Utilization of Food Industry Byproducts in Functional Foods

Maham Nasir[1], Rahila Rauf[2], Iqra Liaqat[3,*], Muhammad Tuseef[1], Summat Abbas[4] and Wilhelmina Garpou Kordor[3]

[1]Department of Food Science and Technology, Faculty of Food, Nutrition and Home Sciences, University of Agriculture, Faisalabad, Pakistan
[2]Department of Food Science and Technology, Faculty of Sciences, Government College Women University, Faisalabad, Pakistan
[3]Department of Food Technology and Nutrition, School of Food Technology, Nutrition and Bio-Engineering, Makerere University, Kampala, Uganda
[4]Department of Food Science and Technology, Faculty of Food and Nutritional Sciences, The University of Chenab, Gujrat, Pakistan
*Corresponding author: iqra.liaqat@students.mak.ac.ug

Abstract

This chapter offers a critical discussion on the use of food industry byproducts in functional foods, focusing on their advantage in improving food sustainability, functionality, and nutritional quality. The main goal would be to find out about the bioactive compounds contained within the byproducts, including polyphenols, carotenoids, dietary fibers, and omega-3 fatty acids, which afford antioxidant, anti-inflammatory, and cardioprotective effects. It underlines the use of novel extraction procedures such as enzymatic bioconversion and supercritical CO_2 extraction in enhancing the bio accessibility and functionality of these compounds. Moreover, the byproduct utilization concerns that have been mentioned in the chapter include: variation in byproduct, composition, contamination, and some consumers' reluctance to consume byproducts. Measures like fermentation, microencapsulation, as well as ideas implementing the concept of a circular economy can be mentioned as key strategies to bypass these barriers. In addition, the chapter expands the discussion of regulatory, economic, and technological consequences of implementing byproduct valorization internationally. Green aspects and high-tech solutions can turn byproducts from the food industry into useful functional compounds to enhance the circular economy and, at the same time, improve people's health and the environment's condition.

Keywords: Food byproducts, Food industry, Dietary fibers, Plant-derived products, Functional foods

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Introduction

The food industry sector, which forms the foundation for food security in almost every economy, ranks as one of the biggest culprits of waste generation. Every year, at least 1.3 billion tons of byproducts and food processing residues are produced all over the globe, and most of these are still not fully exploited, grown on 28% of agricultural area (Sharma et al., 2021). These byproducts include fruit skins, vegetable pulp, cereal husks, dairy residues, and fish shells, all of which are normally considered waste or else processed for the lowest value uses like animal food or biofuel (Lalramhlimi et al., 2022). Not only does this represent a significant set of losses, where huge amounts of potentially useful materials could be utilized, but also severe ecological consequences are involved since such wastes are found to release carbon dioxide causing global warming, pollute the environment when dumped improperly and add pressure on existing landfill spaces (Rohini, 2020).

Today, the adoption of sustainable practices globally is increasingly encouraged due to the dire need to reduce the impact of global warming, preserve the environment, and efficiently utilize existing resources (Dwivedi et al., 2022). There has been a recent push for a circular economy, defined as the reuse, recycling, and upcycling of waste material to produce added-value products. In this part, food industry byproducts offer perhaps the best chance for creating functionally valuable food ingredients, thus serving the twin goals of sustainability and improved profitability (Iriondo-DeHond et al., 2018).

Functional foods or foods with health-promoting or disease-preventing effects in addition to their basic uses as energy providers or building blocks of the body have emerged as the most strategic areas of opportunities for the food business (Gupta & Mishra, 2021). These products are mostly retail health products that are aimed at mitigating these health conditions or other disease risks. The increase in overweight and lifestyle diseases, along with enhanced consumer knowledge of the link between food and health, drives the demand for functional foods (Birch & Bonwick, 2019).

Sources from food industry products frequently contain bioactive compounds, including polyphenols, flavonoids, carotenoids, dietary fiber, and omega-3 polyunsaturated fatty acids (PUFAs), that are reported to have antioxidant, anti-inflammatory, and other potential health benefits (Reguengo et al., 2022). For example, citrus peel, a byproduct of citrus, has hesperidin and naringin that have antioxidant and cardiovascular disease protective properties (Simitzis & Deligeorgis, 2018). Likewise, grape pomace, a solid by-product of wine production, contains highly concentrated amounts of resveratrol and other polyphenolic compounds as proactive agents against diabetes and cancer (Simitzis & Deligeorgis, 2018).

The process of incorporating food industry byproducts in functional foods is however not without some challenges. For instance, sorghum bioactive compounds may present variability in terms of byproduct composition, risk of contamination, as well as technological barriers involved in the extraction of bioactive compounds from sorghum (Stamenković et al., 2020). Moreover, consumer acceptance is critical since there may be social acceptance issues attached to 'waste-derived' ingredients. Nonetheless, other problems, like inaccessibility of the plant cell wall, polyphenol-protein interactions, optimization of downstream processing, use of non-leaching solvents or sustainable enzymes, and fermentation of bioactive product recovery, can be dealt with prospects provided in the recent advent of supercritical matic hydrolysis and fermentation (Sengupta et al., 2020).

This chapter follows a critical analysis of how food products or new food products can serve as sources of political capital in the development of functional foods. It explores the information related to bioactive compounds enriched in byproducts, techniques that can be employed for their extraction, and application, together with the use of momentous health contributions when those byproducts are utilized in functional food products. In addition, the chapters examine the technical, economic, and regulatory implications of valorization of the byproducts for both adopting and non-adopting countries and provide a view of the new technology and prospects of valorization of byproducts.

Food Industry Byproducts: Sources and Composition

Byproducts and waste materials are produced in large quantities by the food processing industry around the world during the processing of different foodstuffs (Sadh et al., 2018). Despite being considered waste and utilized mostly in industries for feed or compost, these byproducts are bioactive compounds in nutritional and health-enriched foods. Optimal use of these byproducts can help counter sustainability issues and support the creation of new functional food products (Sadh et al., 2018). Food processing generates a variety of byproducts according to the type of raw material used and the type of processing done to it. Examples of byproducts produced by some industries include: Seed, cereals bran, skins and seeds of fruits and vegetables, dairy whey, and seafood waste (Sadh et al., 2018).

Orange and mandarin peels are among the most generated fruit wastes throughout the world, originating from juice production (Kandemir et al., 2022). These peels are rich in flavonoids (e.g., hesperidin, naringin), vitamin C, and essential oils, which have been demonstrated to possess antioxidant, antimicrobial, and cardioprotective properties (Kandemir et al., 2022). Grape pomace is the by-product produced during wine production, although they are more differentiated than the general term suggests, including seeds, skins, and stems (Beres et al., 2017). It is also an important source of polyphenols, such as resveratrol, anthocyanins, and tannins, with antidiabetic, anticancer, and neuroprotective properties. Tomato by-products include skins and seeds remaining after crushing tomatoes for pasting or making juice (Laranjeira, 2020). Tomato pomace contains a high amount of lycopene, which is a carotenoid with antioxidant and anticancer properties (Laranjeira, 2020). A heaped residue of wheat milling, wheat bran is rich in dietary fiber, phenolic acid, and antioxidants (Saini et al., 2023). It has been evidenced in research to enhance the benefits of gut health and might protect against chronic diseases. Thus, rice polishing or rice bran contains oryzanol, tocopherols, as well as tocotrienols, which act as cholesterol-controlling and anti-inflammatory agents (Tufail et al., 2024). Some of the citrus by-products are mentioned in Figure 1.

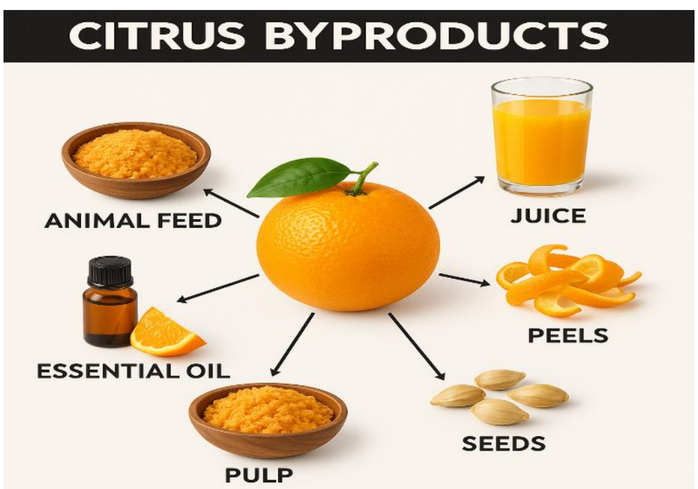

Fig. 1: Citrus byproducts obtained from citrus fruits (www.canva.com)

Whey is the residual of cheese and casein processing (Kassem, 2015). It provides large amounts of proteins, including beta-lactoglobulin and alpha-lactalbumin, and bioactive peptides are also involved in muscle anabolic and immune-modulating actions (Kassem, 2015).

Scales and Shells are normally thrown away but are reservoirs of collagen and chitin in their entirety (Mehta et al., 2023). Skincare and functional foods are made from collagen, respectively; Chitin can be transformed into chitosan, a bioactive polymer used in the food and pharmaceutical industries (Mehta et al., 2023).

Nutritional and Bioactive Components

Food industry byproducts contain several bioactive compounds that are precious for functional food products (Helkar et al., 2016). They differ with the input material, but usual bioactives include polyphenols, carotenoids, omega-3 fatty acids, dietary fibers, and proteins. Polyphenols, which can be extracted from fruit and vegetable by-products like grape pomace and citrus peels, are powerful antioxidant chemicals that fight free radicals and decrease the dangers of modern ailments, including diabetes and cardiovascular diseases (Maqbool et al., 2023). Carotenoids such as lycopene in tocotrienol in carrot skins have benefits regarding eye health, immunity, and protection against free radicals (Anbualakan et al., 2022). The consumption of fish byproducts, especially the liver, has benefits to the heart and the brain. The compounds also possess a counter-inflammatory effect (Butler, 2019). Some byproducts, including wheat bran and apple pomace, are high in the diet, which are good for the digestive system and lower cholesterol levels (Lyu et al., 2020). Dairy whey proteins and fish-derived collagen peptides, for instance, enhance muscle bulk, enhance skin flexibility, and support joint health (Xu et al., 2023).

Creative use of byproducts in functional foods offers a unique strategy to enhance food sustainability, nutritional quality, and consumers' health. The escape of byproducts from food production rises with food production, and most of such byproducts are disposed of or underutilized (Vlaicu et al., 2023). That being said, in moderation, these byproducts are becoming increasingly beneficial due to modern innovative food science practices that turn them into functional ingredients. When it is applied to the technique of extraction of bioactive components, their incorporation into food products, and transformation into valuable food ingredients, it becomes evident that this undermines food quality and delivers measurable health perks to consumers (Wibisono et al., 2025). Table 1 below enlists some common food industry byproducts and their functional food applications.

Table 1: Food industry byproducts and their functional food applications.

Byproduct	Source	Key Bioactive Compounds	Health Benefits	Functional Food Applications	Reference
Citrus Peel	Juice production	Flavonoids (e.g., hesperidin, naringin), vitamin C, essential oils	Antioxidant, anti-inflammatory, cardioprotective	Fortified beverages, antioxidant powders	(Zhao et al., 2020)
Apple Pomace	Juice manufacturing	Polyphenols (e.g., phloridzin), dietary fibers	Antidiabetic, gut health improvement	Nutritional bars, fiber-enriched snacks	(Girotto et al., 2024)
Grape Pomace	Wine production	Resveratrol, anthocyanins, tannins	Antioxidant, antidiabetic, anticancer	Nutraceuticals, functional beverages	(Constantin et al., 2024)
Wheat Bran	Milling industry	Dietary fibers, phenolic acids	Gut health, cholesterol reduction	Cereal products, bakery items	(Călinoiu & Vodnar, 2018)
Rice Bran	Rice polishing	Oryzanol, tocopherols, tocotrienols	Anti-inflammatory, cholesterol-lowering	Functional oils, fortified snacks	(Zubair et al., 2023)
Dairy Whey	Cheese production	Whey proteins (e.g., beta-lactoglobulin), bioactive peptides	Muscle synthesis, immune support	Protein shakes, sports nutrition products	(Awuchi, 2022)
Fish Scales	Seafood processing	Collagen, gelatin	Skin health, joint health	Collagen-enriched beverages, supplements	(Rategari et al., 2024)
Tomato Pomace	Tomato processing	Lycopene, polyphenols	Antioxidant, anticancer	Tomato paste, functional sauces	(Jiménez Bolaño et al., 2024)
Banana Peel	Banana processing	Prebiotic fibers, polyphenols	Gut health, antioxidant	Prebiotic powders, fortified flours	(Zahid et al., 2021)
Coffee Grounds	Coffee brewing	Chlorogenic acids, caffeine	Antioxidant, metabolic enhancement	Functional beverages, energy bars	(Bevilacqua et al., 2023)
Soybean Hulls	Soy processing	Isoflavones, fibers	Hormonal balance, cholesterol reduction	Functional bakery items, nutraceuticals	(Colleti et al., 2020)

Methods of Incorporating Food Byproducts

Extraction Method

The bioactive compounds from the food byproducts can only be utilized when they extract their anti-bacterial, anti-inflammatory, and other healing elements (Ben-Othman et al., 2020). Major progress has been recorded during the extraction processing, where new technologies like the supercritical CO_2 technology present enhanced prospects as compared to conventional solvent extraction methods (Dhara et al., 2022). For instance, the supercritical CO_2 extraction method involves the use of CO_2 at high pressure and high temperature to extract bioactive molecules such as polyphenols, flavonoids, and antioxidants from by-products such as fruit peels and seeds (Ghafoor et al., 2022). They include its nontoxic features, high extraction efficiency, and weaker environmental impact, making the method suitable for enhancing the bioactive properties of byproducts in food industries.

However, the use of supercritical CO_2 extraction in the food industry is gradually expanding, which is not without some constraints; high initial capital investment as well as the issue with the scale-up of processes (Essien et al., 2020). Further, while this technology can effectively extract bioactives, the end products have to fulfill food safety regulatory requirements and processes that may hinder commercialization. Consequently, more work has to be done to fine-tune these extraction techniques for different products as well as make the process cheap enough while meeting food hygiene standards (Hämäläinen, 2020).

Incorporation of Food By-products Directly into Food Products

Given that one of the most critical goals of functional ingredient processing is to add nutritional value, the practice of incorporating byproducts directly into food products offers a wealth of potential. Examples of this approach are the addition of wheat bran to bread or citrus peel powder to drinks (Sharma et al., 2016). One of these wheat by-products that offers health benefits is wheat bran; it contains dietary fiber, minerals, and antioxidants. It also has a positive nutritional value when it is incorporated into bread; besides, it plays a role in improving the digestion process because it increases fiber consumption (Cheng et al., 2022).

As with the examples above, citrus peel, which is usually thrown away after the extraction of juice, is also extremely rich in flavonoids, vitamins, and essential oils (Russo et al., 2021). This makes it easy to add citrus peel to beverages as a functional ingredient, providing improved functionality that includes the ability to function as an antioxidant and provide support to the immune system of the consumer.

Although the fortification of food products has many nutritional positives, several challenges are still evident. This may pose a problem of change in sensory characteristics of these fortified products and hence may not be acceptable in the market (Chadare et al., 2019). Pre-additive pulses, such as adding wheat bran to bread affect the texture or taste of bread which may lead to poor perception by consumers (Wang & Jian, 2022). Moreover, the use of ingredients derived from byproducts in foods should be done cautiously so that a formulation that delivers nutrients in their richest forms, with high bioavailability, and conforms to standard food safety standards is developed. To overcome these challenges, detailed investigations into primary consumer preferences, their sensory assessment, as well as the formulation of appropriate functional food fares from byproducts are imperative for their successful incorporation (Cakmakci et al., 2024).

Conversion into Functional Ingredients

A more advanced strategy for using byproducts is their conversion into functional ingredients, for instance, prebiotic fibers, proteins, or natural colors (Sharma et al., 2016). Banana peels, apple residues, and grape shells have been employed to produce prebiotic-rich powders, proteins, and colors for functional foods (Vilas-Franquesa et al., 2024). These powders can be employed in functional foods, being incorporated in yogurt, smoothies, or energy bars, where they also possess functionalities of improving digestion and immunity.

Also, byproducts may be converted to protein isolates, which are of interest when it comes to creating plant-based protein goods. For instance, the enrichment of soybean or chickpea byproducts through protein isolation results in products that are applicable in the production of meat substitutes or protein-enhanced beverages (Neji et al., 2022). Grapes or beetroot byproducts have been used in the production of natural colors that can substitute artificial food colorants. There is a shift in consumers' preference for natural colorants over synthetic colorants since natural colorants are believed to have health benefits that are free from toxic substances (Novais et al., 2022).

Health Benefits of Polyphenols Fraction from Apple Pomace

Apple pomace originating from the juice and cider industries contains large quantities of polyphenolic compounds, especially flavonoids, that possess antioxidant activities (Tsoupras et al., 2024). Previous research has also demonstrated that apple pomace polyphenols have marked antidiabetic properties. For instance, Szabo et al. (2022) have shown that polyphenol extract from apple pomace was capable of decreasing the blood glucose levels in diabetic mice through the impact on enzymes related to the carbohydrate metabolism process. Corresponding to this effect, it can also help arrest increased blood sugar levels, which is common in diabetes, to give a management or prevention possibility (Russo et al., 2021).

In addition, apple pomace contains large amounts of dietary fiber, which plays an important role in supporting the digestive system (Lyu et al., 2020). Fiber can enhance satiety, decrease cholesterol levels, and enhance gut health, thus promoting good metabolism (He et al., 2022). Nevertheless, more limited attention is given to the apple pomace, although it has many positive effects on diet and health, mainly due to its perishability and challenges related to the processing of stable functional foods (Lyu et al., 2020).

Citrus Flavonoids and Cardio Protection

Oranges, lemons, and grapefruits are some of the most popular fruits in the world, and most of the time, their skin is thrown away (Russo et al., 2021). However, citrus peels are a good source of flavonoids like hesperidin, naringin, and rutin, where a lot of studies have been reported concerning their protection against cardiovascular illnesses. According to Deng et al. (2022), these citrus flavonoids can help decrease the likelihood of cardiovascular disease (CVD) by positively affecting the endothelium, decreasing hypertension, and decreasing low-density lipoproteins (LDL) cholesterol. The anti-inflammatory activity of citrus flavonoids adds to its cardio protection by averting ongoing oxidation, which is among the leading causes of heart ailments.

These health-beneficial effects of citrus flavonoids are eye-opening, but one should note that bioavailability often becomes an issue because of low solubility in water and poor absorbability in the gut. Therefore, it may be essential to develop other techniques like microencapsulation (discussed below) to increase their bioavailability and efficiency in functional foods (Dadwal & Gupta, 2023).

Additional Byproduct Utilization in Functional Foods

Cosmetics

Cereal byproducts are increasingly being employed in the formulation of cosmetics and functional foods because of their functionality and natural advantages in human foods (Skendi et al., 2020). Avocado seeds, which used to be thrown away, are employed in cosmetic products due to their nutritive content, with high concentrations of phenols used in lotions and creams for their anti-inflammatory qualities and as a skin moisturizer (Marra et al., 2024). Equally, mango kernels that contain mangiferin are used in sunscreens for their ultraviolet B protective and antioxidant properties (Garcia-Villegas et al., 2023). In the nutraceutical industry, commonly the byproduct of beetroot, named beetroot peel, containing betacyanins, is used in supplements for inflammation control and reduction in blood pressure.

Soybean hulls derived from soybean processing contain high amounts of isoflavones and fibers that make them suitable for hormone-regulating supplements and cholesterol-control functional foods (Usman et al., 2024). Also, the shrimp shells that contain chitosan are used in the preparation of acne products and are recommended for healthy dietary supplements, cholesterol regulators, and obesity management (Thambiliyagodage et al., 2023). However, there are always major issues like the efficiency of extraction, public awareness of these products, and other related barriers that have to be tackled to fully embrace them in cosmetic-related as well as nutraceutical uses.

Enzymatic Bioconversion and Biotechnological Innovation

Recent years have seen enzymatic bioconversion play a significant part in the functional food formulation enhancement of the limited range of opportunities offered to the food industry (Mao et al., 2024). Techniques include the use of enzymes to affect byproducts or to hydrolyze specific molecules with the increased biological activity of bioactive compounds.

For example, higher amounts of flavonoids and phenolic compounds are being extracted from citrus peel polysaccharides by the action of cellulase and pectinase on the said matrix; this enhances the antioxidant capacity (Stanek-Wandzel et al., 2024). Likewise, enzyme-mediated hydrolysis of protein-laden co-products like dairy whey or fish waste can liberate bioactive peptides with the likes of antihypertensive or antimicrobial effects, such as proteases (Frias et al., 2020). These enzymatically treated compounds are highly bioaccessible, which makes them fit for use in functional foods for the management of particular health issues.

Other related strategies support enzymatic methods by employing novel microorganisms and engineering techniques to optimize the utilization of byproducts. For instance, genetically modified microbial strains are genetically engineered to produce particular enzymes that can handle the type of byproducts that appear in a certain process (Liu et al., 2019). Fermentation strategies can also help in the conversion of macronutrient-poor food by-products, such as cereal bran or fruit pomace, to functional ingredients with prebiotic fibers and bioactive metabolites using probiotics like *Lactobacillus* species (Wichienchot & Ishak, 2017). Furthermore, the technology to produce enzymes has also evolved to be cheap, thus, the methods above can be utilized in large-scale food processing.

However, some issues remain as follows: Byproducts and flexibility also create great challenges to the enzymatic treatments in many ways since enzymes have different effectiveness depending on the substrate (Wang et al., 2018). Furthermore, because many of these functional foods result from enzymatic or microbial processing, consumers need to be made more aware and informed to be more accepting of such products. There are also regulatory obstacles, mainly related to the utilization of GMO technology and new enzymes for increasing the consumption rate.

Challenges and Solutions in Utilization

One major advantage comes with the conversion of byproducts into functional ingredients; it also has some challenges. During functional ingredient extraction and processing, the bioactivity and nutritional profiles of the byproducts must be carefully preserved (Gemechu, 2020). However, the processes remain difficult to scale up and are thus a major issue, hindering the large-scale application of functional ingredients from byproducts (Bartkiene et al., 2020). From a purely economic standpoint, it is critical to assess possible conversion processes, taking into account the cost of raw material, processing expenses, and market demands.

The use of byproduct-derived ingredients in functional foods faces several problems that may hinder their utilization. Some of these challenges are associated with taste factors, shelf life, and the feasibility of applying methods of processing (Qiu et al., 2025). However, today's progressive advancement in food science, including fermentation, microencapsulation, and enzymatic processing, provides solutions to these problems.

Bitter Taste of Maize and Consumer Acceptance

However, one of the main problems associated with the application of food byproducts, especially those from fruits and vegetables, is that the majority of them taste bad (Gómez & Martinez, 2018). For instance, the citrus peel contains a lot of flavonoids, however, it has considerable bitterness, which limits its uses, especially in terms of blending with other foods and beverages that consumers would readily accept (Rahman et al., 2024). Likewise, apple pomace, despite being an appreciable source of dietary fiber, has a chewy structural component that is undesirable in some food products.

These taste-related difficulties have led researchers to try out fermentation as a solution. Co-processing can be applied to mitigate bitterness, which is encountered in other byproduct-derived ingredients, through the degradation of compounds that influence bitter tastes. For instance, the enzymatic hydrolysis of citrus peel pulp using particular yeasts or bacteria isolates can decrease its bitterness, besides augmenting its nutritional value by increasing its beneficial bioactive compounds' bio accessibility (Sangeeta et al., 2024). Fermented byproduct ingredients can then be included in different food items, including drinks, yogurts, and baked goods.

Perishability and Shelf Life

Another challenge is that food byproducts are perishable; most byproducts, like peels and pomace, contain high moisture levels, and hence, it becomes easy for them to spoil (Majerska et al., 2019). This short shelf life makes its incorporation in functional foods difficult because byproducts must be processed and stabilized immediately to retain their bioactive compounds.

Microencapsulation has recently been developing to be an effective answer to this issue. Byproduct microencapsulation includes encapsulation coatings that are essentially less reactive and include byproduct starch, proteins, or lipids to form a stable, ambient-temperature powder (Samborska et al., 2021). It can help prolong the freshness of the components whose raw materials are byproducts and also guard unstable bioactive compounds against degradation brought on by heat, light, or humidity. For example, the flavonoids present in citrus fruits and polyphenols from apple pomace can be microencapsulated to improve their stability and, in effect, retain their bioactive properties during storage (Marcillo-Parra et al., 2021).

Bio accessibility of Bioactive Constituents

If the bioactive compounds from byproducts are extracted and then used in the development of functional foods, their functionality depends on their bioavailability. Some of the bioactive compounds, including the polyphenols and flavonoids, are poorly absorbed in the Gastrointestinal tract because of their low solubility or because they undergo rapid metabolism.

To overcome this problem, a few approaches have been designed to improve the accessibility of bioactive compounds in byproducts. Another interesting strategy is enzymatic bioconversion, the process in which bioactive compounds are transformed by specific enzymes into forms that can be more easily absorbed (Esmaeili, 2024). For instance, enzymes can be applied to hydrolyze complex carbohydrate substances into simpler sugars so that some bioactive compounds might be absorbed well in the gut (Karas et al., 2017). By the use of enzymes during processing, antioxidants in byproducts can also be released in a way that increases their health benefits.

Newer Trends and Directions of Research

The directions for using the byproducts of the food industry in effective foods are in the improvement of technologies, functional foods related to personalized nutrition, and sustainability (Granato et al., 2020). There are new approaches, including precision fermentation, nanotechnology, and enzymatic bioconversion, to improve bioactive compounds extraction and their further modification so that they will have good bioavailability and efficacy in functional food products. The rewards of integrating these approaches include: There is also reduced wastage, and the overall costs are brought down since companies embrace environmentally friendly practices.

Further, cross-coupled studies are necessary for assessing neglected byproducts and their biological properties. This will involve life cycle assessments as well as circular economy to act as catalysts to sustainable practices. A multi-stakeholder approach needs to be adopted for the translation of innovation into a solution that fits for purpose, makes them acceptable to the consumer, as well as to determine suitable regulatory frameworks conducive to byproduct-based functional foods in the global market.

The growing concern with sustainable practices within the food systems has been associated with the circular economy idea, where more food residuals are regarded as resources (Zucchella & Previtali, 2019). Incorporation of byproducts in functional foods is a noble way of reducing the food waste level within the food industry alongside boosting schemes on sustainability and lessening the depletion of the environment's natural resources (Espro et al., 2021). New processing technologies like waterless extraction technologies and zero-wash kitchen technologies will play a part in solving sustainable food processing.

Conclusion

Byproducts' incorporation into functional foods as an applied strategy in food waste management is a potential solution, and all these can impact the consumers' health. This is because the use of biologically active compounds present in byproducts can produce enhanced functional value foods that have additional health attributes. However, several constraints like taste, shelf stability, and bioavailability need scientific intervention in the form of fermentation, microencapsulation, and enzymatic bioconversion. The inclusion of personalized nutrition and enzymatic bioconversion in the functional food industry, therefore, shifts a new paradigm in the use of food industry byproducts. Such strategies not only help the reuse of otherwise discordant material while adding value to it, but also adopt effective nutritional modification approaches for handling critical health issues. Still, these goals pose several problems associated with standardization, consumers' acceptance, and regulation, which should be solved through the cooperation of academic, industrial, and government approaches. Byproducts are still awaiting to be fully exploited due to more studies that the public needs to undergo to increase their knowledge of functional foods.

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