonic microbiota, which their metabolites can further regulate.
Extending shelf-life		Polyphenols can extend the shelf-life of dairy products, acting as antimicrobial agents against foodborne pathogens.
Improving sensory properties and general acceptability of a product		New sensorial features (flavour, colour, texture, etc.)
	Questionable bioavailability	The use of microencapsulation can improve the bioavailability of polyphenols in dairy products.
	Modification of cheese-making properties of milk	Using a different type of polyphenols can improve their effect on the dairy matrix; a better characterisation of the interaction of the polyphenols with the dairy matrix will help find more suitable polyphenols sources.
	Undesirable sensory effects	The use of microencapsulation can improve the oral perception of polyphenols fortified dairy products.
	Unknown addressability, products without a clear health claim	When designing a dairy product fortified with polyphenols, the product should incorporate a polyphenol-blend with a particular health claim (i.e. improvement of the antioxidant status, maintaining cardiovascular health, maintaining a healthy and diverse microbiota, etc.)

3.3. Dairy foods added with dietary fibres

Dietary fibres are defined as (1) non-digestible insoluble and soluble carbohydrates (>3 monomeric units) and lignin, which is intact and intrinsic in plants, and (2) synthetic or isolated non-digestible carbohydrates (>3 monomeric units) that have physiological effects on human health (Food and Drug Administration, 2018). Food industries have focused on increasing the fibre content of dairy products aiming to help consumers to achieve the recommended daily intake of this component, which is 25–30 g/day, and as a marketing strategy, as they may use a nutritional claim on the labels (Iriondo-DeHond et al., 2018). Many regulatory agencies, including the European Parliament and Council, allow the designation of 'source of fibres' and 'high in fibres' if the product contains higher than 3 and 6 g/100 g of dietary fibres, respectively (European Parliament & Council Regulation, 2006 2006).

The consumption of dietary fibre has been associated with several health effects. For example, dietary fibres with high water-holding capacity may help the bowel movements through the colon. Furthermore, those with high viscosity may act as a cation exchanger, resulting in the removal of toxic substances and decreased absorption of dietary cholesterol. In addition, serum lipid and glucose levels are usually reduced when high viscosity fibres are consumed (Keskin et al., 2021).

Thus, dietary fibres may reduce the risk of non-communicable diseases, such as coronary heart disease and type-2 diabetes (Yegin, Kopec, Kitts, & Zawistowski, 2020).

Plant-derived by-products, such as skins, peels, seeds, hulls, pomace, husks, stores, and cores, are recognised for the high concentration of nutrients and bioactive compounds, including dietary fibres (Iriondo-DeHond et al., 2018). Several agro-industrial side-streams of fruits, vegetables, and cereals processing have been used as dietary fibre sources in dairy products, such as hazelnut skin (Bertolino et al., 2015), and by-products from orange (Sendra et al., 2010; Crizel, Araujo, Rios, Rech, & Flôres, 2014), apple, banana, passion fruit (Espírito Santo, Cartolano, et al., 2012,b; 2013), pomegranate (Ismail, Hameed, Refaey, Sayqal, & Aly, 2020), pineapple (Sah, Vasiljevic, McKechnie, & Donkor, 2016), tomato, broccoli, artichoke (Lucera et al., 2018), asparagus (Sanz, Salvador, Jimenez, & Fiszman, 2008), Tunisian date (Jridi et al., 2015), celery, pear, spinach (Saraç & Dogan, 2016), rice, sunflower, corn, and barley (Ayar, Siçramaz, Öztürk, & Öztürk Yilmaz, 2018). Furthermore, pomaces from apple (Issar, Sharma, & Gupta, 2017), olive (Ribeiro, Bonifácio-Lopes, et al., 2021), and grape (Lucera et al., 2018) have been previously used in dairy products. In most of the studies, dried and sieved fibre-rich ingredients from agro-industrial side-streams are incorporated in the dairy products (Sendra et al., 2010; Crizel et al., 2014; Espírito Santo, Cartolano, et al., 2012,b; Espírito-Santo et al., 2013; Ismail et al., 2020). Other approaches have used fibres obtained from apple pomace by acid-alkali digestion (Issar et al., 2017) or centrifugation and freeze-drying olive pomace (Ribeiro, Bonifácio-Lopes, et al., 2021).

Yoghurts and fermented milk are the most used dairy products for supplementation with fibre-rich side-streams to increase dietary fibre content (Espírito Santo, Cartolano, et al., 2012,b, 2013; Bertolino et al., 2015; Issar et al., 2017). However, other dairy products may also be the target applications, such as ice cream (Ayar et al., 2018; Crizel et al., 2014; Ismail et al., 2020), dairy desserts (Jridi et al., 2015), cheese (Lucera et al., 2018), and butter (Saraç & Dogan, 2016).

The addition of fibre-rich side-streams as ingredients in dairy foods can improve the nutritional value of the products not only by increasing the dietary fibre but also by the concentration of other beneficial compounds, such as phenolic compounds (Ribeiro, Queiroga, et al., 2021), short-chain and PUFAs (Espírito Santo, Cartolano, et al., 2012; Ribeiro, Bonifácio-Lopes, et al., 2021), and protein, fat, and mineral contents (Ismail et al., 2020).

Although the use of fibre-rich ingredients obtained from side-streams may increase the nutritional value and increase the content of phenolic compounds in the dairy product, it may also change their physicochemical composition. For instance, the addition of passion fruit peel powder, orange fibre, Tunisian date, and asparagus by-products, and red and white grape pomace increased the acidity of yoghurts, ice cream, dairy desserts, and spreadable cheese (Ismail et al., 2020; Jridi et al., 2015; Lucera et al., 2018; Espírito Santo, Perego, Converti, & Oliveira, 2012; Sanz et al., 2008; Espírito). On the other hand, adding hazelnut skin or tomato peel did not affect the pH and titratable acidity values of yoghurts and spreadable cheeses (Bertolino et al., 2015; Lucera et al., 2018). Thus, the differences may be associated with the by-product characteristics, as orange fibre, pomegranate peel powder, and grape pomace, for example, have low pH values (3.4–4.0), which contributes to the decrease in the pH of the products (Ismail et al., 2020). Furthermore, the use of food side-streams in fermented milk may increase the counts of starter and/or probiotic culture (Espírito Santo, Perego, et al., 2012)

The addition of fibre-rich side-streams in dairy food processing may also affect the texture profile of final products. For example, Sah et al. (2016) observed a lower firmness of yoghurts added with pineapple peel powder (1 g/100 g, fibre content not mentioned), which was associated with incompatibility of the polysaccharides of the by-product and milk proteins resulting in a weak gel. However, in other studies, products with increased cohesiveness (Espírito Santo, Perego, et al., 2012; Jridi et al., 2015), thickness (Jridi et al., 2015), apparent viscosity (Espírito-Santo et al., 2013), and consistency (Sanz et al., 2008) were obtained after the addition of the fibre-rich ingredient. Some dietary fibres may interact with proteins and form a harder structure (Espírito-Santo et al., 2013; Jridi et al., 2015; Sendra et al., 2010).

The impact of fibre-rich ingredients obtained from side-streams on other dairy foods' technological properties depends on the product. In yoghurts, adding these ingredients may decrease the fermentation time, as probiotic and starter cultures may use dietary fibre and other sugars (Sah et al., 2016). This result is of industrial interest, as fermentation is the most time-consuming step in fermented milk processing. Furthermore, in yoghurts and dairy desserts, the addition of fibre-rich ingredients may decrease (Jridi et al., 2015), maintain (Espírito-Santo et al., 2013) or increase (Bertolino et al., 2015) syneresis. The presence of dietary fibre, mainly insoluble fibres, may promote a rearrangement of the gel matrix, contributing to a higher whey expulsion from the gel (Bertolino et al., 2015). However, some soluble fibres, such as pectin, may increase the water-holding capacity, precluding the whey separation (Espírito-Santo et al., 2013).

Adding fibre-rich ingredients from side-streams may impact ice creams' overrun values and melting rate. The impact depends on the source material: for example, fruit-derived side-streams increased the overrun values while grain-derived side-streams showed the opposite behaviour (Ayar et al., 2018). The decrease in overrun has been associated with lower bubble stability, higher organic acid content, and higher mix viscosity (Ismail et al., 2020). Some fibres may have edges like stones (Espírito-Santo et al., 2013), which impair the bubble structure and ability to retain air, decreasing the overrun values. At the same time, products with higher organic acid content and higher mix viscosity may show insufficient foaming capacity (Ismail et al., 2020). For example, Ismail et al. (2020) reported that the addition of 2.5 g/100 g of Doum fruit syrup to an ice cream added with 0.25 g/100 g pomegranate peels powder (9.13 g/100 g dietary fibre) increased the acceptability of ice creams compared to the product added only with the fibre ingredient, resulting in a product with creamy colour, good flavour, and soft texture and body. On the other hand, some fibres may entrap air and increase air retention (Ayar et al., 2018). Longer melting rates were reported in a previous study after by-product incorporation (pomegranate peel, 9.13 g/100 g fibre content) (Ismail et al., 2020). In ice creams, products with high overrun values and intermediate melting rates are desired, resulting in aerated products and sufficient time for the consumer to consume the product before it melts.

In cheeses, the type and concentration of fibre-rich ingredients obtained from the side-streams impact cheese weight loss during ripening and, consequently, cheese yield. For example, red wine pomace, artichoke by-products, and tomato peel added at 5 g/100 g concentrations into final products increased the weight loss. In contrast, higher concentrations (10 g/100 g) decreased weight loss (higher yield). Furthermore, the results were associated with higher water holding capacity of the dietary fibres at high concentrations (Costa et al., 2018). Thus, an adequate concentration of fibre-rich ingredients should be evaluated to obtain cheeses with a higher yield.

The impact of the fibre-rich ingredients from side-streams on the sensory profile and acceptance of dairy products is also dependent on their type and concentration used in the manufacture. Decreases in the sensory acceptance of the products have been reported after the addition of such ingredients, such as passion fruit fibre added into yoghurts (Espírito-Santo et al., 2013), pomegranate peels added into ice creams (Ismail et al., 2020), and dietary fibre from orange albedo, celery root, celery leaf, stone pear, and spinach added into butter (Saraç & Dogan, 2016). The negative impact on sensory properties was associated with the development of graininess and sandy mouth feeling, astringent taste, and loose texture (Espírito-Santo et al., 2013; Ismail et al., 2020). However, one study reported no significant impact of adding flour from fruit and grain side-streams on the sensory acceptance of ice cream (Ayar et al., 2018). Thus, when sensory properties of dairy foods are considered, the addition of fibre-rich ingredients from agro-industrial side-streams should be studied case by case in a way that the maximum concentration used will not negatively affect the sensory profile and acceptance of the product.

For technological applications, the concentration of fibre-rich ingredients should be optimised to obtain products with similar or improved sensory acceptance compared to the conventional product without fibre (Issar et al., 2017; Bertolino et al., 2015; Espírito-Santo et al., 2013) Finally, agro-industrial side-streams may also be used as fibre sources and fat replacers in dairy products (Crizel et al., 2014)

3.4. Dairy foods added with functional lipids

Lipids are extremely diverse biomolecules with a wide variety of structures and functions. They include neutral lipids (NL), such as waxes, triacylglycerides, fatty esters and cholesterol esters, fatty acids, and polar lipids (PL). PLs have amphipathic properties because of several subclasses of glycolipids and phospholipids, while some lipid vitamins and carotenoids may also behave as PLs. Several lipid molecules possess bio-functional properties with several health benefits. For example, dietary omega-3 (n-3) PUFAs have been characterised as functional lipids. In contrast, several of the amphipathic/amphiphilic PLs molecules, and especially those bearing the functional mono-unsaturated oleic acid and/or an n-3 PUFA in their structures, have beneficial health properties against inflammation, thrombosis, and chronic disorders, according to recent studies (Anto, Warykas, Torres-Gonzalez, & Blesso, 2020; Lordan, Tsoupras, Mitra, & Zabetakis, 2018; Tsoupras, Lordan, & Zabetakis, 2018). Another class of functional lipids is lipid-soluble vitamins (e.g., vitamin D), with many health benefits.

Several bio-functional lipid molecules have been found in dairy products, such as vitamin D, n-3 PUFAs, oleic acid, and PLs bioactives, with several documented health benefits (Anto et al., 2020; Lordan et al., 2018), while the focus has also been given to fortify the animal diet with such functional lipids to increase the concentration of these lipid bioactives in ruminants and thus in their milk and the resulting dairy products (Fougère & Bernard, 2019; Isenberg, Soder, Pereira, Standish, & Brito, 2019; Vargas-Bello-Pérez et al., 2021). For example, the inclusion of dietary vegetable sources rich in unsaturated fatty acids (UFA) in sheep diets would be an effective nutritional strategy to decrease saturated fatty acids and increase polyunsaturated FA contents in cheeses without detrimental effects on milk yield and milk composition (milk fat percentage and milk protein percentage) (Vargas-Bello-Pérez et al., 2021). Therefore, the fortification of dairy with functional lipid bioactives seems to enhance the overall functional properties and health benefits of dairy products.

Over the past few years, there have been several reports on the fortification of dairy products in several ways. Due to a proposed link of dairy saturated fatty acids (SFA) with several diseases, many researchers have attempted to fortify dairy fat content with UFA rich sources to improve the functional properties and nutritional quality of the resulting fortified dairy products. For example, the development of fortified dairy with UFA-rich sources has been found as an innovative strategy to obtain high-quality products with functional potential (Villamil et al., 2021). Fish oil and plant-derived oils like flaxseed oil are among the most researched UFA-rich sources utilised for dairy fortification. However, it should also be considered that such a fat replacement may result in physicochemical, textural, and sensory effects on the dairy matrix. Nevertheless, state of the art modern technological improvements has minimised such impact, such as the technique of microencapsulation, which improves the oxidative stability and releases properties of UFA and allows the oil entrapment with minimal effects on the quality of dairy products. In contrast, non-thermal technologies allow greater UFA fortification, improving thus the nutritional quality of resulting dairy products (Villamil et al., 2021).

In a study focusing on co-encapsulating echium oil, phytosterols and synaptic acid and adding them into yoghurt, it was found that the microcapsules offered protection against oxidation. The final product had good sensory properties (Comunian et al., 2017).

In a work on ovine cheese, the possibility of using oil extracted from chia seeds (*Salvia hispanica* L.) was studied, being the oil a good source of n-3. Two different levels (3 and 5 g/L) of chia oil were added to the curd. This fortification with the oil resulted in positive cheese yield, lipid, and α-linolenic contents. The sensory properties of the final products were assessed favourably (Muñoz-Tébar et al., 2019). In a similar study on caprine cheese, the cheese was fortified with conjugated linoleic acid (CLA) and n-3 fatty acids. The animals were fed with a fortified feed containing extruded linseed. The feed fortification increased UFAs, CLA, and *trans*-vaccenic acid precursors both in the milk and in the final product. The levels of n-6 fatty acids remained the same, and therefore the ratio of n-6/n-3 was reduced by 7-fold. This study proved that the fortification of animals' diet positively affects the resulting end products' nutritional value (cheese in this case) (Santurino, Calvo, Gómez-Candela, & Fontecha, 2017).

Processed cheeses fortified with walnut paste (a high source of n-3 PUFA) beneficially improved the levels of their human health-promoting fatty acids. At the same time, good sensory and technological properties were maintained (Abbas, Abdelmontaleb, Hamdy, & Aït-Kaddour, 2021). More specifically, the fortified cheeses contained significantly lower SFA levels and higher amounts of functional UFA (mainly α-linolenic acid), with a favourable reduction of the n-6/n-3 PUFA ratio. This further suggests that the product has strong anti-atherogenic and anti-thrombotic properties. It has been reported that the lower this ratio in a food/diet, the better the anti-inflammatory and anti-thrombotic health outcome against the risk for chronic disorders (Simopoulos, 2008). Processed cheeses with walnut paste presented good sensory properties. Scanning electron micrograph analyses showed a uniform distribution of walnut in the protein matrix. At the same time, they also had higher acidity, protein, fat, and ash contents with lower meltability and oil separation index than the control ones.

Several quality characteristics of yoghurts (e.g. physicochemical, rheological and sensorial) containing n-3 fatty acids as emulsions or microcapsules were reviewed recently (Gumus & Gharibzahedi, 2021). This study found that the most important n-3 fatty acids sources to fortify yoghurts are algal oils, flaxseed, and fish. This fortification led to increased bioavailability of functional fatty-acid rich oils and decreased the serum lipidemic profile and, therefore, risk factors related to obesity. However, more work is needed to improve the yoghurts' sensory qualities.

Chia extracts rich in n-3 UFA have been used to fortify yoghurts with these functional lipids (Kwon, Bae, Seo, & Han, 2019). The addition of chia seed extract improves the growth of lactic acid bacteria during the fermentation to produce this dairy fermented food, several physicochemical properties (viscosity, syneresis, and water-holding capacity) of yoghurt, and health-beneficial effects of thus fortified yoghurt, such as increased radical scavenging activity of yoghurt and significant inhibition of lipopolysaccharide-induced production of hydrogen peroxide in human colon cells (Kwon et al., 2019)

Apart from the fortification of yoghurt with UFA and because yoghurt has a low vitamin D content compared to other dairy products like butter, the fortification of yoghurt with vitamin D may confer positive health outcomes (Gasparri et al., 2019). In a recent systematic review and meta-analysis of randomised trials conducted by Gasparri et al. (2019), vitamin D-fortified yoghurts were shown to increase serum 25-OH-D (25-hydroxy vitamin D), and improve the lipid profile, glucose metabolism, and anthropometric parameters of pregnant women, adults and elderly subjects with or without diabetes, prediabetes, or metabolic syndrome.

However, in the case of fortified dairy with vitamin D, recent evidence suggests that the lipid component of the fortified foods alters vitamin D absorption. For example, a recent single-blinded, cross-over postprandial study examined the effect of changing the lipid component of a vitamin D3 fortified dairy drink on postprandial 25-OH-D concentrations (McCourt, Mulrooney, O'Neill, O'Riordan, & O'Sullivan, 2021). In this study, all participants consumed one dairy drink per visit, such as a lipid-free dairy drink (control), a dairy drink fortified with a pre-formed oleic acid micelle, or a dairy drink fortified with olive, a dairy drink fortified with fish oil. It was found that there were no time/drink, time, or drink effects on 25-OH-D in vitamin D sufficient participants (>50 nmol/L). In comparison, there was an effect of time on changes in 25-OH-D concentrations after the distribution of olive oil dairy drink with vitamin D (<50 nmol/L), suggesting that olive oil may improve vitamin D absorption from fortified foods (McCourt et al., 2021). Nevertheless, further research is needed to examine the practical implications of changing the lipid component of fortified foods in the absorbability of functional lipids, including vitamin D.

On the other hand, even though butter is a good source of fat-soluble vitamins and antioxidant systems, it is not a good source of UFAs. Supplementation of butter with microcapsules rich in n-3 UFAs vegetable oils like chia oil, which were added to the butter during the working stage, increased the concentration of n-3 UFAs in butter up to 8% with reasonable oxidative stability and did not affect sensory characteristics (Ullah et al., 2020).

Apart from the fortification of dairy with classic lipid molecules and lipid vitamins, attempts on using lipophilic carotenoids or lipid extracts rich in carotenoids, such as marine-derived extracts rich in astaxanthin, for fortifying dairy products have also been proposed not only for the improvement of antioxidant capacity of these products but also for the creation of new functional properties that are increasingly popular with the consumer. For example, a recent study has evaluated the functional properties of acid curd cheese that were fortified with concentrated astaxanthin lipid preparation (ALP), which was recovered from shrimp by-products (shrimp shells) (Dmytrów, Szymczak, Szkolnicka, & Kamiński, 2021). The addition of ALP increased the lipid content and decreased the moisture in the cheese. The cheeses with ALP had a lower pH after four weeks of storage and higher titratable acidity immediately after ALP addition. The cheese fortified with ALP also showed better antioxidant stability during storage. This may be due to greater antioxidant activity in the cheese due to the higher ALP addition. The addition of astaxanthin into cheeses improved the colour and enhanced their sensory properties (Dmytrów et al., 2021).

Finally, in a systematic review, the role of fortified dairy products in cardiometabolic health was evaluated by Soto-Méndez et al. (2019); In randomised clinical trials with human subjects who consumed dairy products fortified with phytosterols, fatty acids, minerals or vitamins, the consumption of these products was associated with improved cardiometabolic health. Forty-four studies were compiled and lead to the conclusion that, the consumption of dairy products fortified with n-3 fatty acids and phytosterols reduced serum low-density lipoprotein (LDL) cholesterol levels. In contrast, the consumption of dairy products fortified with n-3 fatty acids reduced the serum triacylglyceride levels.

Overall, there are several options for the dairy processors to achieve a sustainable status of their formulations and guarantee a positive image with consumers. These options should be optimised and evaluated, considering the optimisation of intrinsic quality parameters of each product and with the simultaneous realization of sensory studies with consumers to obtain a global understanding of the situation. Finally, the economic aspects must be carefully investigated and also the regulatory aspects. These integrated approaches will benefit the whole dairy industry, regardless of its size, and contribute to their competitiveness in a global market.

4. Concluding remarks

Dairy food processors should adjust their manufacturing processes to decrease the production of by-products and adhere to the circular economy concepts. Considering the Sustainable Development Goals and the actions to be taken before 2030, the use of side-streams and underexploited agro-industrial side-streams can be potential ingredients to design functional dairy foods. This would enhance the nutritional composition (e.g., fibres, antimicrobial, and antioxidants) of products while decreasing the waste of bioactive-rich agro-industrial side-streams. Although some research outputs are available on the feasibility of using side-streams as sources of bioactive ingredients, legislation on novel food products should also be updated more constantly to keep up with the scientific advancement in this sector. Additionally, any health claims should be based on evidence obtained through human interventions.

The development of functional dairy foods with added bioactive compounds still represents a challenging cross-sectoral activity beyond food science and technology. Instead, a multi-actor approach should be considered to align the sustainability issues, technology and legislation matters, and clinical evidence of functionality.

Author's contributions

D. Granato: conceptualization, writing and review; L. Barros, A. Mocan, A. G. Cruz, A. Tsoupras, I. Zabetakis, M. Carocho, T. C. Pimentel: writing and review.

Declaration of competing interest

The authors declare no conflict of interest.

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References

Abbas, K. A., Abdelmontaleb, H. S., Hamdy, S. M., & Aït-Kaddour, A. (2021). Physicochemical, functional, fatty acids profile, health lipid indices, microstructure and sensory characteristics of walnut-processed cheeses. *Foods, 10*, 2274.

ACTRN12621000038897. The effects of Lutein/Zeaxanthin supplementation on cognitive function in adults with self-reported mild cognitive complaints. Available at: https://trialsearch.who.int/Trial2.aspx?TrialID=ACTRN12621000038897.

Alongi, M., & Anese, M. (2021). Re-thinking functional food development through a holistic approach. *Journal of Functional Foods, 81*, Article 104466.

Anto, L., Warykas, S. W., Torres-Gonzalez, M., & Blesso, C. N. (2020). Milk polar lipids: Underappreciated lipids with emerging health benefits. *Nutrients, 12*, 1001.

Asioli, D., Aschemann-Witzel, J., Caputo, V., Vecchio, R., Annunziata, A., Naes, T., et al. (2017). Making sense of the "clean label" trends: A review of consumer food choice behavior and discussion of industry implications. *Food Research International, 99*(1), 58–71.

Asioli, D., & Grasso, S. (2021). Do consumers value food products containing upcycled ingredients? The effect of nutritional and environmental information. *Food Quality and Preference, 91*, Article 104194.

Ayar, A., Siçramaz, H., Öztürk, S., & Öztürk Yilmaz, S. (2018). Probiotic properties of ice creams produced with dietary fibres from by-products of the food industry. *International Journal of Dairy Technology, 71*(1), 174–182.

Bertolino, M., Belviso, S., Dal Bello, B., Ghirardello, D., Giordano, M., Rolle, L., … Zeppa, G. (2015). Influence of the addition of different hazelnut skins on the physicochemical, antioxidant, polyphenol and sensory properties of yoghurt. *LWT-Food Science and Technology, 63*(2), 1145–1154.

Best, I., Casimiro-Gonzales, S., Portugal, A., Oliveira-Montenegro, L., Aguilar, L., Muñoz, A. M., et al. (2020). *Phytochemical screening and DPPH radical scavenging activity of the three morphotypes of Muritia flexuosa L.f. from Peru, and thermal stability of a milk-based beverage enriched with carotenoids from these fruits*. Heliyon, Article e05209.

Boz, Z. (2021). Moving food processing to industry 4.0 and beyond. *Food Technology Magazine, 75*(6), 1–6.

F. Business Insights. Functional Foods. Available at: https://www.fortunebusinessinsights.com/functional-foods-market-102269. Access on 22 Jan 2022.

Caleja, C., Ribeiro, A., Barros, L., Barreira, J. C. M., Antonio, A. L., Oliveira, M. B. P. P., et al. (2016). Cottage cheeses functionalized with fennel and chamomile extracts:

Comparative performance between free and microencapsulated forms. *Food Chemistry, 199*, 720–726.
Campi, M., Duenas, M., & Fagiolo, G. (2021). *Specialization in food production affects global food security and food systems sustainability, 141*. World Development, Article 105411.
Campo, C., Assis, R. Q., Silva, M. M., Costa, T. M. H., Paese, K., Guterres, S. S., et al. (2019). Incorporation of zeaxanthin nanoparticles in yoghurts: Influence on physicochemical properties, carotenoid stability and sensory analysis. *Food Chemistry, 301*, Article 125230.
do Carmo, M. A. V., Granato, D., & Azevedo, L. (2021b). Antioxidant/pro-oxidant and antiproliferative activities of phenolic-rich foods and extracts: A cell-based point of view. In D. Granato, & (Org (Eds.), *Advances in food and nutrition research: Application of polyphenols in foods and food models, 98* pp. 253–280).
Chernyshova, M. P., Pristenskiy, D. V., Lozbiakova, M. V., Chalyk, N. E., Bandaletova, T. Y., & Petyaev, I. M. (2019). Systemic and skin-targeting beneficial effects of lycopene-enriched ice cream: A pilot study. *Journal of Dairy Science, 102*, 14–25.
Comunian, T. A., Chaves, I. E., Thomazini, M., Moraes, I. C. F., Ferro-Furtado, R., de Castro, I. A., et al. (2017). Development of functional yoghurt containing free and encapsulated echium oil, phytosterol and sinapic acid. *Food Chemistry, 237*, 948–956.
Condezo-Hoyos, L., Gazi, C., & Perez-Jimenez, J. (2021). Design of polyphenol-rich diets in clinical trials: A systematic review. *Food Research International, 149*, Article 110655.
European Parliament, Council Regulation. (2006). EC) No 1924/2006 on nutrition and health claims made on foods. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006R1924-20141213&from=EN. (Accessed 3 October 2021), 2006.
Crizel, T. D. M., Araujo, R. R. D., Rios, A. D. O., Rech, R., & Flôres, S. H. (2014). Orange fibre as a novel fat replacer in lemon ice cream. *Food Science and Technology, 34*(2), 332–340.
Cutrim, C. S., & Cortez, M. A. S. (2018). A review on polyphenols: Classification, beneficial effects and their application in dairy products. *International Journal of Dairy Technology, 71*(3), 564–578.
Da Silva, D. F., Matumoto-Pintro, P. T., Bazinet, L., Coullard, C., & Britten, M. (2015). Effect of commercial grape extracts on the cheese-making properties of milk. *Journal of Dairy Science, 98*(3), 1552–1562.
Dabija, A., Codina, G. G., Gatlan, A.-M., & Rusu, L. (2018). Quality assessment of yoghurt enriched with different types of fibres. *CYta – Journal of Food, 16*(1), 859–867.
Dmytrów, I., Szymczak, M., Szkolnicka, K., & Kamiński, P. (2021). Development of functional acid curd cheese (tvarog) with antioxidant activity containing astaxanthin from shrimp shells preliminary experiment. *Foods, 19*(10), 895, 4.
Domingos, L. D., Xavier, A. A. O., Marcadante, A. Z., Petenate, A. J., Jorge, R. A., & Viotto, W. H. (2014). Oxidative stability of yoghurt with added lutein dye. *Journal of Dairy Science, 97*, 616–623.
EFSA. (2008). Regulation (EC) Nº 1333/2008 of the European parliament and of the Council of 16 december 2008 on food additives. Accessed on november 23rd 2021. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008R1333-20210808&from=EN.
Escher, G. B., Borges, L. C., Santos, J. S., Cruz, T. M., Marques, M. B., do Carmo, M. A. V., et al. (2019). From the field to the pot: Phytochemical and functional analyses of *Calendula officinalis* L. Flower for incorporation in an organic yoghurt. *Antioxidants, 8* (11), 559–582.
Espírito Santo, A. P., Cartolano, N. S., Silva, T. F., Soares, F. A., Gioielli, L. A., Perego, P., … Oliveira, M. N. (2012a). Fibres 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.
Espírito Santo, A. P., Perego, P., Converti, A., & Oliveira, M. D. (2012b). Influence of milk type and addition of passion fruit peel powder on fermentation kinetics, texture profile and bacterial viability in probiotic yoghurts. *Lebensmittel-Wissenschaft und -Technologie, 47*(2), 393–399.
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 fibre. *Food Research International, 50*(1), 224–231.
European Commission. Milk Market Observatory. Available at: https://ec.europa.eu/info/sites/default/files/food-farming-fisheries/farming/documents/world-production-main-dairy-products_en.pdf.
Fidelis, M., & Granato, D. (2021). Technological applications of phenolic-rich extracts for the development of non-dairy foods and beverages. In D.(O. Granato (Ed.), *Advances in food and nutrition research: Application of polyphenols in foods and food models, 98* pp. 101–123).
Food and Drug Administration. (2018). Scientific evaluation of the evidence on the beneficial physiological effects of isolated or synthetic non-digestible carbohydrates submitted as a citizen petition (21 CFR 10.30). February 2018. Available at: https://www.fda.gov/regulatory-information/search-fda-guidance-documents/guidance-industry-scientific-evaluation-evidence-beneficial-physiological-effects-isolated-or. (Accessed 3 October 2021).
Fougère, H., & Bernard, L. (2019). Effect of diets supplemented with starch and corn oil, marine algae, or hydrogenated palm oil on mammary lipogenic gene expression in cows and goats: A comparative study. *Journal of Dairy Science, 102*, 768–779.
Fox, P. F., & Guinee, T. P. (2022). Overview of cheese. In P. L. H. McSweeney, & J. P. McNamara (Eds.), *Encyclopedia of dairy sciences*. Amsterdam, Netherlands: Elsevier.
Gasparri, C., Perna, S., Spadaccini, D., Alalwan, T., Girometta, C., Infantino, V., et al. (2019). Is vitamin D-fortified yoghurt a value-added strategy for improving human health? A systematic review and meta-analysis of randomized trials. *Journal of Dairy Science, 102*, 8587–8603.
Gies, M., Descalzo, A. M., Servent, A., & Dhuique-Mayer, C. (2019). Incorporation and stability of carotenoids in a functional fermented maize yoghurt-like product containing phytosterols. *Lebensmittel-Wissenschaft und -Technologie, 111*, 105–110.
Granato, D., Reshamwala, D., Korpinen, R., Azevedo, L., Crmo, M. A. V., Cruz, T. M., et al. (2022). From the forest to the plate - hemicelluloses, galactoglucomannan, glucuronoxylan, and phenolic-rich extracts from unconventional sources as functional food ingredients. *Food Chemistry, 381*, Article 132284.
Granato, D., Santos, J. S., Salem, R. D. S., Mortazavian, A. M., Rocha, R. S., & Cruz, A. G. (2018). Effects of herbal extracts on quality traits of yoghurts, cheeses, fermented milks, and ice creams: A technological perspective. *Current Opinion in Food Science, 19*, 1–7.
Gumus, C. E., & Gharibzahedi, S. M. T. (2021). Yoghurts supplemented with lipid emulsions rich in omega-3 fatty acids: New insights into the fortification, microencapsulation, quality properties, and health-promoting effects. *Trends in Food Science & Technology, 110*, 267–279.
IRCT20191018045149N1. The effect of lycopene on serum level of cardiac biomarkers. Available at: https://trialsearch.who.int/Trial2.aspx?TrialID=IRCT20191018045149N1.
IRCT20201227049857N1. The effect of astaxanthin supplementation in patients with coronary artery disease. Available at: https://trialsearch.who.int/Trial2.aspx?TrialID=IRCT20201227049857N1.
Iriondo-DeHond, M., Miguel, E., & Del Castillo, M. D. (2018). Food byproducts as sustainable ingredients for innovative and healthy dairy foods. *Nutrients, 22*(10), 1358, 10.
Isenberg, B. J., Soder, K. J., Pereira, A. B. D., Standish, R., & Brito, A. F. (2019). Production, milk fatty acid profile, and nutrient utilization in grazing dairy cows supplemented with ground flaxseed. *Journal of Dairy Science, 102*, 1294–1311.
Ismail, H. A., Hameed, A. M., Refaey, M. M., Sayqal, A., & Aly, A. A. (2020). Rheological, physio-chemical and organoleptic characteristics of ice cream enriched with Doum syrup and pomegranate peel. *Arabian Journal of Chemistry, 13*(10), 7346–7356.
Issar, K., Sharma, P. C., & Gupta, A. (2017). Utilization of apple pomace in the preparation of fibre-enriched acidophilus yoghurt. *Journal of Food Processing and Preservation, 41*(4), Article e13098.
Jalali-Jivan, M., Fathi-Achachlouei, B., Ahmadi-Gavlight, H., & Jafari, S. M. (2021). Improving the extraction efficiency and stability of β-carotene from carrot by enzyme-assisted green nanoemulsification. *Innovative Food Science & Emerging Technologies, 74*, Article 102836.
Jones, S. T., Aryana, J. J., & Losso, J. N. (2005). Storage stability of lutein during ripening of cheddar cheese. *Journal of Dairy Science, 88*, 1661–1670.
Jridi, M., Souissi, N., Salem, M. B., Ayadi, M. A., Nasri, M., & Azabou, S. (2015). Tunisian date (*Phoenix dactylifera* L.) by-products: Characterization and potential effects on sensory, textural and antioxidant properties of dairy desserts. *Food Chemistry, 188*, 8–15.
Kandylis, P., Dimitrellou, D., & Moschakis, T. (2021). Recent applications of grapes and their derivatives in dairy products. *Trends in Food Science & Technology, 114*, 696–711.
Keskin, S. O., Ali, T. M., Ahmed, J., Shaikh, M., Siddiq, M., & Uebersax, M. A. (2021). *Physico-chemical and functional properties of legume protein, starch, and dietary fibre—a review* (p. e117). Legume Science.
Kiros, E., Seifu, E., Bultosa, G., & Solomon, W. K. (2016). Effect of carrot juice and stabilizer on the physicochemical and microbiological properties of yoghurt. *Lebensmittel-Wissenschaft und -Technologie, 69*, 191–196.
Kusumowardani, N., Tjahjono, B., Lazell, J., Bek, D., Theodorakopoulos, N., Andrikopoulos, P., et al. (2022). A circular capability framework to address food waste and losses in the agri-food supply chain: The antecedents, principles and outcomes of circular economy. *Journal of Business Research, 142*, 17–31.
Kwon, H. C., Bae, H., Seo, H. G., & Han, S. G. (2019). Short communication: Chia seed extract enhances physiochemical and antioxidant properties of yoghurt. *Journal of Dairy Science, 102*, 4870–4876.
Lamothe, S., Azimy, N., Bazinet, L., Couillard, C., & Britten, M. (2014). Interaction of green tea polyphenols with dairy matrices in a simulated gastrointestinal environment. *Food & Function, 5*(10), 2621–2631.
Lee, N. K., Jeewanthi, R. K. C., Park, E. H., & Paik, H. D. (2016). Short communication: Physicochemical and antioxidant properties of Cheddar-type cheese fortified with Inula britannica extract. *Journal of Dairy Science, 99*(1), 83–88.
Leema, J. T. M., Jothy, T. P., & Dharani, G. (2022). Rapid green microwave-assisted extraction of lutein from *Chlorella sorokiniana* (NIOT-2) – process optimization. *Food Chemistry, 372*, Article 131151.
Leme, A. C. B., Fisberg, R. M., Baranowski, T., Nicklas, T., Callender, C. S., Kasam, A., et al. (2021). Perceptions about health, nutrition knowledge, and MyPlate food categorization among US adolescents: A qualitative study. *Journal of Nutrition Education and Behavior, 53*(2), 110–119.
Liu, Z., Natalizio, F., Dragone, G., & Mussatto, S. I. (2021). Maximizing the simultaneous production of lipids and carotenoids by *Rhodosporium toruloides* from wheat straw hydrolysate and perspectives for large-scale implementation. *Bioresource Technology, 340*, Article 125598.
Lordan, R., Tsoupras, A., Mitra, B., & Zabetakis, I. (2018). Dairy fats and cardiovascular disease: Do we really need to be concerned? *Foods, 7*, 29.
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.
McCourt, A. F., Mulrooney, S. L., O'Neill, G. J., O'Riordan, E. D., & O'Sullivan, A. M. (2021). Postprandial 25-hydroxyvitamin D response varies according to the lipid

composition of a vitamin D3 fortified dairy drink. *International Journal of Food Sciences & Nutrition, 6*, 1–11.
Milinčić, D. D., Popović, D. A., Lević, S. M., Kostić, A., Tešić, Ž. L., Nedović, V. A., et al. (2019). Application of polyphenol-loaded nanoparticles in food industry. *Nanomaterials, 9*(11).
Miranda, B. V., Monteiro, G. F. A., & Rodrigues, V. P. (2021). Circular agri-food systems: A governance perspective for the analysis of sustainable agri-food value chains. *Technological Forecasting and Social Change, 170*, Article 120878.
Moon, J.-Y., Hua, S., Qi, Q., Stores-Alvarez, D., Mattei, J., Casagrande, S. S., et al. (2022). Association of sugar-sweetened beverage consumption with prediabetes and glucose metabolism markers in hispanic/latino adults in the United States: Results from the hispanic community health study/study of latinos (HCHS/SOL). *Journal of Nutrition, 152*(1), 235–245, 2022.
Mozas-Moral, A., Fernandez-Ucles, D., Medina-Viruel, M. J., & Bernal-Jurado, E. (2021). The role of the SDGs as enhancers of the performance of Spanish wine cooperatives. *Technological Forecasting and Social Change, 173*, Article 121176.
Muñoz-Tébar, N., De la Vara, J. A., Ortiz de Elguea-Culebras, G., Cano, E. L., Molina, A., Carmona, M., et al. (2019). Enrichment of sheep cheese with chia (*Salvia hispanica* L.) oil as a source of omega-3. *Lebensmittel-Wissenschaft und -Technologie, 108*, 407–415.
NCT03750968. Lutein & Zeaxanthin in Pregnancy - Carotenoid Supplementation During Pregnancy: Ocular and Systemic Effects (L-ZIP). Available at: https://clinicaltrials.gov/ct2/show/NCT03750968.
Ngamwonglumlert, L., & Devahastin, S. (2019). Carotenoids. In P. Karelis, L. Melton, & F. Shahidi (Eds.), *Encyclopedia of food chemistry*. Amsterdam, Netherlands: Elsevier.
Noguerol, A. T., Pagan, M. J., Garcia-Segovia, P., & Varela, P. (2021). Green or clean? Perception of clean label plant-based products by omnivorous, vegan, vegetarian and flexitarian consumers. *Food Research International, 149*, Article 110652.
Oksuz, T., Tacer-Caba, Z., Nilufer-Erdil, D., & Boyacioglu, D. (2019). Changes in bioavailability of sour cherry (*Prunus cerasus* L.) phenolics and anthocyanins when consumed with dairy food matrices. *Journal of Food Science & Technology, 56*, 4177–4188.
Ordóñez-Santos, L. E., Esparza-Estrada, J., & Vanegas-Mahecha, P. (2021). Ultrasound-assisted extraction of total carotenoids from Mandarin epicarp and application as natural colorant in bakery products. *LWT- Food Science and Technology, 139*, Article 110598.
Pap, N., Reshamwala, D., Korpinen, R., Kilpelainen, P., Fidelis, M., Furtado, M. M., et al. (2021). Toxicological and bioactivity evaluation of blackcurrant press cake, sea buckthorn leaves and bark from Scots pine and Norway spruce extracts under a green integrated approach. *Food and Chemical Toxicology, 153*, Article 112284.
Peker, H., & Arslan, S. (2016). Effect of olive leaf extract on the quality of low-fat apricot yoghurt. *Journal of Food Processing and Preservation, 41*(5), 1–10.
Qin, Y., & Horvath, A. (2022). What contributes more to life-cycle greenhouse gas emissions of farm produce: Production, transportation, packaging, or food loss? *Recycling, 176*, Article 105945.
Raikos, V., Ni, H., Hayes, H., & Ranawana, V. (2019). Antioxidant properties of a yoghurt beverage enriched with salal (*Gaultheria shallon*) berries and blackcurrant (*Ribes nigrum*) pomace during cold storage. *Beverages, 5*(1), 2.
Ribeiro, T. B., Bonifácio-Lopes, T., Morais, P., Miranda, A., Nunes, J., Vicente, A. A., et al. (2021a). Incorporation of olive pomace ingredients into yoghurts as a source of fibre and hydroxytyrosol: Antioxidant activity and stability throughout gastrointestinal digestion. *Journal of Food Engineering, 297*, Article 110476.
Ribeiro, F. A., Queiroga, R. C. R. E., Souza, E. L., Voss, G. B., Borges, G. S. C., Lima, M. S., et al. (2021b). Incorporation of phenolic-rich ingredients from integral valorization of Isabel grape improves the nutritional, functional and sensory characteristics of probiotic goat milk yoghurt. *Food Chemistry, 369*, Article 130957.
Rizk, E. M., El-Kady, A. T., & El-Bialy, A. R. (2014). Characterization of carotenoids (lyco-red) extracted from tomato peels and its uses as natural colourants and antioxidants of ice cream. *Annals of Agriculture Science, 59*, 53–61.
Rotz, C. A., Montes, F., & Chianese, D. S. (2010). The carbon footprint of dairy production systems through partial life cycle assessment. *Journal of Dairy Science, 93*, 1266–1282.
Sagar, N. A., Pareek, S., Sharma, S., Yahia, E. M., & Lobo, M. G. (2018). Fruit and vegetable waste: Bioactive compounds, their extraction, and possible utilization. *Comprehensive Reviews in Food Science and Food Safety, 17*(3), 512–531.
Sah, B. N. P., Vasiljevic, T., McKechnie, S., & Donkor, O. N. (2016). Physicochemical, textural and rheological properties of probiotic yoghurt fortified with fibre-rich pineapple peel powder during refrigerated storage. *LWT-Food Science and Technology, 65*, 978–986.
Salehi, F. (2021). Quality, physicochemical, and textural properties of dairy products containing fruits and vegetables: A review. *Food Sciences and Nutrition, 9*, 4666–4686.
Santurino, C., Calvo, M. V., Gómez-Candela, C., & Fontecha, J. (2017). Characterization of naturally goat cheese enriched in conjugated linoleic acid and omega-3 fatty acids for human clinical trial in overweight and obese subjects. *PharmaNutrition, 5*(1), 8–17.
Sanz, T., Salvador, A., Jimenez, A., & Fiszman, S. M. (2008). Yoghurt enrichment with functional asparagus fibre. Effect of fibre extraction method on rheological properties, colour, and sensory acceptance. *European Food Research and Technology, 227*(5), 1515–1521.
Saraç, M. G., & Dogan, M. (2016). Incorporation of dietary fibre concentrates from fruit and vegetable wastes in butter: Effects on physicochemical, textural, and sensory properties. *European Food Research and Technology, 242*(8), 1331–1342.
Sendra, E., Kuri, V., Fernández-López, J., Sayas-Barbera, E., Navarro, C., & Perez-Alvarez, J. A. (2010). Viscoelastic properties of orange fibre enriched yoghurt as a function of fibre dose, size and thermal treatment. *LWT-Food Science and Technology, 43*(4), 708–714.
Šeregelj, V., Pezo, L., Šovljanski, O., Lević, S., Nedović, V., Markov, S., et al. (2021). New concept of fortified yoghurt formulation with encapsulated carrot waste extract. *Lebensmittel-Wissenschaft und -Technologie, 138*, Article 110732.
Sharma, P., Segat, A., Kelly, S. A., & Sheehan, J. J. (2019). Colourants in cheese manufacture: Production, chemistry, interactions, and regulation. *Comprehensive Reviews in Food Science and Food Safety, 19*, 1220–1242.
Simonetti, A., Perna, A., Grassi, G., & Gambacorda, E. (2021). In vitro phenols bioaccessibility and antioxidant activity of goat milk yoghurt fortified with *Rhus coriaria* leaf powder. *Journal of Food Science, 86*(4), 1400–1409.
Simopoulos, A. P. (2008). The importance of the omega-6/omega-3 fatty acid ratio in cardiovascular disease and other chronic diseases. *Experimental Biology and Medicine, 233*(6), 674–688.
Siwach, R., Tokas, J., & Seth, R. (2016). Use of lycopene as a natural antioxidant in extending the shelf-life of anhydrous cow milk fat. *Food Chemistry, 199*, 541–546.
Sobral, D., Costa, R. G. B., Machado, G. M., Paula, J. C. J., Teodoro, V. A. M., Nunes, N. M., et al. (2016). Can lutein replace annatto in the manufacture of Prato cheese. *Lebensmittel-Wissenschaft und -Technologie, 68*, 349–355.
Soto-Méndez, M. J., Rangel-Huerta, O. D., Ruiz-López, M. D., Martínez De Victoria, E., Anguita-Ruiz, A., & Gil, A. (2019). Role of functional fortified dairy products in cardiometabolic health: A systematic review and meta-analyses of randomized clinical trials. *Advances in Nutrition, 10*, S251–S271.
Statista. Forecast volume of fresh dairy products produced in the European Union (EU 27) from 2015 to 2030*. Available at: https://www.statista.com/statistics/546942/fresh-dairy-products-production-volume-european-union-28/.
Statista. Size of the worldwide functional food and beverage market 2020-2028. Available at: https://www.statista.com/statistics/1264080/functional-food-and-beverages-global-market-size/Access on 22 Jan 2022.
Stubler, A.-S., Heinz, V., & Aganovic, K. (2020). Development of food products. *Current Opinion in Green and Sustainable Chemistry, 25*, Article 100356.
Stupar, A., Šeregelj, V., Ribeiro, B. D., Pezo, L., Cvetanović, A., Mišan, A., et al. (2021). Recovery of β-carotene from pumpkin using switchable natural deep eutectic solvents. *Ultrasonics Sonochemistry, 76*, Article 105638.
Tlais, A. Z. A., Fiorino, G. M., Polo, A., Filannino, P., & Di Cagno, R. (2020). High-value compounds in fruit, vegetable and cereal byproducts: An overview of potential sustainable reuse and exploitation. *Molecules, 30*(25), 2987, 13.
Tseng, M.-L., Chiu, A. S. F., Chien, C.-F., & Tan, R. R. (2019). Pathways and barriers to circularity in food systems. *Resources, Conservation ad Recycling, 143*, 236–237.
Tsoupras, A., Lordan, R., & Zabetakis, I. (2018). Inflammation, not cholesterol, is a cause of chronic disease. *Nutrients, 10*(5), 604.
Ullah, R., Nadeem, M., Imran, M., Khan, M. K., Mushtaq, Z., Asif, M., et al. (2020). Effect of microcapsules of chia oil on Ω-3 fatty acids, antioxidant characteristics and oxidative stability of butter. *Lipids in Health and Disease, 19*, 10.
United Nations. (2015). Resolution adopted by the general assembly on 25 september 2015. UN general assembly. Available at: https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_RES_70_1_E.pdf.
Vargas-Bello-Pérez, E., Darabighane, B., Miccoli, F. E., Gómez-Cortés, P., Gonzalez-Ronquillo, M., & Mele, M. (2021). Effect of dietary vegetable sources rich in unsaturated fatty acids on milk production, composition, and cheese fatty acid profile in sheep: A meta-analysis. *Frontiers in Veterinary Science, 8*, Article 641364.
Villamil, R. A., Guzmán, M. P., Ojeda-Arredondo, M., Cortés, L. Y., Gil Archila, E., Giraldo, A., et al. (2021). Cheese fortification through the incorporation of UFA-rich sources: A review of recent (2010-2020) evidence. *Heliyon, 30*(7), Article e05785, 1.
Yegin, S., Kopec, A., Kitts, D. D., & Zawistowski, J. (2020). Dietary fibre: A functional food ingredient with physiological benefits. In *Dietary sugar, salt and fat in human health* (pp. 531–555). Academic Press.
Yildirim-Elikoglu, S., & Erdem, Y. K. (2018). Interactions between milk proteins and polyphenols: Binding mechanisms, related changes, and the future trends in the dairy industry. *Food Reviews International, 34*(7), 665–697.