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Review Article

Current progress in the valorization of food industrial by-products for the development of functional food products

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Abstract

Worldwide consumption of food items e.g. agricultural commodities, fruits and vegetables, marine foods, animal products, dairy products etc. increases due to rapid growth of population. However, with the increasing consumption trends a significant amount of waste is generated and results environmental hazards. In addition to that, food processing industries produces a significant quantity of by-products. In order to reduce the environmental pollution, valorization of such by-products into the development of nutritionally enriched functional foods, recovery of bioactive substances such proteins, carotenoids, and phenolics, and encapsulation of bioactive materials can be considered as an efficient eco- friendly approach. Moreover, a variety of underutilized by-products, such as animal blood, grape pomace (GP), Brewer's Spent Grains (BSG), cheese whey, hulls, peels, seeds, and marine algae, are a huge resource of beneficial molecules including vitamins, minerals, and phytochemicals with positive health effects and techno functional properties. The circular economy approach is a crucial tool in food science and technology, ensuring environmental protection and boosting economic growth by reducing the environmental impact of food production and processing. This review focuses on the valorization of by-products from food processing industries as a sustainable waste management strategy.

Keywords

valorization, phytochemicals, bioactive compounds, health benefit, functional foods, quality of life

Abbreviations

BPF – banana flour with pulp; BSF – banana flour with peel; BSG – brewer's spent grains; DDRP – dry distilled rose petals; DDRPE – dry distilled rose petal extracts; GP – grape pomace; PPuF – papaya pulp flour; QoL – quality of life; ROS – reactive oxygen species; SCFA – short-chain fatty acids and lactic acid; TFC – total flavonoid components; TPC – total phenolic compounds; WBF – whole banana flour

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Introduction

The agri-food sector faces significant challenges in achieving sustainable development goals due to the disposal of waste, particularly fruit and vegetable processing residues like peels and seeds, which are predominantly carbohydrates, with trace amounts of protein and fat (Mirabella et al. 2014). Plant-based waste, rich in cellulose and lignin, has potential as a renewable energy source due to its high-water content. Enzymatic degradation of cellulose and hemicellulose releases xylose and glucose, by which ethanol can be transformed into ethanol by microbes. Lignin undergoes aerobic breakdown pyrolysis, producing hydrogen and methane. Bio plastics and enzymes are also produced. Anaerobically, trash is broken down to produce heat, energy, and bio fertilizer. Hydrogels can be made through incineration. By-products can be used as raw materials for food additives, fortifiers, cosmetics, food colouring, and preservatives (Ravindran and Jaiswal 2016). The agricultural products in the raw form and their cultivated leftovers like fruits, vegetables as well meat, poultry, grain processing products crops and dairy products are called as by-products of agricultural (Obi et al. 2016).

In addition, the wastes consist of crop waste, hazardous and poisonous agricultural waste, such as insecticides, pesticides, and herbicides, food processing waste, and animal wastes such manure and animal corpses. These agricultural wastes might be solid, slurry, or liquid in consistency (Lau et al. 2021). Three categories of by-products and wastes exist: (1) by-products are generated by agricultural harvest; (2) by-products of postharvest; and (3) by-products as well as wastes from food processing sectors. Branches, leaves, chaff, and other inedible plant parts, as well as goods unfit for the food market, are examples of agricultural by-products. The majority of postharvest wastes and by-products are the non-food components of the harvested agricultural commodity, such as bran, the husk or hull of grains, and stones, pulp, and peel of various fruits. These components are removed before being made accessible for consumption, contain or have been contaminated by a bio hazardous agent and the by-products are generated by subjecting the harvested and processed item to extra processing to create easily consumable commodities are included in the waste of the food processing sector. This category can contain arrange of liquid wastes, including food extracts and wasted biomass-rich water, as well as a variety of solid wastes, such as fruits and vegetables pomaces, pits and seeds from the production of juice, sauce, or jam, and using grain granules from the processing of grain flours. Marine, poultry, and meat sector wastes are additional wastes from the food business. In the meat sector, the by-products include bones, bloods, viscera, and skin. Whereas, in the marine industry, the by-products mostly consist of cartilage, fractions of fish head, intestines, trimmings, bones, tails, scales, shells, carcasses, skin, damaged or injured fish, eggs, milk or supple roe and frame, crab shells, and liquid waste, such as viscera and blood. Important by-products of the poultry business include feathers and eggshells (Routray and Orsat 2017).

Functional foods are vital parts of a regular diet because they include bioactive substances that enhance the health benefits of conventional nutrients. Because of their content of bioactive compounds - which might arise naturally, originate during industrial processing, or be extracted and added from other sources - they are becoming more and more popular in industrialized nations (Barauskaite et al. 2018). Recently novel nutraceuticals enriched in macro and micronutrients e.g. protein, vitamins, minerals along with natural flavors, and steviol glycosides were formulated for the improvement ofqualityof life (QoL) (Almoselhy 2023).

The elements in functional foods that are extracted, manufactured, or natural provide these health advantages (Butnariu and Sarac 2019). The in-vitro anti-tyrosinase activity of several aqueous extracts made from by-products of pomegranate juice processing was examined (Turrini et al. 2020).

More specifically, a dish can be deemed functional if it is updated with modern ingredients, either through recipe modifications or production process adjustments. Health claims are allocated in the conventional method of finding and characterizing functional ingredients once bioactivity has been proven (Lalić et al. 2023).

According to a study (Baiano 2014), the drinks industry is thought to be responsible for about 26% of food wastes. The cereal manufacture and processing industries is 12.9%, dairy sector is 21%, which is followed by the manufacturing and processing of fruits and vegetables (14.8%), the processing and the enhancement of shelf life of fish products (0.4%), the production, processing, and preservation of meat products (8%), along with other industries (12.7%). Regardless of where they come from, these wastes are challenging to manage due to their elevated organic loading, high water content, and high biological instability, all of which promote activity by microbes. When such wastes are improperly disposed of, the ecosystem is affected by things like aquatic toxic life, ground and surface water pollution, changed quality of soil, phytotoxicity, naturally colored waterways, and odor.

The need for novel bioactive substances that the food industry may employ to create cutting-edge functional goods with claims supported by science is growing due to the food functionalization trend. In this context, natural chemicals and the bioactivities they are linked with have received a lot of interest in recent years. But since natural resources are limited, it will be necessary to find new sources in order to meet the food industry's constant demand for ingredients and additives (Herrero et al. 2015; Okino Delgado and Fleuri 2016).

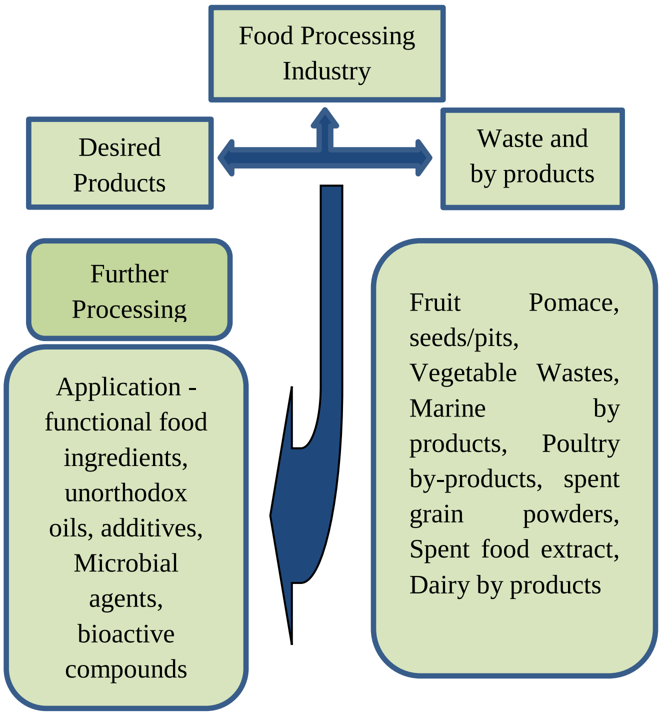

Figure 1. An overview of the general schematic depiction of Food Processing Industry by-products, along with its applications and uses

Bioactive chemicals for food applications can be found in good quantities in agro-waste. Bioactive substances that are separated from agricultural wastes or by-products mostly consist of pigments, fatty acids, volatile oils, vitamins, minerals, and polyphenolic compounds, all of which have important health advantages. Extracted bioactive components, for instance, might be utilized in fortification processes of food, such as the creation of innovative functional, nutritious and useful foods. Agro-waste has a wide variety of bioactive chemicals that have potential uses in the food and pharmaceutical sectors as natural antioxidants and antimicrobials. In order to stop lipid oxidation in meat products, bioactive substances are frequently utilized in the meat processing business. To expand the uses of these bioactive substances, a greater range of micro- and nanoencapsulation techniques are employed to encapsulate them (Bala et al. 2023). The food industries should take use of the high-value components found in these food wastes, such as proteins, polysaccharides, fibers, taste compounds, and phytonutrients, since they may be utilized as useful ingredients like functional components in medicinal and culinary products. These wastes contain components that could be marketed (Baiano et al. 2014).

Despite the growth and potential, the functional food ingredient industry in India faces several challenges that hinder its development. Some of these challenges might include:

a. Regulatory Hurdles: Regulatory frameworks for functional food ingredients may not be well-established, leading to uncertainties and obstacles in product development and marketing.

b. Quality Control: Ensuring the quality and safety of functional food ingredients is crucial, and any lapses in quality control can harm the industry's reputation.

c. Research and Development: Continuous innovation and research are essential for developing new and effective functional food ingredients. A lack of investment or resources in research and development can impede progress.

d. Consumer Education: Educating consumers about the benefits and proper usage of functional food ingredients may be necessary, as awareness can influence demand.

e. Competition: The industry may face competition from both domestic and international players, which could affect market share and profitability.

f. Sustainability: Sustainable sourcing of raw materials and environmentally responsible practices are becoming increasingly important in the food industry.

Despite these challenges, the functional food ingredient industry in India has the potential for further growth and development. Addressing these constraints and fostering a supportive environment for innovation and quality control can lead to a more robust and sustainable industry.

Food Waste/ Food Loss

The food industry is focusing on developing functional foods as consumers become more health-conscious and seek nutrient-dense alternatives. These foods have bioactive molecules with numerous health benefits, making them bioactive molecules. Manufacturers now need to understand the phytochemical and functional characteristics of processed food items. Functional foods

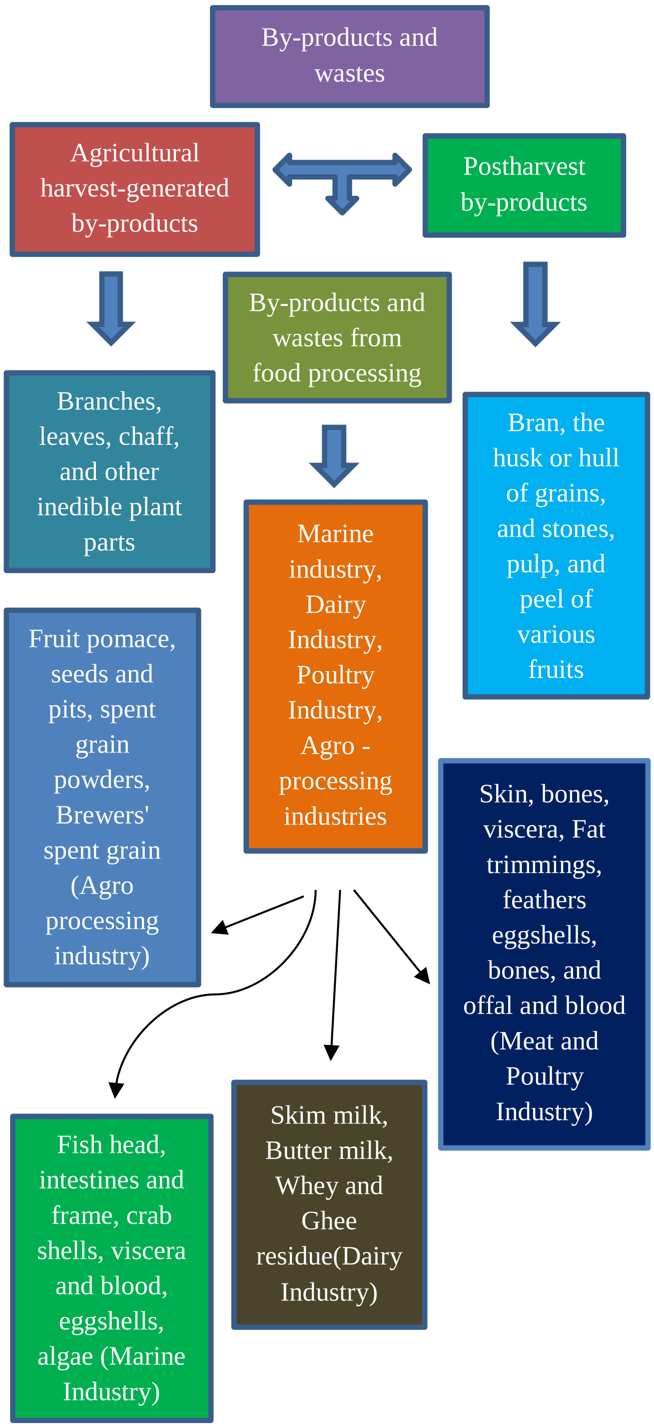

Figure 2. An overview of food industrial by products and wastes

have one or more functional ingredients or components that provide significant or minor functions in the body and enhance general health and welfare. The growing health consciousness of contemporary culture is driving the demand for functional meals. The food industry is also investigating the effects of functional bioactive chemicals on health and wellbeing in food items. Fruits and vegetables contain polyphenols, which have health-promoting properties and may help prevent diseases caused by reactive oxygen species (ROS) (Kumar et al. 2023). The issue of long-term solutions for handling food waste and by products is a significant concern in society. Developing nations produce a lot of waste and by products, which impact the environment, economy, and society. However, many of these products can be a valuable source of essential substances like dietary fibers, proteins, amino acids, starch, oligosaccharides, lipids, micronutrients, and bioactive substances (Torres-León, et al. 2018). Most commonly, the word "food trash" or "by-products" refers to edible food items that were intended for human consumption but were rather disposed away, lost, deteriorated, or consumed by pests. It does not contain unappealing or inedible components of foodstuff. The different food companies dispose of their valuable waste, and some of them reprocess it and utilize it as a functioning food component. These sectors also evolved their economies to survive in the fierce market rivalry.

Food processing industries and their by-products

Wine by-products. Wine by-products have found many applications in the food sector, biorefinery, feed, cosmetics, agriculture, and pharmaceuticals (Aliaño-González et al. 2022; Câmara et al. 2020; Ferreira and Santos 2022; Hassan et al. 2019; Pedroza et al. 2017; Shrikhande 2000). Brewer's Spent Grains (BSG) stands for insoluble materials that are left behind during lagering in the brewing sector. The brewery's most significant by-product is BSG (Bala et al. 2022; Balan et al. 2022; Gupta et al. 2022). The beer industry's by-product, BSG, can be repurposed into cups by incorporating it as a functional element, enhancing the nutritive value of Ćupter due to its high protein content and low cost (Lalić et al. 2023).

Grape Pomace is the leftover material left over after pressing grapes, both red and white to make wine or must. It is made up of seeds, stalks, and skins. As a significant provider of the value-added phenolic chemicals such as flavonoids, phenolic acids, and stilbenes, a significant quantity of GP is produced a significant recovery during the vinification process (Beres et al. 2017; Chowdhary et al. 2021).

By adding winemaking by-products to food, functional food products may be produced and natural functional food components, including dietary fiber and polyphenols, can be added to regularly eaten meals. A by-product of wineries, GP is being valued increasingly as a source of beneficial bioactive compounds like polyphenols and other

Table 1. Wine industry by products and their utilization

By-products of wine	Nutritional and bioactive potential	Utilization	Reference
Grape Pomace (It is made up of seeds, stalks, and skins) (Beres et al. 2017; Chowdhary et al. 2021).	Polyphenol-rich source, has antioxidant, anti-inflammatory, antibacterial, and enzyme properties	Coconut water, creating a beneficial and functional beverage	(Ali et al. 2021; Costa et al. 2021; Gerardi et al. 2020; Goulas et al. 2021; Parisi et al. 2020)
	Total content of phenolic compounds, Antioxidants, Coagulant	Additive in cheese, ice cream, yogurt, and fermented milk, Tofu	(Dos Santos et al. 2017; Gaglio et al. 2021; Hwang et al. 2009; Karnopp et al. 2017; Zeppa et al. 2021)
	Polyphenolic content, Dietary fiber content, Total phenolic content, antioxidants	Muffins	(Bender et al. 2017)
		Cookies	(Theagarajan et al. 2019)
		Bread	(Šporin et al. 2018)
		Brownie	(Walker et al. 2014)
		Biscuits	(Mildner-Szkudlarz et al. 2013)
		Sourdough rye bread	(Mildner-Szkudlarz et al. 2011)
		Extruded cereals	(Oliveira et al. 2013)
		Cereal bars, Noodles, Pancakes	(Rosales Soto et al. 2012)
		Pasta	(Marinelli et al. 2015)
		Tea infusions	(Bekhit et al. 2011)
Grape seed extract	Caseins, Phenols	Cheese, Curd	(Han et al. 2011)
	Antioxidant activity	Enriched cereal bars, pancakes, and noodles	(Rosales Soto et al. 2012)
		White bread	(Coe and Ryan 2016)
Spent grain from brewers and yeasts (Beer)	Proteins and amino acids, hemicellulose, starch, fatty acids, flavonoids, carotenoids and β-glucans	Cooked ham, muffin and hamburger	(Lynch et al. 2016; Saraiva et al. 2019; Shih Wang et al. 2020)
Out layer, seed, stem (Wine)	Potassium, phosphorus, proteins and amino acids, oligosaccharides, polyphenols, and fatty acids	Cheese, fermented milk (goat), and bars of cereal	(Borges et al. 2021; Lucera et al. 2018; Puligundla et al. 2020)

intriguing molecules (including colors, fibers, minerals, etc.) (Antonić et al. 2020; Pereira et al. 2020). Antioxidant-enriched yoghurt from GP seems to be a handy meal option that will pique consumers' curiosity (Chouchouli et al. 2013).

Research on the usage of by products from the wine industry in alcoholic and non-alcoholic drinks has been limited. The sensory qualities of coconut water remain unaffected by this addition, and bioactive compounds pass through the colon without loss. The fortified beverage's anthocyanins and total phenolics degrade slowly, potentially acting as an antibacterial agent against intestinal infections (Costa et al. 2021).

All things considered, the use of grape seed extract as a source of functional components is a fascinating and potentially profitable choice for environmental and business strategies. A variety of natural compounds, including tartaric acid and enocyanine, as well as other sources of natural antioxidants for the food sector may be found in wine-making goods (E163). Natural tartaric acid is used to enhance biscuits, candies, jams, jellies, chewing gum, cocoa powder, and alcoholic beverages. It is employed as a natural preservation agent, a form of emulsifier in the bread processing industry, and as an acidifier in the sectors of wine processing. Anthocyanins found in grape skin are the natural source of enocyanine, sometimes referred to as E163 in the food industry (Tsiviki and Goula 2021).

The antioxidant properties of GP serve as justification for preventing the development of cell malignancy. Reactive nitrogen species and Reactive oxygen species (ROS) reduction may cause irreparable DNA damage and/or impede the growth of cancer cells (Del Pino-García et al. 2017). This finding raises the possibility of using it to treat type II diabetes (Doshi et al. 2015). When male mice were given grape skin in addition to a high-fat diet, there was evidence of the skin's potential effectiveness in treating and preventing metabolic syndrome associated with obesity. Glucose homeostasis and sensitivity of insulin were mediated by grape skin extract (Da Costa et al. 2017).

Empl et al. (2018) found that grapevine shoot extracts have the ability to lower the quantity and amount of intestinal adenoma in both males and females. Again, (Quero et al. 2021) study suggests grape stem extracts may possess antioxidant and anti-cancer properties, accelerating cancer cell death and inhibiting the antioxidant enzyme thioredoxin reductase 1 in Caco-2 cells.

There haven't been many researches done on grapevine leaves to see whether they may be used to cure or prevent certain illnesses. The neuroprotective effects of conventional and organic grapevine leaf extracts and the enzymatic antioxidant activity of leaf extracts as well as their ability to lessen lipid and protein damage were examined *in vivo* by (Meng et al. 2021).

Research suggests that grape seed oil may be beneficial for treating metabolic disorders and inflammatory illnesses, as well as improving glycemic management and insulin sensitivity. Patients with pre-diabetic conditions like hypertension, obesity, metabolic disorder or syndrome, diabetes, and congestive heart failure may benefit from these preventive measures, as evidenced by numerous clinical trials involving grape seed oil (Kaseb and Biregani 2016).

Similar to the food processing sector, when raw materials are used in the production process, wastes as well as the intended products are produced. Pomace, peels, and seeds make up an estimated 25–30% of the waste generated during the preparation of fruits and vegetables (Galanakis 2013). Furthermore, even though the harvest still has enough nutritious components, pieces of plant like stalks, leaves and stems are frequently drove back into the field (Gustavsson et al. 2011).

The possible use of jabuticaba as a prebiotic by product was demonstrated by the probiotic strains *Lactobacillus acidophilus*, L. casei, and *Bifidobacterium animalis* subsp. *lactis*, which metabolized phenolic compounds and enhanced synthesis of short-chain fatty acids and lactic acid (SCFA) (Massa et al. 2020). It should be noted that the selectivity of the substrate will be assessed in order to confirm the food by-products' prebiotic potential in conjunction with a range of intestinal bacteria, including pathogen strains.

Plant by-products. Foley et al.(2011) emphasized cutting waste and making better use of available resources. Effective use of the food produced would contribute to both global food security and a decrease in the negative environmental effects of agriculture. In addition to being consumed in greater quantities, fruit and vegetables have been shown to be the main cause of food waste. According to a study (Aboukhalaf et al. 2023), a wild edible plant *Scolymus hispanicus*, could be considered as a potential functional and nutraceutical food with antioxidant and antimicrobial activities.

The estimated worldwide food loss from various food items is studied by (FAO 2011). Fruits and vegetables account for 44% of trash, followed by roots and tubers (20%), cereal (19%), and other commodities that also generate a substantial quantity of garbage. Dry distilled rose petals extract (DDRPE) has been considered to be promising by-products extracted from the rose oil production in the perfumery industry for the development of bulgarian dry fermented sausage and provides significant health benefits (Balev et al. 2022). Dry distilled rose petal extracts (DDRPE) and l-ascorbic acid coupled with edible alginate coating has been considered to be an effective way in order to preserve fish freshness (Vangelova et al.2022).For instance, fruits and vegetables are often produced in season, and in tropical nations in particular, overproduction during the growing season without appropriate use results in food waste. According to Vangelova et al. (2022), significant quality changes occur during frozen storage of m. *Longissimus dorsi*, m. *Semimembranosus* and perirenal adipose tissue from lambs fed a diet supplemented by dihydroquercetin or dry distilled rose petals (DDRP).

Fruit wastes. It may be processed in a number of methods, including slicing, pulping, and juicing, producing bagasse, peel, core, and crown as by products. The resulting by products are frequently discovered in food components that serves a purpose demonstrating their potential for usage in food preparation as useful functional components. Examples of these substances include vitamin C, A, and E, phenolics, flavonoids, carotenoids, fatty acids, and hemicelluloses (Roda and Lambri 2019). Using by-products of orange juice, Kaderides and Goula (2019) created a novel material for walls for Spray-drying peelings of pomegranate phenolic extract encapsulation. In this way, two food by-products with health-promoting qualities - pomegranate peel extract and orange juice waste - were combined to create a single, multifunctional meal. Utilization of cocoa shell as an important by product of cocoa powder processing in wheat semolina during extrusion cooking significantly affects density and expansion index of extrudates (Toshkov et al.2021). Peel, seeds, and adhering pulp are by-products of the industrial processing of jaboticaba, accounting for around 40% of the fruit itself. It concentrates variety of biological elements; the peel of the jaboticaba is a great source of significant phyto chemicals that are advantageous for culinary and pharmaceutical formulations (Gurak et al. 2014).

Utilizing waste from bioactive fruit processing, such as seeds and pomace, to extract bioactive compounds including lipids, dietary fiber, flavonoids, and pectinare a relatively recent approach. Natural sources of polyphenolic compounds like antioxidants with health-

promoting qualities, are sought after by food scientists and business (Kim et al. 2012).

Melon seeds, then, could be excellent substitutes for creating unique functional foods that have a variety of advantages. The recent popularity of mango peels can be attributed to their valuable contents, which include vitamins E and C, enzymes, carotenoids, polyphenols, and phytochemicals with antioxidant and functional (Ajila et al. 2007). The massive quantity of waste produced during the industrial manufacture of pomegranate juice is one disadvantage, especially with regard to the peels from the outside, which are a potentially valuable source of phenolic compounds (such ellagitannins and ellagic acid) (Turrini et al. 2019).

The impact on the addition of whole banana flour (WBF), banana flour with pulp (BPF), and banana flour with peel (BSF) derived from greenish bananas, as well as pre-emulsified sunflower oil on the physicochemical and technological characteristics of fat-reduced frankfurters was investigated by (Pereira et al. 2020). WBF, BPF, and BSF were added to the sausage to improve its sensory qualities and reduce cooking loss, boost oxidative stability, and increase emulsion stability. This resulted in a healthier version of sausage that included animal fat up to 50% less. Vacuum frying process has the ability to improve the qualitative properties in terms of shelf stability, crispiness and nutritive value of king orange peel for the development of chocolate candy fillings (Hien and Nguyet 2021).

Mango peel flour is now utilized in functional food manufacturing to make a wide range of products, including noodles, bread, biscuits, and sponge cakes (Abdul Aziz et al. 2012). Additionally, according to According to Luo et al. (2014), mango kernels contain more gallotanins than the fruit's peel. Mango peel and kernel extracts high in gallotannins have been suggested by the authors as a possible source of anticancer agents. Pomegranate pomace, a waste product from fruit and vegetable processing, is gaining popularity due to its nutritional value. Jabuticaba, a fruit with medical benefits, has been found to cure diarrhea, asthma, stomach and intestinal diseases, and increase HDL cholesterol levels (Moura et al. 2018). Qualitative improvement of toffee containing reduced fat could be obtained by incorporating mango kernel fat and pectin improving the quality characteristics of low-fat toffee in a high-speed homogenizer (Azab et al. 2022).

In order to make functional meals, Gurak et al.(2014) created freeze-dried (48 °C/48 h) pomace. Another significant source of pomace high in bioactive chemicals is apples. Dried apple pomace can be used to dietetic foods as one technique to control apple pomace. Apple pomace's sensory properties may be preserved to a comparatively high degree after freeze- drying, indicating that the product's freeze-dried form could be beneficial as an addition in the creation of functional meals (Rana et al. 2015).

Apple pomace is a significant dietetic food ingredient since it is high in dietary fiber and a variety of polyphenolic chemicals, primarily flavonols, flavanols, and phenolic acids. Apple pomace helps regulate body weight by supporting intestine and stomach processes and has a cancer-prevention impact (Kołodziejczyk et al. 2013).

Another high-nutrient, potentially useful dietary element is apricot kernel. Research published in scholarly journals has demonstrated the high protein content of apricot kernels. Furthermore, according to many researches, apricot kernels are utilized in the creation of noodles, bread, and cookies, and they have also been employed as a fat substitute in cookies (Dhen et al. 2018;vSeker et al. 2008).

High thermal stability in the fat derived from rambutan seeds suggested potential use in the food sector. The primary fatty acids found in fats from rambutan seeds are omega-9 oleic acid and omega-6arachidonic acid, respectively (Solís-Fuentes et al. 2010). Bioactive substances that have been extracted are added naturally to functional meals. For instance, it has been demonstrated that pomace, or the peels, skins, and seeds of fruits and vegetables, which are rich in polyphenolic chemicals, it also be a helpful source of raw materials for cellulose, hemicellulose, or lignin (Banerjee et al. 2017). The most recent technique uses *Komagataeibacter xylinus* to produce the flesh of citrus pomace or nanocellulose produced by bacteria derived from manufacturing waste. This type of cellulose has been shown to be strong and very pure. Peel and squeeze residue from citrus fruits is an inexpensive raw material that may be used to produce bacterial nanocellulose in an environmentally friendly and cost-effective manner, reducing the amount of waste that would otherwise result from processing unprocessed citrus fruit pomace. It also helps minimize the usage of synthetic ingredients (Fan et al. 2016).

It has been discovered that blueberry leaves, which are often lost during mechanical harvesting, are rich in phenolic compounds, anthocyanins, and chlorogenic acid - compounds recognized for their antioxidant qualities (Hicks et al. 2012; Kim et al. 2010; Routray and Orsat 2014).

In addition to having a pleasing appearance, flavor, and texture, functional foods also need to include high-value ingredients that contribute to their health, like the bioactive ingredients found in waste materials and by-products from the processing of tropical fruits. These ingredients will aid in the food's recovery and pave the way for the sustainable production and management of food. Fruit by-products may have positive health effects when used in functional food preparation, such as in bread goods (Sudha et al. 2016).

One may use potato peels, which make up a large amount of the trash from the potato processing sector, as a natural antioxidants source (Singh et al. 2011). Potato peel waste can yield useful components that can be recovered, offering a less expensive substitute for synthetic antioxidants used in the food industry (Salim et al. 2017).

A cake that was made using varying percentages of guava skin flour (30%, 50%, and 70%) revealed that the flour addition was marked by a low amount of lipids and carbs and a high level of fiber, β-carotene, and phenolic compounds. Guava skin flour can therefore be used to partially replace wheat flour in cake recipes, increasing the cake's nutritious content without degrading the texture (Bertagnolli et al. 2014).

Sójka et al. (2015a) studied industrial plum pomace-derived polyphenol extracts, which showed strong antioxidant activity and high polyphenol concentrations. The extracts contained flavonols, hydroxycinnamic acids, anthocyanins, and procyanidins. The extraction methods were suitable for producing high polyphenol concentrations, making them potential functional food additives. The color of the fruit's skin also influenced the polyphenol content, with darker skin containing higher polyphenol content. Additionally, studies have demonstrated the health-promoting qualities of plums, including their ability to fend off osteoporosis, heart and digestive disorders, and some cancers (including breast cancer) (Hooshmand and Arjmandi 2009).

Vegetables by-products. The ancillary goods that are frequently thrown away or squandered throughout production or other phases of food processing and preparation are known as vegetable by-products.

Table 2. Plant industry by-products and their utilization

By-products	Functional compounds	References	Utilization	References
Peel and core (Pineapple)	Carotenoids, fatty acids, hemicelluloses, and Vitamin C, A and E	(Banerjee et al. 2020; Roda and Lambri 2019; Mohamad et al. 2019)	Sausages, cookies, probiotic yogurts, and cereal bars	(De Toledo et al. 2017; Díaz-Vela et al. 2015; Sah et al. 2016)
Peel and seed (Melon)	Phytosterols, carotenoids, fatty acids, pectin, peptides, Vitamin E, flavonoids	(Gómez-García et al. 2021; Fundo et al. 2018; Morais et al. 2017)	Cookies, cakes and breads	(De Toledo et al. 2017; Siddeeg et al. 2014)
Peel and seed (Watermelon)	Polysaccharides, Proteins, carotenoids, fatty acids and tocopherols	(Ho et. al. 2018; Morais et al. 2017; Petkowicz et al. 2017)	Fruit bars, cakes, and breads	(Munir et al. 2016; Waghmare and Arya 2014)
Seed kernel, peel, seed and (Mango)	Proteins, amino acids, starch, calcium, magnesium, provitamin A, vitamin C and K, aromatic compounds, fatty acids, flavonoids, mangiferin, antioxidants, minerals	(Mwaurah et al. 2020; Oliver-Simancas et al. 2020)	Breads Idli and mathi	(Chen et al. 2019) (Kaur and Brar 2017)
Peel and seed (Papaya)	Fatty acids, carotenoids flavonoids, and phytosterols	(Da Silva and Jorge 2017)	Breads	(Waghmare and Arya 2014)
Outer layer and seed (Passion fruit)	Pectin, carotenoids, soluble fiber, and flavonoids	(Villacís-Chiribog et al. 2020)	Fermented soymilk, pork burger, and preserved meat items	(Albuquerque et al. 2017; López-Vargas et al. 2014; Ramli et al. 2020)
Zest, seed and Pomace (Apple)	Proteins, starch, soluble fiber, pectin, polyphenols, potassium, calcium and phosphorus, total phenol content, insoluble fiber, soluble fiber, total dietary fiber	(Antonic et al. 2020; Kringel et al. 2020)	Baked items like Bread, cookie, cakes, biscuits, chicken sausage	(Alongi et al. 2019; De Toledo et al. 2017; Sudha et al. 2007; Waghmare and Arya 2014; Yadav et al. 2016)
Cauliflowers, as well as other Brassica	Vitamins, phenolics, glucosinolates (GLS),	(Ahmed and Ali 2013;Bhat and	Bakery items like bread, cakes, snacks, soups	(Alvarez-Jubete et al. 2014; Amofa-Diatuo et al. 2007; Klopsch et

species by-products	Phytosterols Fiber, Iron, lutein, and β-carotene	Karim 2008; Gul et al. 2015)	drinks, Dhokla, pancake idli, and crackers	al.2019; Krupa-Kozak et al. 2019, 2021; Lafarga et al. 2019; Stojceska et al. 2008;)
Peel (Banana)	Proteins, fatty acids, carotenoids, soluble fiber, dopamine and L-dopa and fructooligosaccharides as well as amino acids	(Azam et al. 2020; Emaga et al. 2007; González-Montelongo et al. 2010; Singh et al. 2016)	Chicken or frankfurter sausage, bread, gluten-free Riss, cereal bar and orange juice	(Carvalho and Conti-Silva 2018; Gomes et al. 2022; Pereira et. al. 2020; Khoozani et al. 2020; Zaini et al. 2020)
Potato Skin	Anthocyanins, glycoalkaloids, phenolic compounds, Dietary fiber, and flavonoids	(Jimenez-Champi et al. 2023)	Bakery products (Breads, Cakes), meatballs	(Curti et al. 2016; Jeddou et al. 2017)
Waste of Red pepper	Carotenoid, polyphenol	(Šeregelj et al. 2019)	Yoghurt	(Ivanović et al. 2023; Šeregelj et al. 2019)

During the preparation process, vegetables may lose up to one-third of their value. It's interesting to note that some vegetable portions are purposefully thrown away because of their bad texture or flavor. For instance, throughout the production process, vegetable pieces including seeds, bagasse, and hulls are largely thrown away. The stem and leaves of several vegetables, such broccoli, cauliflower, and pumpkin, are thrown away rather than eaten (Lau Sabran and Shafie 2021). Valorisation of sugar beet (*Beta vulgaris* L.) leaves using novel processing techniques could be efficiently utilized for the development of useful functional components e.g. total phenolic compounds (TPC), total flavonoid components (TFC) etc. (Ebrahimi et al. 2022).

The betalains were isolated from *Beta vulgaris* L. or red beetroot pomace in a study by (Kaur et al. 2021) and a functioning Kulfi enhanced with betalains enclosed was created. Because of their antioxidant and antimicrobial qualities, by products of lignocellulosic agriculture, such as sawdust, spent coffee ground nut residues, wheat straw residues, and rice and wheat bran, have been widely regarded as a clean source of phenolic compounds with potential applications in a range of industries (Fermoso et al. 2018). Nanoencapsulation is a potential approach to mask some off-putting odors and fragrances and shield different food components from specific physiological circumstances or degradation. By decreasing the size of their particles, BACs may become more stable, bioavailable, soluble, and delivered, all of which might lead to an increase in their functional activity (Chaudhari et al. 2021).

The nutritional value of the black carrot is enhanced by its high anthocyanin content, which also includes dietary fiber, minerals high in potassium, ascorbic acid, thiamine, riboflavin, and niacin (Arscott and Tanumihardjo 2010). Traditional medicine has made extensive use of jack leaves, fruits, and bark because of its hypoglycemic, wound-healing, anticarcinogenic, antibacterial as well as antifungal qualities. More antibacterial activity has been demonstrated for jackfruit peel pectin when it comes to bio-nanocomposite materials for bone repair (Ranasinghe et al. 2019). High energy wet media milling has the ability to modify structural characteristics and functional properties of fiber-rich by-products of white cabbage (Von Ulardt et al.2020). Artichokes are edible parts of the plant, with 60-75% of the commercial processing process resulting in waste. This waste, including leaves, stems, and bracts are used for bioactive ingredients for food functionalization, high-molecular-weight inulin extraction, and animal feedstuff. Recent attempts have explored applications for this fraction, such as obtaining bioactive components to functionalize meals (Pasqualone et al. 2017), extracting high-molecular-weight inulin (Lopez-Molina et al. 2005), and using artichoke leftovers for animal feed (Megıas et al. 2002).

Various percentages of papaya pulp flour (PPuF) - 15%, 30%, and 50% - were tested as wheat flour substitutes in cookie recipes (Varastegani et al. 2015).

Marine by-products. A universal definition for marine by-products does not exist. Marine by-products were formerly frequently regarded as garbage or fish offal (Rustad 2003). The number of fish by-products generated by the processing industries will only increase due to the rising demand for fishery products as a source of vital nutrients and a well-rounded diet for wellness (Ferraro et al. 2013; Lopes et al. 2015).

When it is possible to separate the different components of marine by-products, the best value will be achieved. Such as prioritizing the extraction of oil from heads, viscera, or fish skin protein derivatives. Fatty fish wastes are an invaluable raw material for companies that extract fish oil, especially in the high fat season. By proving that salt does not impede the creation of an oil of high quality, the possibilities of oil extraction and oil purity from salty maatjes herring byproducts (viscera, fraction of heads, skin, frames, etc.) (Aidos et al. 2001). Fish by products have a high endogenous enzyme load and microbial load, which can generate significant problems for the environment and technical issue of food science and technology. They can swiftly deteriorate if handled or kept incorrectly (Arvanitoyannis and Kassaveti 2008; Chalamaiah et al. 2012).

Fish by-products fall into two categories: stable goods like bones, heads, and skin, and readily degradable items with high enzyme content like viscera and blood. Maintaining the quality of these by-products and producing high-value goods depend on their proper collection and handling (Rustad et al. 2011). Due to geographical spread of fish production, landing, and processing locations, local processing is the best management option for converting residues into valuable products (Olsen et al. 2014).

Seafood by-products can be refined to provide high-value components for bioactive compounds and nutraceuticals. Marine-derived calcium-binding peptides may have applications as dairy free functional food or beverage ingredients for people with lactose intolerance, anticarcinogenic ingredients or as agents for the prevention and treatment of osteoporosis (Harnedy and FitzGerald 2012).

Seaweeds are becoming more and more popular in the food sector (Wells et al. 2017) as renewable sources of high-value chemicals for usage in baked goods, dairy products, seafood, meat products, and vegetable-based products. They improve the nutritional value, composition, and health advantages (Roohinejadet al. 2017). In addition to being utilized for their phycocolloids, which include carrageenan, agar, and alginates, macroalgae are also useful in the food sector for their gelling, thickening, and stabilizing qualities (Tavares Estevam et al. 2016; Ścieszka and Klewicka 2019).

One of the hydrocolloid's best practical qualities is its ability to bind water effectively. Seaweeds include κ-carrageenan, ι-carrageenan, and λ-carrageenan, which have the ability to thicken and produce gels. Carrageenan is used to bind milk proteins, retain milk solids, stop protein whey fractionation, and allows crystallization in milk ice creams, among other uses in dairy and pastry goods including cheese, chocolate milk, and cocoa (Ścieszka and Klewicka 2019).

Cheese and other dairy products can benefit from the usage of seaweeds, which provide vital nutrients and trace elements. Cheese can be fortified with calcium-rich algae to avoid the problems with absorption brought on by casein immobilization. To add iodine and spicy qualities to cottage and fresh cheese, add *Saccharina latissima*, formerly known as *Laminaria saccharina* (Okhotnikov et al. 2020). Cheese may be made healthier by using seaweeds to lower its salt level compared to regular dairy products (Lee 2011).

Seaweeds have been found to be a promising strategy for supplementing fermented dairy products, improving their nutritional value and shelf-life. Studies have shown that seaweed extracts can enhance milk quality and shelf life (Nuñez and Picon2017; Estevam et al. 2017).

O'Sullivan et al. (2014) tested brown algae species *Ascophyllumnodosum* and *Fucusvesiculosus* as functional ingredients in milk, while evaluated other brown, green, and red seaweed species in milk. Brown seaweed *Laminariaochroleuca* has been used for gluten-free fresh pasta production, resulting in a product with similar mechanical properties and higher fiber and mineral contents (Fradinho et al. 2019).

Paszkiewicz et al. (2016) claim that the viscous liquid form of fish gelatine at room temperature is seen to be a special rheological feature that may be used in the creation of biomaterials under "green" process settings. Fish gelatine has a lower gel strength and melting temperature than mammalian gelatine, mostly because of the variations in their amino acid makeup (Kwak et al.

Table 3. Valuable components and the utilization of fish by-product
*Adapted from Stevens et al.(2018) Copyright 2018, Elsevier

By-Product	Important elements	Application
Fractions of heads, Frames (bones, flesh, fins)	Proteins, peptides, lipids, collagen, gelatine, minerals including calcium, flavour	Products like meals, oils of fish, food, animal grades hydrolysates which produced by hydrolysis, foods for pet, human, nutraceuticals, cosmetics
Trimmings	Proteins, peptides, lipids	Food, fish meal, fish oil, food grade hydrolysates, animal grade hydrolysates, pet food
Viscera	Proteins, enzymes peptides, lipids, enzymes such as lipases	Food, animal grades generated by hydrolysis called hydrolysates, meals and oils occurred from fish, energy sources, fertilisers
Skin (with belly flap)	Collagen, gelatine, lipids, proteins, peptides, minerals, flavour	Protein source, oil, cosmetics, food, nutraceuticals, cosmetics, leather, fuel, fertilisers
Blood	Proteins, peptides, lipids, thrombin and fibrin	Energy source, fertiliser, therapeutants

2017). As a result, the type and supply of collagen affect the functional characteristics of gelatine, such as its melting point, gel strength, and viscosity. Furthermore, because different polypeptide chains have different lengths during processing and extraction, variables such as temperature and time combinations, as well as chemical composition, can also impact the techno-functional characteristics of gelatine. Adding sorbitol and sucrose to fish gel solutions made from rainbow trout (*Oncorhynchus mykiss*) skin improved the fish gel solutions' characteristics and added confectionery solutes that might be utilized to make gummy candies (Kamer et al. 2019).

Biotechnological procedures are widely acknowledged as environmentally sustainable methods that have the potential to extract valuable components from raw materials beyond the intended one. In recent times, biotechnological procedures like fermentation and biocatalysis have become essential to the processing of seafood; they are useful for recovering different valuable components and offer an appealing substitute for chemical, physical, and mechanical methods when processing seafood by-products (Suresh and Prabhu, 2012).

Animal by-products. By-products of edible meat are packed with vital nutrients because they contain distinct nutrients such minerals, fatty acids, hormones, vitamins, and amino acids, some are utilized as medications. A number of very nutritious organs, including the heart, kidney, brain, spleen, lung, and tripe, are included in the diets of many nations around the world (Toldra and Milagro 2011).

Blood from animals has a high protein and heme iron content, making it a useful dietary by-product (Duarte et al. 1999). In the European Union, blood from animals has been extensively utilized to produce blood pudding, bread, biscuits, and sausages. It's utilized in blood pudding, blood cake, and blood curd in Asia. It is also utilized for non-food products including binders, feedstock, and fertilizer. Blood can be added to food as a color addition, stabilizer, emulsifier, clarifier, and nutritional supplement (blood meal). It is a great source of most trace minerals and can be used as a vitamin stabilizer, lysine supplement, milk replacement, or protein supplement. Blood has a number of technical uses, including raising protein levels and improving the ability to bind to water and emulsify substances (Mandal et al. 1999).

Certain plasma proteins can be employed to increase protein products like pasta or have demonstrated strong protease inhibitory action and substantial protein cross-linking capabilities (Yousif et al. 2003). Due to its 60.0% albumin content, blood plasma has the capacity to gel (Silva and Silvestre 2003). The blood fraction's greatest fat and water binder is plasma. Cooked egg whites and plasma gels look a lot alike. According to Autio, et al., 1985, hot dogs with 2.7% added plasma and cooked ham with 1.5% and 3.0% frozen blood plasma added had more desirable colour. Additionally, blood plasma has a high potential for foaming (De Mendoza et al. 2005), making it a viable substitute for egg whites in baking (Ghost 2001). Because of their excellent gelation and emulsification qualities, Serum albumin, fibrinogen, and immunoglobulins are examples of divided plasma proteins that can be incorporated into feed and food ingredients (Cofrades et al. 2008). Because it can bind a lot of fat, collagen from hides and skins also functions as an emulsifier in meat products. Because of this, it can be used as a filler or ingredient for meat products. The meat was cooked using a collagen sausage business may also be made by extracting collagen from the skins of cattle. In addition to being a main component of jams and aspic, gelatine is used to a variety of dishes (Jamilah and Harvinder 2002).

Dairy by-products. In general, the by-products that the dairy sector produces include viewed as a source of fascinating compounds rather than as worthless trash. Therefore, it is crucial to value by-products in the milk processing business, mostly for financial reasons. The best post processing of by-products that may be used in the manufacturing of the primary dairy products, non-dairy food goods, or non-food uses is known as valorisation. The milk industry's by-products contain functionally interesting components that can be separated out using processing techniques and used again in finished goods, as ingredients in other food products for human and animal nutrition, or to be valorised for uses other than nutrition. The primary goal of the dairy business is to maximize the nutritional value of all the components found in raw milk, which is the primary raw material. The total value of raw milk is enhanced by the value addition of by-products (Lopez 2021).

Different methods are used to valorise lactose and its derivatives from cheese whey, a dairy industry by-product, with uses in the food, feed, pharmaceutical, and cosmetic sectors (Rocha and Guerra 2020). The food industry uses the proteins that are extracted from whey because of its high digestibility, nutritional value, and technological uses, such as emulsifying capabilities. The production of baby milk formula has been the primary use of whey proteins in the past several years in the global market (Fenelon et al. 2019).

When whey proteins are selectively concentrated using Cross flow ultrafiltration (UF), the resulting liquid whey protein concentrates (LWPC) are used swiftly as raw materials in the manufacturing process of various dairy products. The effects of using LWPC in yoghurt compositions in place of some or all of skimmed milk powder (SMP) were investigated by (Henriques et al. 2011). Qualitative improvement of yoghurt spread in terms of nutritional, polyphenolic phytochemical constituents and shelf stability took place while fortified with *Spirulina platensis* (Nazir et al. 2022).

LWPC from bovine whey was also recently employed by (Pires et al. 2021) to make whey cheeses with probiotics or kefir added. The fermentation of beverages containing probiotics and prebiotics (symbiotic drinks) using Second Cheese Whey (Maragkoudakis et al. 2016; Tirloni et al. 2020) investigated the manufacturing of a ready-to-drink beverage made from SCW in the production of dairy products. A key component of baby formula and food processing is lactose. The high lactose concentration in SCW makes its recovery a potentially attractive option when paired with the nitrogen fraction's value-adding (Chen et al. 2019).

Functional foods and beverages are one of the food industry's most ambitious and imaginative sectors because they provide health benefits exceeding the basics of nutrition. They strive to capture buyers' interest. Whereas bioactive proteins are increasingly used in the pharmaceutical and nutritional industries, whey and its components are gaining popularity as functional additions to dietary and wellness goods (Blažić et al. 2018). So far, the primary emphasis of research has been the manufacture of whey-based beverages utilizing either natural sweet and sour whey or powdered, deproteinized, and thinned whey (Barukčić et al. 2019). The globe's top dairy businesses have already produced a new generation of whey-based products (Papademas and Kotsaki 2019).

The application of non-thermal technologies in the production of whey beverages, such as membrane separation, high-intensity ultrasound, or supercritical carbon dioxide technology, is under investigation. The use of non-thermal technology in the production of whey drinks solves the aforementioned concerns while improving the quality of current items (Amaral et al. 2018; Režek Jambrak et al. 2018; Barukčić et al. 2015;

Barukčić et al. 2015). Whey is a common ingredient in many different types of drinks, as are those made using whey-derived substances as WPC, WPI, and whey protein hydrolysate (WPH) (Lappa et al. 2019).

Additionally, whey is utilized in certain regional drinks, such buttermilk, an Indian fermented beverage made from the leftovers of producing butter. After adding acid whey in equal amounts, the beverage age showed good stability and acceptability by the senses after five days under refrigeration (Ghanshyambhai et al. 2015). Whey and buttermilk-supplemented beverage compositions demonstrated acceptable probiotic counts and physicochemical properties. It's noteworthy to note that, despite using two different types of dairy sector by-products, the beverage had acceptable sensory acceptability with the addition of sugar and strawberries, regardless of the formulation utilized (De Bassi et al. 2012).

Post-harvest by-products. Grain processing accounts for approximately 12.9% of all food waste produced globally (Fărcaș et al. 2022). While being abundant in nutrients, cereal waste and by-products are either discarded or largely used in livestock nutrition and biofuel synthesis. In addition to lowering waste and by-product quantities, the grain processing industry is currently seeking to recover compounds with added value that are beneficial to the food industry and to value those that are currently in place in a sustainable manner. Wet milling, which primarily produces starch and glucose, dry milling, which primarily produces flour, and the beer-making process all generate trash and by products. Cereal waste and by-products can be directly utilized, modified slightly, for various uses, or used for the extraction of bioactive substances (Fărcaș et al. 2022). In contrast to the method inside a biorefinery idea, which targets particular components, food applications frequently attempt to employ the entire by-product (Tufail et al. 2022).

Maize bran (60-70 g/kg) is a cheap source of dietary fiber and free radicals that arise naturally as a by-product of milling (Hussain et al. 2021). Often seen as disadvantages in the bread-making process are the high fiber content of the bran and the presence of lipids and lipase in the germ. When lactic bacteria (*Weissella confusa* and *Lactobacillus plantarum*) undergo fermentation and used as components, the nutritional, textural, and sensory aspects of bread made from wheat (which contains 25% fermented by-products) are enhanced. Higher levels of dietary fiber and proteins (11 and 13% of the dry matter, respectively), a notable rise in digestibility of proteins (up to 60%), and a consequent decrease in the starch hydrolysis index (13%), are indicative of this (Pontonio et al. 2019).

The addition of chicken sausages treated with 6% wheat bran greatly boosted the gumminess and chewiness of meat food items. Sausage treated with 3% fiber had sensory acceptance comparable to the untreated control sample; however, as fiber levels have risen, its sensory appeal decreased (Yadav et al. 2018).

Another important by-product of milling wheat is wheat germ. while having a high fat content that causes rancidity and short shelf life, it has seldom been employed in food composition while having a wealth of bioactive components (Danciu et al. 2023).

Wheat flour bread was further fortified with 15% fermented milling by-products (using *Lactobacillus plantarum* and *Lactobacillus rossiae*) utilizing a dough consisting of the germ of wheat and bran to generate a product with 6.53% dietary fiber, or 5% higher than in the wheat flour bread (Pontonio et al. 2017; Schiavon et al. 2013).The inclusion of raw and microwaved wheat germ increased cooking losses and the acidity of cooked pasta during storage, and the enriched samples had a significantly higher lipid, protein, and ash content as well (Pınarlı et al. 2004; Tarzi et al. 2012; Aktaş et al. 2015).

Edible oil is extracted from maize germs using both wet and dry milling methods in the food sector. When maize is dry milled, edible oil can be extracted from the germ fraction using mechanical screw presses or a combination of screw presses and solvent extraction (Papageorgiou and Skendi 2018). Reduced hardness and chewiness after storage was one way that bread fortified with 1-4 percent maize germ protein hydrolyzate improved in texture (Karimi et al. 2021).

The processing of maize starch yields by-products rich in fiber, protein, and antioxidants that may be added to food items as low-calorie, low-cost ingredients to substitute sugar or fat in proportion (Grasso S. 2020). The majority grain consumed by people in northern Europe is rye, which is frequently ground into whole meal flour and used to make baked goods (Verni et al. 2019). Rye bran, a by-product of milling, is a useful supplement to increase the nutritional content and health benefits of meals (Dziki D. 2022).

According to a recent study, emulsion-based meat products can have nutritional fiber from maize bran added to them without losing any of their sensory or

Table 4. Grain industry by-products and waste in the food industry

By-products of grain	Fraction of carbohydrate	Applications in the food industry	Source
Bran (wheat, rye) Brewer's spent grain	Cellulose	Enhancing food items' chemical and sensory qualities	(Ciudad-Mulero et al. 2019; Dapčević-Hadnađev et al. 2018; Herrera-Balandrano et al. 2019; Juhnevica-Radenkova et al. 2021; Ravindran and Jaiswal 2016; Sandak et al. 2019; Skendi et al. 2020)
Cereal brans	Arabinoxylans	Food industry's thickening and stabilizing agent	(Bastos et al. 2018; Dapčević-Hadnađev et al. 2018; Onipe et al. 2015; Pérez-Flores et al. 2019; Ravindran and Jaiswal 2016)
Bran of oats BSG *	Beta-glucans	Alternatives to wheat flour Boost drink satisfaction with food hydrocolloids	(Dapčević-Hadnađev et al. 2018; Izydorczyk and Dexter 2008; Skendi et al. 2020; Zhu et al. 2016)
Brewer's spent grain	Residual undigested starch	Prebiotic components used in the meat sector	(Johansson et al. 2013; Parchami et al. 2021; Skendi et al. 2020; Zhu et al. 2016)
Germs of wheat, corn, Rye bran	Linoleic acid, palmitic acid, oleic acid	Food item that may be beneficial to health Food-grade component that replaces commercial shortening in the food sectors	(Meriles et al. 2022; Povilaitis and Venskutonis, 2015; Zhao et al. 2020)
Wheat germ, Rye bran	Linolenic acid	Food-grade component	(Meriles et al. 2022; Povilaitis and Venskutonis, 2015)
Corn germ	Stearic acid	Replacement of commercial shortening in the food industry	(Zhao et al. 2020)

**BSG – Brewer's Spent Grain*

textural qualities (Fukagawa and Ziska 2019). The stiffness and hardness of chicken nuggets were enhanced by adding corn bran (5-15 g) in a way that was directly correlated with the amount of bran supplied (Pathera et al. 2018).

Another research showed that chicken sausages containing 3% maize bran instead of lean meat had better acceptance, more nutritional fiber, and a longer shelf life (Yadav et al. 2016). Additionally, by-products of the dry grinding of cereal grains include hulls, husks (4-14%), germ, broken grains (6-13%), and powders (7-12%) (Danciu et al. 2023).

Cereal bran is the by-product that is most commonly utilized as a food component among them, particularly in bakery goods. Its use is intended to boost the amount of nutritional fiber by partially substituting flour in baked goods including cakes, muffins, bread, and shortbread cookies (Melini et al. 2020).

According to a recent study, oat bran added to the dough for spaghetti noodle has an impact on the product's digestibility, cooking quality, and textural, nutritional, and antioxidant properties. Pasta dough made by substituting the 50% of the oat bran along with wheat semolina have a greater rate of absorption of water and large quantity of cooking mishap than the control sample prepared with 100% durum wheat semolina. Additionally, it had less calories and less digestible starch components. As a result, this method might be a beneficial choice for dietary diets (Espinosa-Solis et al. 2019). According to Abd El-Baset and Almoselhy (2023), baking temperature and time significantly influenced the development of school meal biscuits stuffed with date paste in order to achieve the sustainable national school meal program. Brewer's wasted grain is mostly offered as animal feed because of its qualities and the important elements it contains that contain nitrogen, but studies have revealed that it also has a good nutritional value for human use (Rachwał et al. 2020). Brewer's wasted grain improves the health-promoting qualities of foods like meat sausages and has no negative effect on the sensory qualities or physicochemical quality indicators of meat products (Choi et al. 2014; Nagy et al. 2017).

Challenges

The industries of food processing generate significant remains globally, with many by-products being rich in bioactive components that can be added to food items if certain protocols are followed. However, some by-products cannot be directly disposed of due to contamination. To utilize these by-products, several obstacles must be overcome, including consumer awareness, marketing to demonstrate product safety, health promotion, disease prevention, and biological function. Additionally, research on sensory attributes and off-flavor is crucial for creating functional products with food by-products, as new chemicals may alter the final product's texture and physicochemical characteristics. Cost is another important factor, as the extraction and obtaining techniques used to collect food by-products can be expensive, impacting the final product.

Therefore, research on extraction and obtaining techniques is essential to reduce costs and create affordable functional meals for a wide range of customers. Further study is needed to address the challenges of scaling up food by-product utilization in the industry.

Conclusions

In order to obtain a diet which promotes health beneficial potentials, the worldwide demand of functional food derived from conventional resources e.g. meat, dairy, vegetables, and fruit etc. has gained significant importance. However, these resources are not sufficient and unable to fulfil the demand of functional foods containing nutrients and bioactive substances. In view of the fact, by-products discharged from food processing industries has been considered as a potential platform to develop the functional food additives. By-products generated from food industries are considered to be an excellent source of proteins, minerals, fatty acids, fibre, and bioactive substances. Food industries by products are important because they may be used as a key raw material for the creation of functional meals which has the ability for disease treatment and prevention. Utilization of food industry by products has been proved as an efficient cost-effective tool which results reduced environmental damage, and sustainable economic status in food processing sector.

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